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MEMOIR 140

No. 122, GEOLOGICAL SERIES

Physiography of Nova Scotia

BY

J. W. Goldthwait

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Geological Survey of Canada
Ottawa, Canada K1A 0E8

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F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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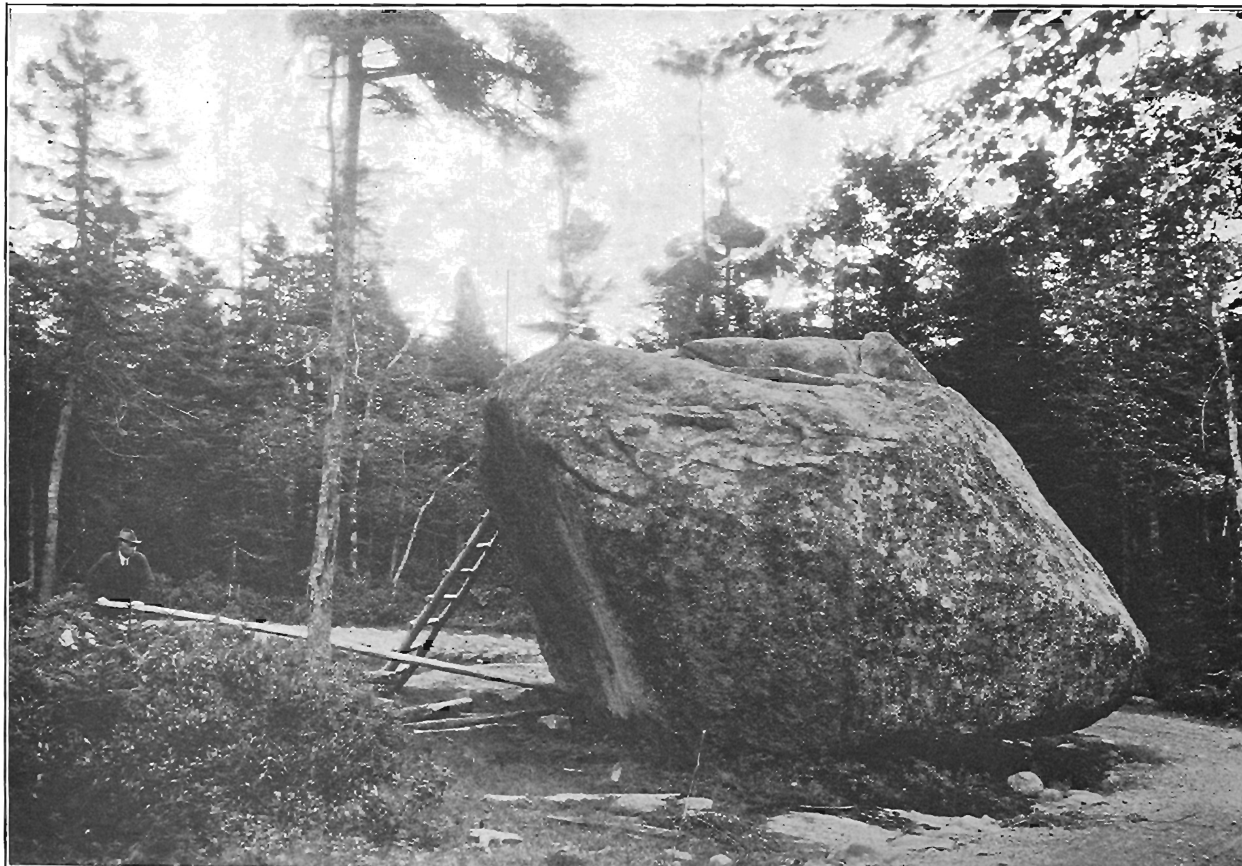
PLATE I



The rocking stone of Spryfield.

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PREFACE

It is the purpose of this book to tell how the landscapes of Nova Scotia originated. It is written not so much for the professional geologist and the physiographer, as for the reader who has a general yet thoughtful interest in his environment.

A fair amount of literature has been issued on the physical features of Nova Scotia—its rock structure, hills and valleys, lakes, river systems, and coast-line. Sir William Dawson's widely read "Acadian Geology," written in 1852, has been a classic for two generations, and is a work of which Nova Scotians are rightfully proud. The maps and reports of the Geological Survey, particularly those prepared by Hugh Fletcher during a long and active service in this field, and by his colleague and successor, E. R. Faribault, supplemented by the researches of L. W. Bailey, Robert Chalmers, and more recently of G. A. Young, M. Y. Williams, W. A. Bell, J. E. Hyde, B. R. MacKay, and other members of the Survey staff, contain much information as to the rock structure of the province. No other province of Canada has been so thoroughly mapped as has Nova Scotia. Many of the reports which deal with these investigations are written in technical language, and are concerned with so many local details that they make little appeal to the amateur or the general reader. They deal mainly with purely geological matters—structural phenomena rather than surface forms. There are, to be sure, descriptions of uplands and valleys and coast-lines; but they are seldom connected in thought with the structure that underlies them, or with the geological changes that have brought them into being. Moreover, these accounts are fragmentary and scattered. To secure a comprehensive description of the surface features of the whole province, one would have to go through several book-shelves of official papers.

It is remarkable that no single, connected study has hitherto been made of the physiography of the entire province of Nova Scotia. A short but very scholarly and illuminating paper by R. A. Daly on "The Physiography of Nova Scotia," written in 1902, classifies the larger elements of Nova Scotian scenery and discusses at some length the relative merits of different theories as to their origin. The features developed by the great continental glacier, during the Ice age, especially, have been given so little attention by field investigators that accounts of the glaciation of Canada and the United States given in standard text books of geology and physiography either refer cautiously to conditions in Nova Scotia or avoid mention of them.

The present memoir makes no pretense to originality in fields adequately covered by other writers. Daly's skilful analysis of the physiographic history of the province forms the plan upon which this book is built; and his conceptions of the several generations of land forms that make up the present landscapes of Acadia have been adopted almost without exception. Dawson's "Acadian Geology" furnishes material for certain pages—notably the description of the submerged forest at Fort Lawrence. To indicate by footnote or a parenthesis every source of information would give the book the appearance of a reference manual instead of a simple, connected story of the origin of Nova Scotian scenery, and such references with rare exceptions have been omitted. Only the chapter that deals with the glacial history of the province is original, both in contents and method of treatment.

It is a pleasure to acknowledge aid, in the field and by correspondence, from many of the gentlemen mentioned above as members of the Geological Survey, as well as from Professor Ernest Haycock of Acadia University, Mr. Donald S. McIntosh, of the Department of Geology at Dalhousie University, and Mr. Harry Piers, Curator of the Provincial Museum at Halifax. Courtesies have been received from Dr. W. Bell Dawson, Superintendent of Tidal Surveys, Department of the Naval Service, Canada, Prof. W. F. Ganong of Smith College, Mr. Charles H. Harvey of the Department of Marine and Fisheries, Principal Sexton of the Technical College at Halifax, Dr. Charles A. Hamilton of Mahone Bay, and many others. During the summers spent in the field (1913 and 1914), it was a pleasure to observe the interest taken by the people of Nova Scotia in the scenery around them; and it is this interest as well as the evident appreciation by summer visitors, of Nova Scotia as a vacation ground, that warrants the publication of a book for the general reader rather than for the specialist.

Physiography of Nova Scotia

CHAPTER I

EVOLUTION OF LANDSCAPES

The face of the land does not consist of features that originated suddenly and thenceforth remained fixed. Landscapes have been developed gradually, by the ceaseless operation of processes obedient to natural laws, processes which are today at work in the same way—and in many cases at the same rate—as in the past.

So slow and quiet in action are the agencies that produce and modify land forms, carving valleys, building hills and mountains, and modelling shore-lines, that they are likely to escape the attention of all except close observers and students of nature. And yet, one need not search long to find places where changes are now going on so fast that they show large results in the course of a lifetime. Sable island, a great sand reef off the coast of Nova Scotia, has lost nearly half its length during the last century and a quarter. A single storm has been known to sweep into the sea an area of sand-hills 3 miles long and 40 feet wide. In fact, any sea-cliff on the shore, where clay or sand is exposed to the attack of the waves, can be seen to retreat, slowly, under the assaults of successive storms, as the sea saws into its base and over-steepens the cliff so that masses of the loosened structure slide or fall to the beach and are swept away. Bars of sand, heaped up by the waves along courses of swift shore currents, grow from year to year, blocking the mouths of harbours that formerly admitted boats. On Sable island is a large pond that served as a harbour of refuge until 1836, when a severe storm barred its entrance with a continuous sandy beach, imprisoning two small boats. Similar changes are going on all along the open coast, where waves and currents have full play. The sea is slowly eating away the borders of the land and forming temporary beaches, upon which the debris is ground up. Winds, also, are fast at work where large supplies of dry sand are exposed. On the sandy shores of cape Sable and Port Mouton, aeolian action plays a prominent part. When the wind springs up, sand grains are lifted from the ground and whirled along in drifting sheets like dry snow, collecting in banks which gradually assume the proportions of hillocks or dunes. With each hard blow, these sand-hills shift their places, creeping inland through wooded ground and burying and killing shrubbery and trees. These are, it is true, land forms more typical of deserts than of well-watered regions; but their occurrence in Nova Scotia prevents our losing sight of the wind as one of the potent agencies that alter the surface. In many parts of the province, where gypsum beds make up the foundation, the ground in some places caves in unexpectedly, producing pits or basins that soon become partly filled with water. These "sinks" or "punchbowls" are caused by the rapid solution of the gypsum by underground waters which, starting as a sheet that slowly soaks down through the minute cracks and pores of the rock, dissolves the gypsum unequally, developing channels and cavities the roofs of which at last collapse for lack of sufficient support. No more convincing proof could be desired of the power of water to dissolve and destroy solid rock, even where water seems to be allowed least freedom of action. Though its work is so rapid and so obvious in gypsum country, it is no less surely going on in rock structures of all kinds, throughout the continent.

Once conscious of these rapid changes, we can see the evidence of changes that are slower, yet ultimately of greater import. The living earth may be likened to a time piece; the second-hand revolves rapidly, but the minute and hour hands move slowly. A glance shows the second hand in motion; but casual observation hardly reveals the motion of the minute hand; and the movement of the hour hand is apparent only when compared at long intervals. The recession of sea-cliffs, the shifting of sand dunes, and the collapsing of sink-holes are advances—mere incidents—in the slow but incessant progress of events, in which the more important changes are hardly appreciated during the brief space of a human lifetime. Slowly, under the disintegrating and decomposing influence of air and moisture, through the transporting agency of rain and rivers, and through the chemical activity of underground water, mountains are reduced to hills, and hills to plains. This is "subaerial denudation"—the stripping of rock waste from the earth's surface while new waste is forming there; and the delivery of this waste, as sediment and dissolved material, to the sea. Careful measurements of the volume of solid matter annually discharged to the sea by Mississippi river, in suspension and solution, when divided by the area which this great river and its tributaries drain, show that the whole central part of the United States is being lowered by denudation at an average rate of one inch in about 760 years. In some districts the rate is many times faster than this; in others it is much slower; for the rate of denudation depends upon many factors, such as the chemical and physical character of the rock, the steepness of the slopes, and the climate. At the rate of one inch in 760 years, it would, of course, require hundreds of thousands of years to reduce the surface of North America to a flat plain at sea-level—the limit down to which these destructive agencies can operate. Indeed, the period necessary to bring about this result would be vastly longer, because as time passed the rate of denudation would become slower, owing to the flattening of all slopes and the consequent reduction of the velocity of rivers. And yet, in the next two chapters, reasons will be found for believing that Nova Scotia has thus been worn flat at least once in fairly recent geological time. The earth is immeasurably old; and in its venerable lifetime, where "a thousand ages . . are as a moment gone," landscapes have taken form and passed away in endless succession.

Although the study of earth features leads us inevitably to attribute the larger topographical units to the operation of rain and rivers, proceeding at different rates on rocks which differ in their resistance, thus carving out a relief which conforms intimately to underground tstrucure, there are plain signs all over Nova Scotia of a recent visitation by an agency far more strange—a great ice-sheet like those now occupying Arctic and Antarctic lands. The vast sheet of ice which once covered a large part of North America has disappeared; but the records of it are so plain and so varied that it is only necessary to be well informed and observant to be fully convinced of its former presence. The story of the growth and disappearance of this vast sheet of ice still has its mysteries for the investigator, as well as the layman; but its existence is no longer questioned, and its action is coming to be more and more fully understood. In Chapter IV it is shown that whereas the ice-sheet was the originator of small features, only, in our modern landscape, it completely transformed the soils, disarranged the river systems, and left its stamp on the coast-line. In Chapter V, the origin of the complex and diversified border of the sea is discussed. This is a study in itself, for it deals mainly with the activity of waves, tides, and currents, in a great variety of circumstances. The last chapter tells of changes in level of land and sea, and the effects which these have had upon both the sky-line and the shore-line of Nova Scotia.

CHAPTER II

UPLANDS

Overspreading the southern half of Nova Scotia, and appearing in many other parts of the Maritime Provinces, is an upland surface of striking uniformity. Although it appears only in detached fragments, separated in some places by lowlands of considerable width, this surface is believed to have been continuous, originally, throughout the region; for the several upland districts show a wonderfully systematic relationship of altitude. By matching the several parts it is possible to trace the ascent of the upland as a single feature, which may be called the "Atlantic upland," from the coast at Yarmouth, Halifax, and cape Canso where it rises from the sea, northwestward to the highlands of New Brunswick and northeastward to the tablelands of Newfoundland and Labrador. In some parts of this large area it forms undulating upland plains; in others, the flat crest-lines of mountains; and in Cape Breton and Newfoundland high tablelands of immense extent. Because this surface or facet cuts straight across the complex rock structure of the region, a structure which shows that it was occupied by high mountains in earlier geological ages, it is believed that the upland originated as a "plain of denudation," formed by the wearing down of mountains to a lowland. The complete flattening of a mountainous region can be accomplished by natural agencies in either one of two ways; it may come about by the wearing down of the land through the unremitting attack of rivers, rain, frost, and other atmospheric agencies; or it may result from the long-continued encroachment of the sea on the borders of the continent. If produced by rain and rivers, this plain of denudation will be a smooth but gently undulating "peneplain," rising only slightly above sea-level; if produced by marine planation, the surface will be a broad, smooth platform, slightly submerged by the sea, and covered with a blanket of marine sediments. Inasmuch as this Atlantic upland now rises from sea-level along the southern coast of Nova Scotia to 1,200 feet on Cape Breton island and 1,500 to 2,000 feet in Newfoundland, it is evident that, whether it originated as a plain of subaerial denudation or as a submerged surface of marine denudation, it has gained its present altitude through a general upwarping of the region.

The division of this once continuous plain into its several fragments has been accomplished since its elevation, and mainly, if not wholly, by rain and rivers hollowing out those parts of the uplifted plain which were occupied by the least resistant rocks. Over hundreds of square miles in Cumberland and Colchester counties, where soft shales and sandstones of the Carboniferous system occur at the surface, lowlands of great extent have been worn down, developing a new plain which lies from 300 to 500 feet below the level of the upland and completely surrounds the resistant mass of the Cobequid mountains. In northern Annapolis county, where a belt of soft sandstones lay between an inclined bed of lava and a great mass of granite, the surface was excavated by rain and rivers making the deep, wide trough of Annapolis valley; whereas the more resistant lava sheet, lying between it and the lowland belt of the bay of Fundy, remained as the high, even-topped ridge known as North mountain. On Cape Breton island, where patches of granite and other hard rocks alternate with infolded strata of a more yielding character, these weak rocks were eaten away, leaving several belts of smooth-crested mountains and one broader tableland.

The disconnexion of the Cape Breton tableland from that of Newfoundland dates from this same period of denudation. The great canyon of the St. Lawrence, now so deeply submerged that it shows only on a submarine map, was carved out by the powerful river while it was flowing down the southeastward slope of the uplifted plain, reaching the sea at Cabot strait, 175 miles southeast of the present Cape Breton island. On the south side of this great canyon, between the granite area of Cape Breton island and the granite areas of New Brunswick and Gaspe, an immense region of soft sandstones, similar to and continuous with those of the Cumberland lowland, was reduced to a great, smooth plain, which shall be called the Acadian plain. Near its curved upper margin, a somewhat more resistant stratum of sandstone projected as a low, crescent-shaped ridge, and, far out on the plain, 50 miles northwest of the Cape Breton tableland, a small group of volcanic masses formed a low cluster of rounded hills. Within the areas of hard rocks, as they remained standing above the deepening lowlands, valleys were cut—valleys which in the lower areas on the south were as a rule broad and shallow, but in the higher tablelands and mountains of the north, particularly at their steep borders, were deep and gorge-like.

At length the whole region sank, letting the sea creep in over the lower, outer part of the dissected upland and spread widely over the new lowlands. By the time the subsidence had ceased, the sea had pushed the outer shore-line inland nearly 100 miles, from Sable island to its present position, converting the outer half of the upland into "banks," and flooding the mouths of the valleys all along the shore, so as to form irregular bays. Off the coast of Newfoundland, east of the old mouth of the St. Lawrence, an area equal to that of the present island became the "Grand Banks." The St. Lawrence canyon was converted into a broad gulf, and the irregular tributary valleys of Cape Breton island became crooked arms of the sea—the Bras d'Or lakes of today; the great saucer-shaped Acadian plain was flooded almost to its upper border, leaving only a crescentic line of hills to project as Prince Edward Island; and the little group of round hills farther north became the Magdalen islands.

At some time late in the geological history of Nova Scotia, perhaps before the beginning of the sinking, perhaps after most of it had taken place, the region was covered by the great North American ice-sheet, which spread seaward over it from centres not exactly located, but mainly, it is thought, from New Quebec and Labrador. It is possible that the ice retired from the region and advanced again more than once during the Glacial period. By erosion of a sort peculiar to ice-sheets, and more especially by the shifting and rearrangement of the mantle of surface deposits throughout the region that it covered, the continental glacier gave finishing touches to the outlines of the shore and the form of the surface. It may have had much to do with the configuration of the shallower places on the banks off the southern coast, where it is believed to have terminated in the sea just as the great Antarctic ice-sheet does today.

This, in brief outline, is the story of the making of the Atlantic upland and its subsequent separation into the several upland districts of the present time. These natural physiographic divisions, in the order in which they will be considered, are:

Southern upland
North mountain
Cobequid mountains
Highlands of Pictou and Antigonish counties
Uplands and northern tableland of Cape Breton island

The extent of each division and its geologic structure are shown on the accompanying physiographic map of Nova Scotia (No. 2006).

SOUTHERN UPLAND

The largest remnant of the Atlantic upland in the Maritime Provinces and the largest single physiographic division of Nova Scotia is the upland that occupies the southern and central part of the peninsula. From the Atlantic coast, where it appears in low islands and capes all the way from cape Canso to cape Sable—a distance of 275 miles—and thence northward 65 miles more; past Yarmouth to St. Mary bay, this gently undulating country rises inland at a rate of about 15 feet to the mile, and reaches an altitude of 600 to 700 feet in the heart of the peninsula. The limits of the upland are, in general, well defined, but they are more pronounced in some places than in others. On the outer side, the shore-line serves as a convenient boundary, although the same rolling hills and valleys extend under water to the edge of the banks, so that the submerged part of the upland exceeds in area the part above sea-level. On the inner and higher side, the edge of the upland is straight and plainly marked from the head of St. Mary bay eastward along the South Mountain escarpment to Kentville. From there to Windsor and eastward through Hants and Colchester counties the upland border is obscured by foothills, where the more easily eroded rocks of the adjoining lowland invade the upland area along a sinuous line, and cause a blending of the higher and the lower districts. Near the junction of Halifax, Colchester, Pictou, and Guysborough counties, the northern limit of the upland again becomes prominent, in a long escarpment that overlooks the valley of the West branch of St. Mary river, whence it passes eastward to the south shore of Chedabucto bay.

A traveller through this region sees, at first, only irregularity and diversity of detail in the landscape, consisting as it does of thousands of low hills and smooth-topped ridges with intervening lakes and muskegs, and fringed along the coast by a ragged line of low points, fiords, and islets. So easy it is to observe those features that are close at hand, and to fail to see the horizon unless it be broken by bold mountain profiles,

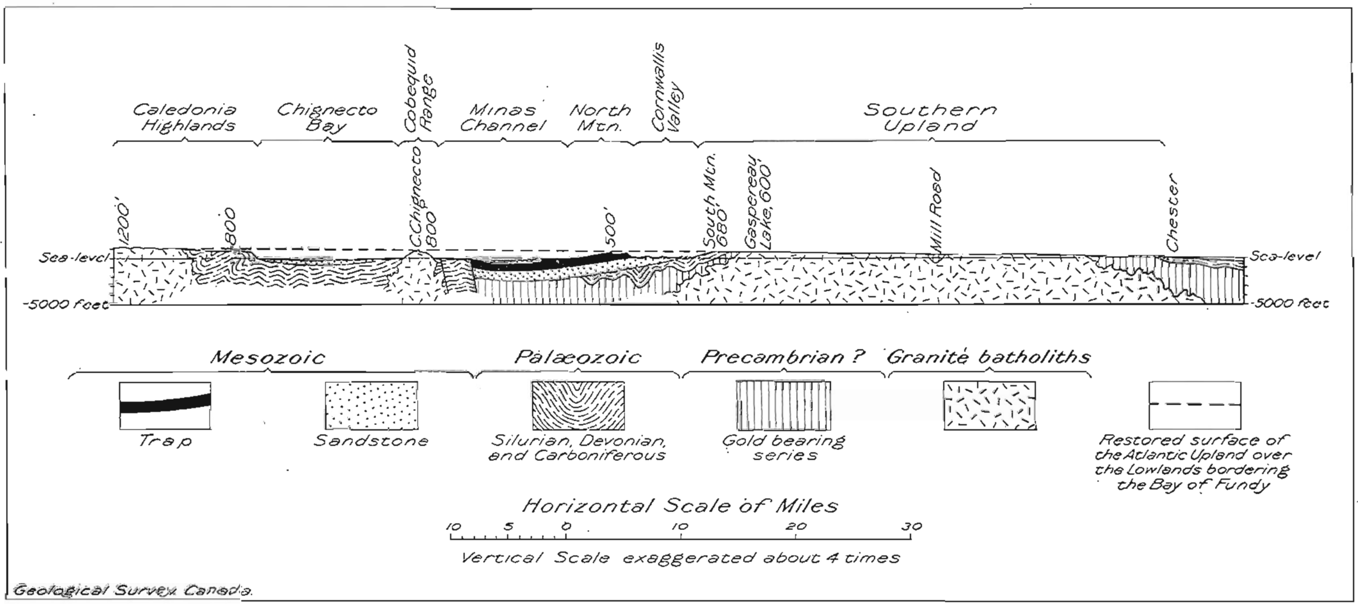


FIGURE 1. Generalized geological cross-section from the Caledonia highlands, N.B., to Chester, N.S.

that only the close observer or the life-long inhabitant of such a district, can fully appreciate the remarkable uniformity of the upland. It shows to best advantage on the railway across the peninsula from Middleton to Bridgewater; particularly in the 20 miles between Alpena and Springfield, where the railway passes over the back of the granite "axis" of the upland. There is seen a flat expanse of low ledges and peat bogs, above which the smooth-topped granite ridges rise scarcely 50 feet, although the average altitude of the district is over 500 feet above the sea. Farther seaward the depressions of the upland deepen into well-defined river valleys; where the flatness of the surface may be seen at its best, from the top of one of the many hills which make up its even sky-line. What makes this Southern upland noteworthy is the marvellous discordance between its smooth surface and the rock structure under it. Cross-sections like Figure 1 reveal the fact that this is an old mountain region, worn almost flat by the agencies of denudation.

DEEP-SEATED ROCK STRUCTURE

On the large geological map (No. 2006), two-thirds of the area of the Southern upland is seen to be occupied by folded beds of slate and quartzite, and the remaining one-third by granite. These two divisions of the structure will first be considered separately, and then in relation to each other.

Folded Slates and Quartzites

The folded beds of the Southern upland are enormously thick. The slates, which lie above, measure over 2 miles in thickness; the underlying quartzite or "whin" formation measures more than 3 miles. The slates are known as the "Halifax formation," from their occurrence in the city of Halifax; the quartzites are called the "Goldenville formation," from one of the many mining camps which are located on them. Fossils are wholly lacking in these rocks; but it is altogether probable that they accumulated as beds of mud and sand on the sea-floor. Beds of similar character are forming on the floor of the sea at the present day over large areas, but at no very great depth; for the deposits consist of sediment spread by the sea along the borders of the continents, where rivers discharge their load of mud and silt, and waves gather additional supplies of it. The wide extent of individual beds of slate and quartzite, from one end of the southern peninsula to the other, indicates that the conditions of deposition were uniform over large areas of this ancient sea-floor. The great thickness of the beds, and their shallow water origin indicates that they accumulated on a floor which sank about as fast as the beds were laid down, leaving the depth of water about the same at the close of the period of accumulation as it was at the beginning. Evidently, then, the sea-bottom sank about 5 miles during this period. This downward movement, which was apparently slow and long continued, occupying hundreds of centuries, and which proceeded evenly throughout the length of the peninsula, is to be remembered as the earliest broad movement of which we have a record in the geology of Nova Scotia—the first of many warpings which have combined to build the land of the present day. It is believed to have occurred during or before the Cambrian period. The thickness of the Halifax and Goldenville formations will be of more direct interest in measuring the extent to which this old mountain region has been denuded.

Some time after the immense beds of mud and sand had been spread out, mountain-forming movements came into action throughout the region. The strata were bent, buckled, and at length tightly folded into a great mass of wrinkled beds, rising high above sea-level. The arches or "anticlines," and troughs or "synclines," have an east-west trend. The anticlinal axes, which are plainly shown on the published maps of the Geological Survey, are commonly about 3 miles apart, and are traceable lengthwise for distances of from 5 to over 100 miles. The crests of the folds rise and fall in the axial direction, forming long, cigar-shaped domes at intervals of from 10 to 25 miles. In some places, the anticlines are symmetrical, with similar angles of dip on the two sides. In most places, however, they are steeper on the south side than on the north; and in one or two instances they are locally overturned. The folds are steeper, more tightly compressed, and more numerous east of Halifax than west of it. In one place, at least, a group lies in cross-section like a fan, resembling the famous folds of the Alps. The block diagrams of the district around the city of Halifax (Figure 2) illustrate how the modern upland surface truncates the upturned edges of these folded rocks as sharply as if they had been shaved down horizontally by a gigantic plane.

Since the Halifax slate formation lies on top of the Goldenville quartzites, and occupies a higher position in all the folds, this slate has been generally stripped off the crests of the anticlines, revealing quartzite in long elliptical areas, and remaining itself only in the intervening troughs. The recognition of pitching anticlines has been of great importance in prospecting for gold; for the auriferous quartz veins mostly occur on the nose of a pitching anticline, where the beds have been warped apart, forming a saddle-shaped space, or have been cracked transversely by the stretching of the arch. Since the rocks are largely concealed by soil, it is not easy to determine the position of the axis of one of these anticlines, and when once located, the utmost care is taken to discover the precise angle of pitch of the fold and the dip of its two limbs, in order to estimate correctly the depths at which the gold-bearing saddle veins will be struck.

East of Halifax the rocks were folded up to so great an altitude that denudation generally stripped away the slates from the quartzites, and quartzites occupy more area than slates. West of Halifax, where the folds do not rise so high, the two rocks occupy about equal parts of the surface. Because of the more open folding in the western part of the region, the truncated domes of quartzite appear there as broad ellipses, or oval areas, in contrast with the cigar-shaped, attenuated areas of the eastern districts.

The great strength of the quartzite beds makes the folds in that formation comparatively large and easy to trace, whereas the soft slates yielded so easily to the lateral pressure that the larger folds in these rocks are much obscured by minor crumplings. The massiveness of the quartzite strata appears also in the manner in which this rock, under the strain of folding, has cracked into rhomboidal joint blocks of large dimensions,

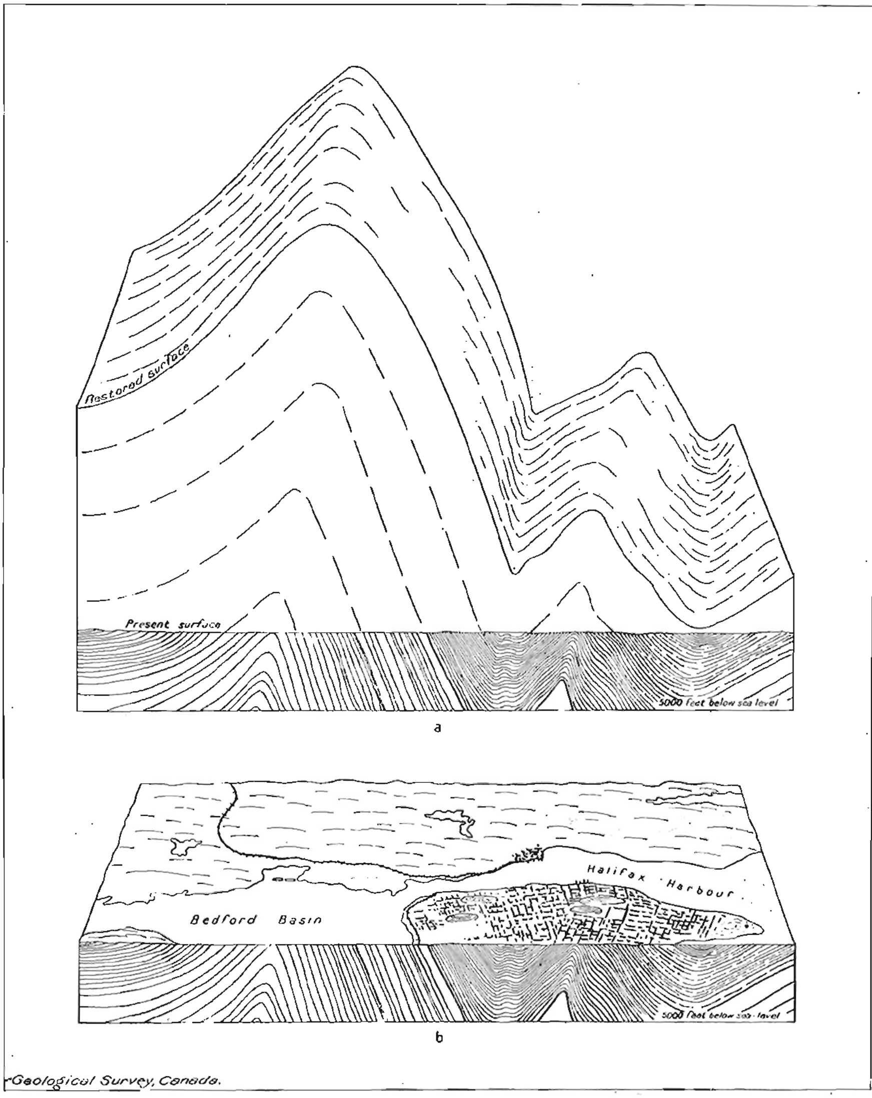


FIGURE 2. Block diagrams showing: (*a*) geological structure at Halifax completely restored; (*b*) present surface and truncated geological structure.

whereas the slate has yielded by splitting into thin cleavage sheets. From outcrops of the coarsely cracked quartzite, thousands upon thousands of angular "whin" blocks have been plucked by the ice-sheet and scattered southward. The rock is pre-eminently a boulder maker, in contrast with the slate, which breaks down into a muddy soil.

Finally, it should be remarked that the bottommost beds of this great gold-bearing formation are nowhere to be seen; for they were eaten away during the folding of the mountains by great masses of molten granite, which invaded the folds from below. The topmost beds, also, are missing; for they were removed by erosion before any later rocks were deposited.

Granite Batholiths

The granite of the Southern upland appears in areas of various shapes and sizes. By far the largest is a crescent-shaped area 90 miles long and 25 miles wide, that reaches from Camperdown heights, near Halifax, inland through the northern part of Lunenburg county, and the southern part of Kings county, and down through Annapolis to Yarmouth and Shelburne counties. This area contains the highest ground of the Southern upland, and completely interrupts the east-west folds of the Precambrian slates and quartzites. Smaller areas of granite, of odd shape, but showing a tendency to trend parallel to the folds, are scattered over the upland from the coast at Barrington to cape Canso.

The granite is ordinarily a coarse-grained rock, composed of irregular granules of smoky quartz, flakes of black mica, and large, rectangular crystals of feldspar, many of them 2 inches in diameter. On account of the prevalence of these conspicuous crystals, the granite is said to be "porphyritic." The crystalline structure and the relations of the granite to the rocks with which it is seen in contact prove that it formed by slow cooling from a hot, molten mass or "magma," probably at a considerable depth below the surface. These deep masses now revealed by denudation are called "batholiths." Both in texture and in composition, the granite is variable. In some places the rock is medium-grained or even fine-grained, and in some it carried white as well as black mica. These variations have led to the supposition, on the part of some investigators, that the granite is not all of the same age, and that the magma was squeezed successively into different parts of the district. In common with granites the world over, these masses are penetrated by irregular veins of "pegmatite" in which feldspar and quartz are curiously intergrown, and an exceedingly coarse texture prevails. These veins consist of the part of the fluid magma which was the last to cool; and they contain a considerable amount of uncommon chemical constituents, for example, boron, chlorine, and fluorine, locked up in unusual minerals like tourmaline, beryl, and fluorspar.

The granite masses are not part of the ancient sea-floor, on top of which the Halifax muds and Goldenville sands were laid down, and are now exposed by uplift and erosion. On the contrary, it is known that the granite ascended as a fluid mass, under intense compression, at the later time of the folding of the old mountain systems, and crystallized into immense, irregular bodies while still deep underground. This is evidenced in several ways: (1), it is found that granite areas cross the belts of slate and quartzite, completely interrupting them for long distances; (2) it is found that many veins of granite branch out from the main granite area through the surrounding strata; (3) near the walls of the enclosing slate and quartzite the granite contains a large number of pieces or "inclusions" of the quartzite, many of huge size. Smaller fragments, though angular when torn from the wall, were partly dissolved and rounded at their corners; the dissolved material, though not foreign to the original paste, altered the proportions of its constituents and consequently rendered it somewhat abnormal in character. Finally, from the granite contact outward through the slates and quartzites, for distances which vary from a few feet to several hundred yards, there are unmistakable signs of alteration by heat and permeating vapours. It may be merely a hardening of the slate into a solid fused mass without any sign of cleavage, or may be a speckled appearance on the slate or whin rock, due to the birth of small crystals of garnet or tourmaline in place of some of the original particles of mud and sand. Indeed, the influence of the intrusive magma has been so strong, in some districts, that the enveloping sediments have been quite made over, or "metamorphosed" into schists and gneisses—rocks which are beautifully foliated, and so thoroughly crystallized that it is difficult to distinguish them in places from the crystalline granite itself, particularly since the granite in these circumstances may take on a similar foliated structure parallel to the contact. Where these pronounced effects are seen to persist for long distances from the granite boundary, it is probable that granite occurs at a comparatively short distance underneath the surface.

Highly altered or metamorphosed strata of this kind are common in the district around Yarmouth, Shelburne, and Lockeport. Good illustrations of the hardening, baking, and invasion of the slate by granite near the contact are seen on the upland immediately west of the Northwest arm, near Halifax.

The geological date of the upfolding of these old Appalachian or Atlantic mountains and of the injection of the granite batholiths into their roots has been fixed at the close of the Devonian period. That the intrusion did not occur before the Devonian is shown by the presence along the northwest border of the district of fossil-bearing strata of Silurian and Devonian age, infolded with the Precambrian rocks so intimately as to show that the folding took place mainly after the deposition of the Lower Devonian rocks. That the intrusion was over before the next, or Carboniferous, period is shown by the presence near Windsor of stratified beds of disintegrated granite soil, or "arkose," at the base of the fossiliferous "Windsor series" of rocks, which belong to the Lower Carboniferous. This, and similar evidence in the Cobequid mountains, in the highlands of Antigonish, and in the tableland of northern Cape Breton island, show us that a great system of mountains was built up by folding and by injection of granite at this early period of geologic history.

Faults

The folded and intruded rocks of the Southern upland have been deeply cracked and dislocated, producing what are known as "faults." Many of these faults have been mapped by Fletcher and Faribault and are shown on the published geological sheets. At the fault-line, where the vertical or steeply inclined crack or fault-plane reaches the surface, the rock belts are offset by the movement which has taken place. In these, and in nearly every other instance in the Southern upland, the offset is towards the left as seen by one who is facing the fault-plane, giving what is termed a "left-hand fault." In many places whole folds, both anticlinal and synclinal, are found displaced in an horizontal direction along the fault-line. The offset at the Country Harbour fault is about 4 miles; that at the Sheet Harbour fault, a little less than 2 miles. The vertical displacement is small; for if it were large, its effects would be seen in differences in the widths of the truncated folds on opposite sides of the fault. The date of the faulting is not known; but since the granite, as well as the slates and quartzites, is faulted, it is clear that the displacements took place after the formation of the granite batholiths. It is also evident that the faulting occurred so long ago that both sides of the fault were afterwards reduced to a common level during the development of the surface of denudation. The trend of the faults, in this district, is as a rule about north 60 degrees west.

RELIEF AND DRAINAGE

Slope of the Upland

Looking now at Map 2006, on which the average altitude of the Southern upland at different points is shown by figures, it is found that though in the main the direction of its descent is southeast, or straight towards the Atlantic coast, there is also a marked falling off in level in a southwest direction, in Digby, Yarmouth, and Shelburne counties. In other words, the upland descends towards the gulf of Maine as well as towards the open ocean, and the arrangement of the submarine contours as shown on the Admiralty charts suggests a continuation of the upland surface as a drowned plain out to the edge of the continental shelf. Tracing the facet inland, no falling off in its level northward is found, in Annapolis, Hants, Colchester, Pictou, and Guysborough counties, where it approaches the bay of Fundy and Northumberland strait. On the contrary, the highest average altitude is reached near its northern boundary, in Kings county, where it lies farthest back from the Atlantic. Beyond the Annapolis Valley and Minas Basin lowland, where weaker rocks have allowed the denudation of the surface to proceed rapidly below the level of the upland facet, the even crest-line of North mountain, with an altitude commonly exceeding 500 feet, stands almost at the level of the upland plane, as projected northwestward from the South Mountain escarpment. The smooth summits of Cobequid mountains in Cumberland county, somewhat farther inland, rising to average altitudes of over 800 feet, carry the plane a little higher in a northwesterly direction; and the Caledonia upland, just beyond the head of the bay of Fundy, with tabular summits at 1,200 feet, identifies the Southern upland as the southernmost remnant of an old surface which originally reached across the bay of Fundy and far into New Brunswick (Figure 1). The slightly lower level of the North Mountain range should not be looked upon as an indication that the old surface near the bay of Fundy is warped down. It is due in all probability to the narrowness of outcrop of the lava sheet and its unfavourable position between the two broad areas of soft rock, one of which has been worn down to form Annapolis valley, and the other, the floor of the bay of Fundy. It would be strange, in such circumstances, if the crest of the mountain remained long at its original height. The relation of the altitudes in the extreme eastern part of the Southern upland to altitudes in the highlands of Antigonish and the upland remnants on Cape Breton island indicates a similar extension of the facet northward and northwestward.

Residual Hills Surmounting the Upland

The highest points on the Southern upland, so far as they are known, are given in the list below. There has been little exploratory surveying on the high barrens of Digby, Annapolis, Yarmouth, and Shelburne counties, where occasional summits may equal in height those already measured in the eastern part of the main granite area; but it is probable that this list represents fairly the highest places in the district.

	Feet
Granite hill, unnamed, 2 miles west of McGee lake, south of Kentville	800
Armstrong hill, granite, a short distance west of the Windsor-Chester road	800
Slate hill, unnamed, on South mountain at Canaan, south of Kentville	755
Slate hill, unnamed, 1 mile east of Newtonville, south of Wolfville	750
Mount Ardoise, slate, southeast of Windsor	738
Granite hill, unnamed, near Carding lake, on the Windsor-Chester road	728
Broom hill, granite, 1 mile west of New Ross	715

In all these places, the hills are gentle domes or swells, the slight relief of which testifies to the thorough condition of denudation of the ancient surface before its uplift. They rise so little above their surroundings that they scarcely deserve to be called "monadnocks," as mountains of residual origin are termed. A few of the lower summits, notably Mount Aspotogan, near Chester, which reaches 480 feet, in a district with an average altitude of barely 250 feet, are fairly representative monadnocks.

The Three Types of Country

The upland area is occupied by three distinct types of rock—granite, quartzite, and slate—and it is natural to expect three different types of country in this one large physiographic division. As regards resistance to subaerial agencies, the granite and the quartzite are about equally matched. Both are very stable, chemically; both are massive in structure, breaking down mainly by weathering along widely spaced cracks or "joints," so as to form large blocks and boulders rather than smaller fragments. The only respect in which the quartzite is at a disadvantage is that it occupies narrow belts, flanked on both sides by belts of slate, the easy destruction of which has exposed the quartzite to a somewhat more vigorous assault by rain and rivers than is felt on the widespread granite areas. The result is that the granite presents by far the most continuous upland surfaces, and reaches the maximum altitudes; the quartzite belts afford broad, smooth ridges and swells with altitudes as a rule equal to those of the neighbouring granite areas; but the uplands underlain by slate are as a rule lower and form wide depressions, with the east-west trend so persistent in the mountain folds. Locally, where the slate was hardened by contact with the granite, or where a small patch of slate is surrounded by quartzite, even this soft rock appears on hilltops of the full upland altitude, and on monadnocks.

The movement of the great ice-sheet across districts occupied by these three kinds of rock tended, on the one hand, to mix their surficial materials or soils; and on the other hand, has led to pronounced differences in the three types of country, both as regards soil and topography. On the granite and quartzite areas, the quarrying of blocks and the production of boulders were vigorously carried on; but little was accomplished in the way of crushing down the fragments to earthy material, because of the toughness of the rock; consequently, little drift was left to cover the glacier-worn ledges. These regions, then, are today rocky surfaces, thickly strewn with large blocks, but so poorly provided with thin, sandy soil that they support little forest growth. On the slate areas, however, where the soft, fissure-filled ledges furnished an excessive supply of easily crushed slate slabs and splinters, there is a comparative abundance of drift, consisting of a plastic matrix of muddy clay, enclosing small pieces of slate and a large supply of cobbles and boulders imported from nearby areas of granite and whin. This thick plastic drift of the slate belts accounts for the presence in them of round-backed, elliptical hills of glacial origin, called "drumlins."

Granite Type of Country. The several granite districts of this upland division are very much alike and a fair picture of them all is obtained in the great crescent-shaped granite axis that lies between Halifax and Annapolis. A good view of the outer part of this granite country is to be had along the Halifax and Southwestern railway, a few miles west of Halifax, between Governor lake and the head of St. Margaret bay. Its surface stands between 300 and 350 feet above sea-level. A more extended view of the very back of the upland is obtained on the Midland division of the railway, in the 20 miles between Springfield and Alpena, where the altitude ranges from 550 to 650 feet.

The entrance into this granite country is perceptible on crossing the boundary, on account of the great numbers of big boulders. They come suddenly into view, by scores and hundreds, as if they had popped out of the ground; and they litter the surface as a rule as far as the granite extends. Ledges, mostly flattish and well smoothed by glacial action, also become common, for the glacial deposit is too thin to conceal them. Farms and settlements cease abruptly at the boundary; and within the barrens, lumber camps and railway villages dependent on them are the only evidences of human occupation. Low, shapeless ridges, rising as a rule less than 50 feet above the average level, and rarely more than 100 or 150, mingle with equally broad, shallow depressions, which are too irregular to be valley-like. Except in a few places where the ice-sheet tore away blocks from ledges so as to leave low crags or cliffs, all the slopes are gentle and subdued. There is no apparent slope over the district as a whole. Even the running water, occupied with the proverbial task of "seeking its own level," appears to be uncertain which way to turn. Sluggish rivers, with boulder-paved channels only slightly cut beneath the upland surface, flow aimlessly about from one shallow lake to another, in many cases passing close by an intervening lake, only to return to it later by a roundabout course, or to receive its waters, delivered by a straggling tributary, miles beyond. Again and again these lazy streams lose themselves in peat bogs or muskegs. A hunter or fisherman who has the misfortune to get lost in the granite barrens will hardly trust these rivers to guide him out of the wilderness. Even with a canoe, he will be confronted at every turn by the impossibility of foretelling which arm of an irregular lake or which stillwater along the river leads downstream. Through the naked ledges, fire-charred tree trunks and odd boulders that cover miles of desolate country have a most depressing effect upon the observer, whether his interest in the landscape lies in its elements of beauty or in its commercial value and productivity, yet he will find some compensation as he perceives attractive camp sites and fishing grounds, or as he surveys the acres of flower-filled peat bogs, where pink blossoms of rhodora, sheep laurel, and huckleberry, in their season, form masses of solid colour. The barrenness of this country is of twofold origin. The depressions, occupied since the Glacial period by muskegs and ponds, because of the lack of slope to direct the streams and the irregular scattering of glacial drift, have never been hospitable to forest trees. Blueberry, alder, and other heath-loving plants and shrubs, flourishing for many centuries, have built up thick beds of water-soaked material which is annually overflowed by the flooded streams -a sour peat, in which no trees can develop to maturity, not even the black spruce, fir, and hackmatack, the leaning spikes of which look like the masts of sinking ships. In contrast with these natural peat barrens, it appears that the higher parts of the surface, where granite ledges and boulders and thin yet dry soil prevail, formerly supported a heavy growth of hemlock and hardwood. Lumbering, followed quickly and repeatedly by forest fires, has not only swept the region clean of its timber, but has consumed the precious humus which had taken thousands of years to form. The incombustible residue, a sandy subsoil, of which quartz constitutes the major part, is generally too acid and light to allow the reclamation of the surface by heavy growth. Hundreds of acres of these fire-swept barrens are destined to remain as they are for centuries to come.

Quartzite Type of Country. Blending with the granite surface, and usually barren, like it, are the broad, smooth ridges of the quartzite country. In the northern part of Halifax county, where quartzite constitutes the innermost and highest part of the Southern upland, being separated from the outer quartzite belt by a long, narrow belt of granite, the country has the appearance of a plateau, composed of long, low, east-west ridges, where the almost perpendicular strata of the truncated folds come to the surface. Blocks of quartzite, as large as those of the granite country, but more angular than the granite boulders, clutter the ground, and there is so little soil that trees grow only in crevices in the rocks. The soils, derived mainly from the quartzose rocks of the immediate vicinity, are acid and inhospitable. Where the forest has not been utterly destroyed by fires, fir predominates on the ridges, and a mixed growth, including hemlock, oak, birch, beech, and pine, occurs on the slopes. The intervening hollows in the upland are sandy, swampy flats, drained by slowly moving streams, which follow the trend of the strata in a general way; but follow it imperfectly because of obstructing patches of glacial drift. In this high, interior part of the upland, the valleys are shallow, because the trunk rivers into which they lead follow the general slope of the uptilted plain, on courses transverse to the folds, and must, therefore, cross many hard quartzite bands before they reach the Atlantic. Peat bogs here, as in the granite country, are natural barrens, dating from the close of the Ice age.

To the south of the great granite axis, in Lunenburg and Queens counties, although slate occurs over a large part of the upland, quartzite is also extensive, and its limits are distinctly shown by a monotonous flatness of surface and an over-plentiful scattering of great blocks of whin.

In descending from the lake region, where the expanded rivers cover much of the upland surface, Lahave, Medway, and Liverpool rivers gradually sink below the upland, in channels that deepen into true river valleys, 100 to 200 feet deep, before they reach tidewater, at the heads of their long, drowned mouths or estuaries. Tributaries from both sides drain chains of lakes, lagoons, and stillwaters, in which the east-west trend of the rock belts shows more or less definite control. Rapids and low waterfalls appear at points where the rivers cross ribs of quartzite. The fall at ten such water-power sites on Medway river aggregates 120 feet. The fall on Liverpool river, in the 16 miles between Indian Gardens and tide-water at Milton, is 255 feet, which is almost all concentrated in rapids at twelve water-power sites. In the last 300 feet or so of descent from the lakes to the sea, the large rivers mentioned fall at the rate of 15 or 20 feet to the mile.

A somewhat different kind of surface is seen in the quartzite belts of Yarmouth county, for there the general slope of the upland from interior to coast, and consequently the trend of the larger streams of the region, are southward or southwestward, along the strike of the folded structures instead of across them. This has resulted in a more definite development of long, smooth, quartzite ridges near the coast, and a more pronounced deepening of the intervening valleys as they approach the sea. Furthermore, the direction of the movement of the ice-sheet, in this district, was south-southwestward; and this has added to the contrasts between the quartzite and the slate districts.

Slate Type of Country. The areas occupied by slate are productive and picturesque as compared with the granite and quartzite areas. This is due chiefly to the different way in which the rock had yielded to glaciation, affording a mantle of drift that is both rich in clay and moderately thick. In the interior of Queens county, the broad slate belts between New Germany and Caledonia, just south of the granite axis, constitute a well-settled farming district characterized by hundreds of elliptical drift hills or "drumlins." Even the obnoxious granite boulders, brought in from the neighbouring granite barrens of Annapolis county by the southeastward movement of the ice-sheet, and sprinkled all over the surfaces of the drumlins, have not prevented this district from developing into an agricultural region. The hills rise from 40 to 100 feet above the well-smoothed floor of slate, where bogs take up a large share of the area. The drumlins, which appear in the lakes as islands, both singly and in groups, are usually wooded; but those around the lakes have been cleared and farmed in most places, and the granite boulders have been built into great stone walls. Whether the gracefully curved drumlin profiles show naked on the sky-line, or, clothed with forests, rise above the surface of a lake, they afford a pleasant contrast with the monotony of the adjoining quartzite country. Were it not for the drumlins, these slate districts would be very flat; for the ice-scraped surfaces of the soft bedrock show at a nearly constant altitude in the low ground between the drift hills.

Slate areas appear at various places on the seacoast, notably around Halifax, Chester, Lunenburg, and Yarmouth. In all these places, as in the interior, the bedrock topography is subordinate to the drumlin topography. At Halifax, Citadel hill, the hills of McNab island, Thrumcap, and similar round-backed hills in and near the city, are drumlins. Those which lie exposed to the attack of the sea have been severely cliffed. At Chester, drumlins of beautiful form appear as peninsulas and islands and great natural sections of their ice-laid structure are seen where the waves are busily sawing away their exposed ends and sides (*See* Plate XIV). Bunker Island and other hills at Yarmouth belong to a local group of drumlins, developed along a narrow belt of slate, parallel to which a second belt appears, with drumlins, near Argyle. Indeed, so fully do these peculiar hills depend upon plastic drift for their development, and so surely do they spring up where the right material is provided, that one not knowing the character of the underlying rocks, but seeing the elliptical hills, would be justified in inferring that they are underlain by slate.

NORTH MOUNTAIN

Running parallel to the northern border of the Southern upland, and separated from it by the long, straight valley of Annapolis and Cornwallis rivers, is a high range of lava or "trap" rock, which has been known for three centuries as North mountain. Like a great palisade, enclosing the fertile valley, it reaches from cape Blomidon southwestward along the edge of the bay of Fundy for 120 miles, to Brier island. At its northeast end it is separated from the Cobequid range by Minas channel and the drowned Minas basin. At its southwest end it dips beneath the sea, forming a long line of dangerous ledges. At three points it is crossed by deep tidal gaps or "passages." Two of these act as side entrances to St. Mary bay, and the third, the great gateway known as Digby gap, allows the 30-foot tides to race in and out of Annapolis basin. From one end of this range to the other the crest-line matches in altitude that of the South Mountain escarpment which bounds the Southern upland. From Blomidon to Digby it does not rise much above nor fall much below 550 feet, as compared with the 600-foot surface of South mountain. Beyond Digby there is a slow and steady decline of the range down Digby neck to its end on Brier island, which corresponds to the southwestward slant of the Southern upland in Digby and Yarmouth counties. As in the Southern upland, the evidence shows that this slanting sky-line is a narrow remnant of an upwarped surface of denudation—a mere scrap of an upland which once covered all the Maritime Provinces. Upon the upwarping of the region to approximately its present altitude, rain and rivers began hollowing out the soft belt of sandstone that forms the Annapolis valley, and the broader area of soft rocks that now form the floor of the bay of Fundy; but left the hard belt of trap standing like a wall between them.

STRUCTURE

The structure of North mountain is unique, and leads to many unusual elements of form. The ridge consists of a thick series of lava sheets, tilted gently towards the northwest. Some of these sheets are compact and massive, with columnar cracks or "joints," caused by contraction when they cooled; others are spongy from the occurrence of millions of bubbles, where steam and gases were imprisoned by the quickly formed crusts of successive flows. These holes or bubbles have long since been filled with mineral deposits, making "amygdules," and the rock thus completed is called an "amygdaloid." The commonest minerals in the amygdules are soft, fibrous zeolites, of white, grey, or flesh colour; but green carbonate of copper commonly shows as a stain on the lighter minerals, and in some places metallic copper appears in wiry threads or granular particles. Many of the cracks in the columnar trap rock are filled with vein deposits of red jasper and of waxy blue chalcedony, which bleaches white upon exposure. These rare features of composition of the trap and amygdaloid sheets are of the highest value as aids in tracing the course of the ice-sheet across the province; for fragments which could have come only from North mountain have been identified on the Atlantic coast, between Halifax and cape Sable.

RELIEF

When seen in profile from where a transverse gap affords a good point of view, North mountain is plainly an unsymmetrical ridge, with a long, gentle slope towards the north and a short, precipitous descent towards the south. This is due directly to its structure; for the long, northward slope is the "dip slope" or back of the inclined trap-sheet, and the abrupt southern face of the mountain which overlooks Annapolis valley is the weather-worn edge of the sheet, steepened by the removal of the soft sandstones from beneath it. What has been said regarding the truncation of folded beds of quartzite and slate by the surface of denudation in the Southern upland applies with equal force to the abrupt termination of the sheets of trap at the top of North mountain, where the beds are bevelled by the flat upland plane (Figure 1). The uniform thickness of the lava sheets, revealed in cross-section at the gaps, and their attitude show that the beds formerly extended to far greater altitudes, but have been worn down to the level of the mountain top in spite of the resistant character of the rock. To call this great ridge the product of a violent upheaval, or a record of some grand overturning of the strata following a period of volcanic outbursts, as writers of tourist circulars carelessly do, entirely misrepresents the facts, by placing the emphasis wholly upon the preparatory chapters of the history of the range. Although it is true that the lava beds have been tilted up into a slanting position, the cause of the mountain as it is now seen is the quiet and steady process of denudation. But for the work of rain and rivers during the Tertiary period, the region would still be a smooth plain, stretching continuously from the ocean to the interior of New Brunswick, without a mountain in sight. The weak rocks north and south of the trap belt have been slowly eaten out by the rapacious agencies of denudation, and only the hard ridges remain.

For the greater part of its length of 120 miles, and continuously from Digby to Brier island, North mountain is double. The compound form is plainly seen wherever a good profile of the mountain is in view, as at Petite passage or Sandy cove. The double ridge disappears beneath the sea at Brier island, where the central hollow is drowned so as to cause conspicuous re-entrants in the shore-line at both ends of the island. There are at least three explanations—all plausible—of the compound topography of the range: (1) The two crests may be edges of the topmost trap-sheet, broken by two cracks or faults that run parallel to Annapolis valley and are less than 2 miles apart. In that case, the median hollow upon the mountain occupies the downthrown angle between the inclined blocks along the more northerly fault-line, and the two south-facing escarpments are both fault scarps. To this hypothesis objection may be made that there are no other evidences of these two faults, or of any faults with a northeastward trend. A more serious objection, however, is that the two crests of the mountain are of similar height for 80 miles, from Blomidon to Digby. Faults as great as this commonly vary considerably in the amount of displacement in distances of a score or more of miles. Their scarps, therefore, change in height and their crest-lines rise and fall proportionately. It would be singular enough if one fault scarp maintained a uniform height of 550 feet for 80 miles; it is almost inconceivable that two parallel fault scarps should do so, or that, in the 40 miles west of Digby, the two scarps should decrease at the same rate, as these do. Furthermore, it is very unusual to find two faults so close together, extending so far with perfect parallelism. (2) Longitudinal faulting like that assumed in the preceding hypothesis may have been followed by denudation to a nearly level plain; and after the upwarping of this plain, renewed denudation may have eaten away the non-resistant rocks on either side of the trap belt, leaving it standing as an even-crested double ridge. Thus the uniform crest-line of both ridges might be explained, and the westward decline between Digby and Brier island would be explained by the warping of the plain of denudation at the time of its re-elevation. The same objection applies to this hypothesis as to the foregoing one—namely, it demands the existence of two parallel fault-lines, only 2 miles apart, running 120 miles—a rare, if not unheard-of condition. It has the advantage, however, of not requiring a uniform dislocation throughout this distance. (3) The trap-sheet consists of three successive beds; two sheets of resistant trap, with a bed of soft amygdaloid, sandwichwise, between them, all dipping northwestward and worn down unequally by denudation since the uplift of the facet. It is true that amygdaloid occurs extensively along the central hollow west of Digby. It is too easily broken down by decay and too thoroughly covered with soil to be generally exposed to view; but the glacial drift here is full of fragments of it, whereas that on the trap ridges on either side contains little. It is supposed that after denudation had shaved down the hard and soft structures of the entire region to a smooth surface, the upwarping of the district, giving the rivers a new lease of life, enabled them to excavate the soft sandstones of the Annapolis Valley belt, and to wear away the similar weak rocks over the broad belt where the bay of Fundy now lies, as well as to hollow out the long, narrow strip of amygdaloid in the middle of the mountain. This hypothesis has the advantage that it does not require faulting along two lines so near together and so nearly parallel; yet it accounts for the evenness of crest-line and the steady decline towards Brier island, in the same way that the second hypothesis explains it.

GAPS

There are a large number of notches or gaps of various sizes in the mountain wall. Those west of Digby are the deepest and most prominent. Three of them, only, reach below sea-level—namely, Digby gap,

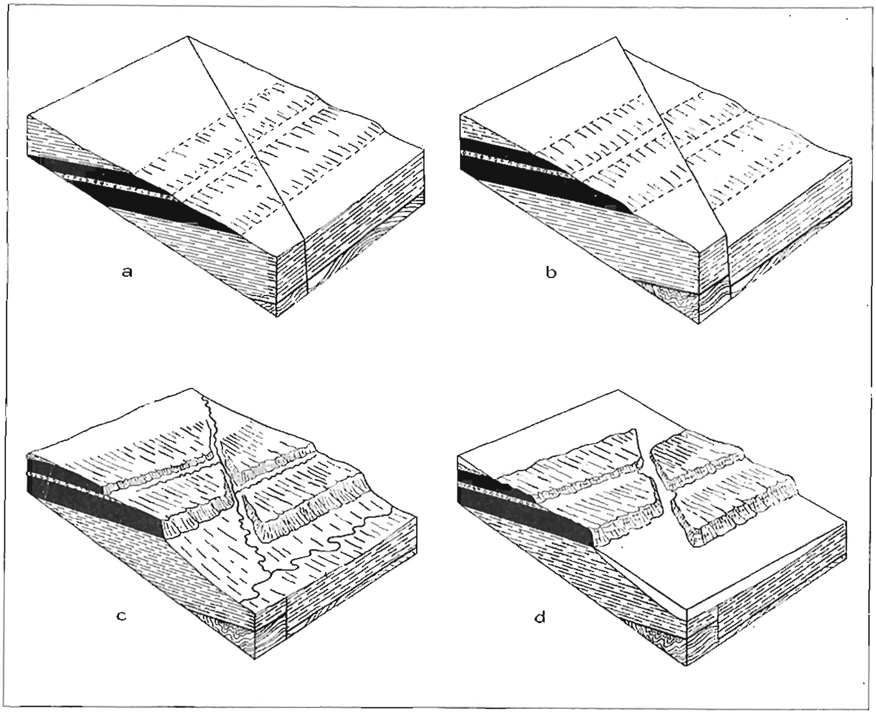


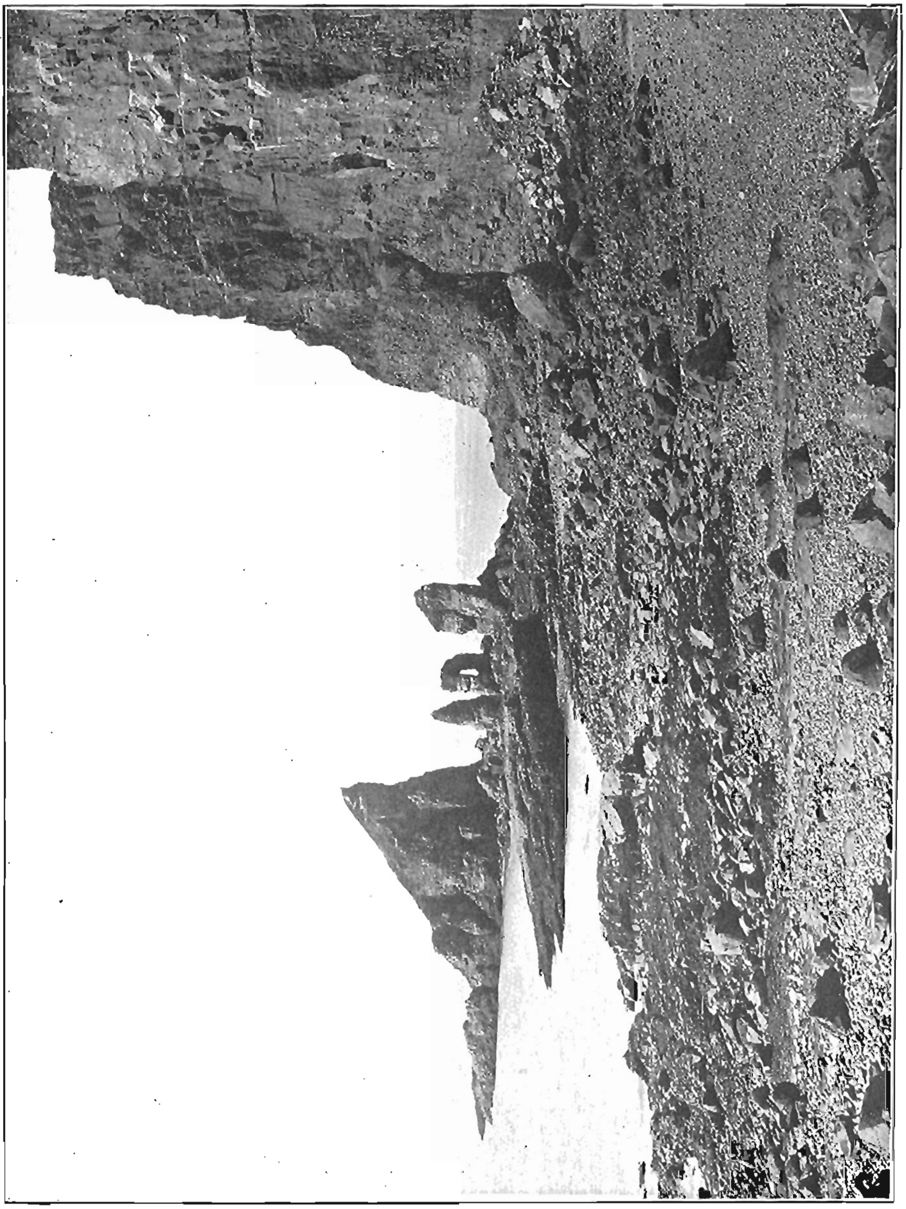
Figure 3. Block diagrams showing how the gaps in North mountain originated.

Petite passage, and Grand passage; but gaps as wide as these occur between Deep cove and Roxville, between Gulliver hole and Rossway, at Centreville, at Sandy Cove, at Mink Cove, and at Little River. What is their origin? Their resemblance to gaps in the trap ranges of the Connecticut valley and Watching mountains of New Jersey—mountains which resemble this one in every respect—suggests that in common with them these were originally water gaps, occupied by transverse rivers. The relation of Digby gap to the submerged valley of Annapolis basin, for which it is the only outlet, confirms this view. The gaps are located on oblique faults, along which the whole mountain structure has been dislocated. Map 2006 shows that at each of the three passages there is a marked jog or offset in the shore. The whole mountain has the appearance of having been shoved over a little, so that it lies farther north on the west side of the gap—in other words, the faults are "right-hand" faults. Jogs like this show not only at the three passages, but at several angular points in the shore of Digby neck. Exactly similar features occur in the trap ranges of the Connecticut valley and New Jersey, where the arrangement of the broken ridges is wonderfully systematic. The relation of the topography to the structure at these oblique faults is illustrated by Figure 3. Comparing the present worn-down surface with that produced directly by faulting, shown in Figure 3 b and c, it will be seen that the shoving over of the mountain is not necessarily due to any horizontal shifting of the rocks, such as was found in the faults cutting the folds of slate and quartzite near Country Harbour and Sheet Harbour (page 12), but rather to the wearing down of the dislocated sheet of trap on the upheaved and downthrown sides to a common level. The displacement by faulting may have been a vertical one, as shown in Figure 3 b, in which case the movement alone had no effect on the outcrop of trap, except to change its altitude; but on account of the inclined position of the trap-sheet, denudation, though reducing the surface of the upper block to the level of the lower one, would shift the outcrop of the trap-sheet down the dip of the beds as far as the angle of dip and the displacement by faulting required. Where the altitude of the tilted sheet had been changed by the faulting, the escarpments were worn back unequal distances and thrown out of line (Figure 3 c and 3 d).

CAPE SPLIT HOOK

The last structural feature of North mountain to be considered is the semicircular hook at its eastern end, which encircles Scotsman bay, and separates Minas basin from the bay of Fundy. This hook is the result of warping or "dishing" of the trap-sheet, which, after running without marked change of dip for 120 miles, suddenly curves northward around the nose of the dish-like fold, whose axis lies beneath the waters of Minas channel (Figure 4). From "the lookoff" above Canning around the bend of North mountain at cape Blomidon, the crest-line steadily falls, and the trap belt narrows until it tapers to a point at cape Split. It emerges again only in a fragment at Cape d'Or across the channel. The triangular form of Minas basin and Cobequid bay reflects closely the eastward extension of this dish or fold, the axis of which passes eastward from cape Blomidon to Truro, where the soft red sandstones that underlie the trap are broadly exposed. That the structure is somewhat complicated is shown by additional outcrops of trap at Partridge island, Five Islands, and Bass River—probably outlying patches of the same trap-sheet, brought down by minor folding or faulting. Folds exactly similar to this one occur in the trap-sheets of Connecticut valley and New Jersey.

PLATE II



Cape Split.

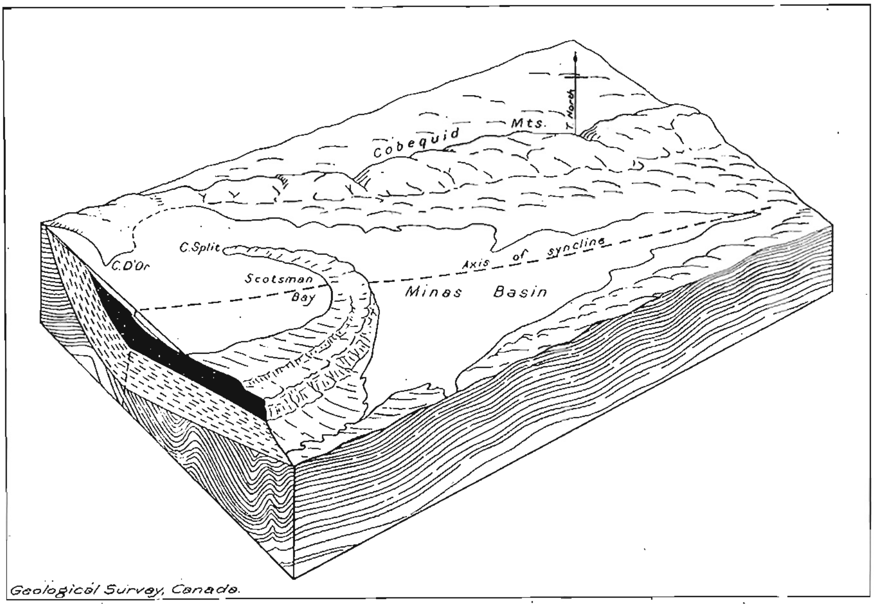


FIGURE 4. Block diagram showing the Cape Split hook and the dish fold in Minas basin.

COBEQUID MOUNTAINS

Cobequid mountains are a long, narrow remnant of the Atlantic upland, stretching 75 miles across Cumberland county, from the head of the bay of Fundy almost to Northumberland strait. Although the upland belt looks mountainous, when seen at close range from the lowlands on the north and south, and although its flanks look bold and its top uneven when seen from the railways which cross it through two deep gaps, the belt is in reality so flat topped that if it were 40 miles wide instead of 8 or 10, it would be called a dissected plateau. When seen from a distance, particularly from a high altitude, the flatness of the range is quite distinct. Broad, rounded summits, ranging in altitude from 850 to 1,000 feet, blend to form a somewhat rolling surface with an average altitude of somewhat over 900 feet.

STRUCTURE

This highland, like the Southern upland, manifestly owes its presence to the strength of its structure. The crystalline rocks of which it is mainly composed—granite, syenite, diabase, and felsite—are topographically resistant, in contrast with the weak, crumbling sandstones and shales of the surrounding lowlands. Infolded and enveloped masses of contorted schists and slates of Silurian and Devonian age, punctured in places by off-shoots of the igneous mass and hardened by contact with it, indicate that here, as in the Southern upland, an epoch of mountain folding, near the close of the Devonian period, was accompanied by the ascent of a huge body of molten rock into the roots of the folds; and that the structure has since suffered from excessive denudation, which ended in the etching out by rain and rivers of the surrounding lowlands.

RELIEF

The approximate accordance of the summits of the Cobequids is the more striking because the range is narrow and completely surrounded by the lowlands of Cumberland county. During the wearing down of these lowlands by subaerial agencies, the mountain structure might be expected to suffer severely from the attack of tributaries of unequal size. The steep north and south flanks of the range—in some places precipitous—are deeply carved by torrential streams. The great depth of these carved valleys seems strange, and is hard to account for by the operation of streams so small, fed from a watershed so narrow, yet the erosion is insignificant compared with the widespread denudation of the adjoining country from the old 900-foot level to the present lowland of 200 to 400 feet.

WIND GAPS

Folly Lake pass near Wentworth and Halfway Lake pass north of Parrsboro are the most remarkable features of the Cobequids. The former is used by the Intercolonial railway in getting through the mountain barrier into Nova Scotia—for these mountains almost completely block the connexion by rail between Halifax and Sydney in the east and Montreal and the interior of Canada in the west. Instead of avoiding the barrier by going 75 miles around the east end of the range, or by going a nearly equal distance westward to get through the gap north of Parrsboro, the railway climbs the valley of Folly river for 9 miles at a grade of nearly 50 feet to the mile, passes across the range at a summit altitude of slightly over 600 feet, and descends by another steep grade to the lowland of Cumberland county. The scenery from the car window looking over the railway embankment into the deep gap and out beyond its mouth to the broad, undulating plain is impressive—the more so because it is come upon after many miles of travel through relatively featureless lowlands. It gradually comes over the stranger who sees this country for the first time that the Cobequid mountains are almost as large a factor in the isolation of Nova Scotia as is the sea. Were it not for the pass, the railway from Truro to Amherst would have to cross the range at a summit level of about 900 feet instead of 600.

The floor of the pass, at its highest point, is occupied by a lake that has an extent of about 200 acres. From this lake, the two small streams that flow northward and southward into Wallace and Folly rivers, respectively, receive most of their volume, either by surface outlet or by seepage, and in return flow in springs. The gap is too wide and too deep to have been eroded by these streams, dependent as they are upon the rainfall on a narrow belt of upland. Moreover, if this were the cause of the gap, many other gaps of similar width and depth at the heads of other streams, would be found in the stretch of 75 miles along the range. But it is most significant that the pass is nearly as wide at its summit as at the two ends, if the knolls and banks of glacial drift so thickly heaped upon its sides and floor be excluded. The only way in which a gap so nearly uniform in width could be excavated across a mountain range is by a great river maintaining for sufficient time a course transverse to the hard and soft structures. The abandonment of the gap, here, as in hundreds of cases studied in North America and Europe, is due to the diversion of the through-flowing river by stream piracy, converting the water gap into a "wind gap." Subsequently, as the lowland belts on both sides of the range were eroded to lower and lower levels, the pass may have been deepened near its two ends by the relatively small streams that drained it in opposite directions—streams which, though small and feeble at first, would become increasingly efficient as the lowlands to which they flowed were reduced. This does not explain the occurrence of the lake at the summit. This lake owes its existence to the blocking of the gap by thick masses of glacial drift in the form of kames or morainic mounds. During the northward retreat of the front of the ice-sheet there was a stage when its margin rested against the north side of the mountains, and a tongue of ice still lingered in the pass. A considerable outflow of water from its melting front poured through the gap, both along the margins of the ice-tongue and through tunnels or canyons within. As the ice melted, these temporary river beds, slumping where the ice wall had been withdrawn from the gravels, became kame terraces along the valley side, and narrow, linear mounds or kame ridges on its floor, so disposed that they blocked the drainage of the central and highest part, forming the lake. There has not been time since the Ice age for the visible and underground outlets of this lake to dig out the enclosing gravels and thus to drain away the water of Folly lake.

Although the pass north of Parrsboro, traversed by the Cumberland railway, had a history similar to that of the pass at Folly lake, it is, in some ways, more striking. It is deeper and wider than Folly Lake pass; its flat floor, 500 feet or more below the summit of the range on either side, stands only 85 feet above the sea at its highest point, where large glacial gravel deposits conceal the rock floor of the pass. Kame terraces appear conspicuously on its sides, and have been mistaken for marine benches, elevated by post-glacial unwarping. The floor is undulating, with numerous kame mounds and ridges like those which surround Folly lake. The present watershed is located on the crest of one of these kame moraines, which runs across the gap beteeen Gilbert and Summit lakes. If all the drift could be removed from the floor of the gap, it would appear to be a wide, rock-bottomed water gap or wind gap of nearly uniform width, cut to a level equal to that of the neighbouring lowlands.

This hypothesis of the origin of the two great gaps in the Cobequids raises the question of the source of the two rivers that formerly passed through them. Can their old paths be traced to-day? Unfortunately, their courses across the lowlands have been obliterated by the wearing down of the surface since the desertion of the water gaps, or are concealed by glacial deposits. The floor of Folly Lake pass stands 300 or 400 feet above the lowlands (assuming that the bedrock floor beneath Folly lake is covered by only a thin mantle of drift), and it, therefore, appears that the adjacent lowlands have been worn down 300 or 400 feet since the river deserted that gap; and so it cannot be expected that any trace will be found of the old course on the present plain. The old streams have wholly vanished, and new ones have grown up. In the case of Parrsboro pass, a better chance of finding the old course of the transverse river seems possible, for its floor lies almost on a level with the country to the north and south, showing that the abandonment of the gap was comparatively recent. Indeed, it is possible that the desertion of this pass is due to the ice-sheet, which while it overspread the region put a stop to all stream action, and on retiring revealed a new drift-covered surface which deflected the rivers into new courses. The river through Parrsboro pass probably flowed southward rather than northward under the influence of the southward slant of the Atlantic upland, which was complete when the course of the river across the mountains was first established. North of the gap today a small river—river Hebert—drains some of the swampy district in the gap, and receives one large tributary from the west, north of the mountains. As River Hebert valley descends northward, it gains in depth until near its mouth the slopes on either side rise gently to a height of 200 feet or more above the valley floor. Nothing in this valley indicates that the river is a reversed stream, following the line of an old southward-flowing river, but Halfway river rising on the northern slope of the Cobequids west of the gap flows southeastward towards its entrance. It turns aside sharply just before it reaches the gap, and straggles northward into Halfway lake, whence it continues as a sluggish tributary of river Hebert. The gravelly deposits around the head of the pass appear to have determined the northward flow of the stream by blocking its natural course through the gap. On the east side of the gap several streams unite to form Maccan river. It is possible that some of these also were formerly tributary to Parrsboro river, and that during the glacial period their southwestward course was blocked. Even if both Halfway river and the upper waters of the Maccan formerly flowed through the gap their volume alone would hardly account for the existence of a valley of such size, they must have been small tributaries of a larger river. The upper part of this trunk river is represented today by the Petitcodiac, the drowned gorge of which now forms the estuary below Moncton, N.B., and aims directly towards the Parrsboro gap. If so, the course of this old river across the intervening lowland has, since the abandonment of the gap, been completely erased by denudation and glaciation. If this river originally cut the gap through the Cobequids it may have been diverted to the Bay of Fundy depression considerably before the Ice age, and the small survivors of the south-flowing system, Halfway river and the Maccan waters, may have been able to continue the lowering of the floor of the pass until the ice-sheet buried it.

HIGHLANDS OF EASTERN PICTOU AND ANTIGONISH COUNTIES

Where Cobequid mountains terminate, about 10 miles southwest of Pictou, the crystalline rocks disappear beneath a cover of the softer bedded rocks that compose the encircling lowlands. Ten or 12 miles farther east, and about 5 miles south of New Glasgow, the hard rocks—and with them the highlands—reappear, spreading out widely over the eastern part of Pictou county and reaching a long, narrow projection northeastward past Antigonish and Arisaig to cape George. The geology of this district, particularly that around Arisaig, has been worked out in detail and its structure and physiography have been described by M. Y. Williams in Memoir 60 of the Geological Survey.

A large part of the highlands is occupied by hardened quartzites and slates, not unlike those of the Southern upland in composition, but apparently of less ancient date, for the fossils in them prove that they belong to the Ordovician period—at least one period later than that which the Gold-bearing series is thought to represent. As in the Southern upland, these bedded rocks are closely folded into anticlines and synclines, and the structure is displaced by stocks of granitic rocks of various sorts, and locally of considerable size. In addition to these, the strata are punctured in many places by smaller intrusions of dense, fine-grained rocks, which are the necks of ancient volcanoes. The lava is of two or three different sorts. From this fact, and from the various relations of these igneous masses to the successive stratified formations, it is evident that there have been several periods of injection of magma as well as repeated mountain foldings. Since the upfolding of the old marine sands and muds into anticlines and synclines, and the squeezing of igneous masses through them, the structure has been worn nearly flat, as in the other upland districts—and, by inference, throughout the whole region. Following this denudation the land has again been elevated and redissected by its streams, and rivers have reduced the neighbouring districts of softer rock to lowlands. During the Glacial period, these highlands were covered by the ice-sheet which moved over it first eastward and later southward, but without greatly altering its surface.

As in the other upland districts, the surface of this highland looks rough and irregular when seen at close range from the lowland or from one of its own valleys, yet when seen from its own level and from a distance it appears to deviate little from a plain. In the southern part the average altitude is about 800 feet; but in the Arisaig district it rises to nearly 900 feet. The borders of the highland are fairly well defined, although the scattered arrangement of volcanic plugs and other resistant masses of rock cause some irregularity in its outlines. From the Intercolonial railway a good view can be had of the escarpment that forms the northern boundary of the highland between Piedmont and Avondale, where the railway skirts the base of the highland; and another of the southern boundary between James river and Antigonish. Streams have excavated deep gorges and valleys beneath the uplifted surface, through which they descend with many rapids and falls from the boggy summit of the highland to the well-drained plains of the lowland. At two or three points near the northern border the hilltops exceed the general altitude sufficiently to be termed "mountains." Thus McNeil mountain, 2 miles south of Malignant Cove—a hard volcanic plug—reaches the altitude of 1,010 feet, the highest known point in Nova Scotia outside of Cape Breton island. Sugarloaf mountain, one mile north of McNeil mountain, has an altitude of 680 feet, and a similar structure, and shows part of the enclosing slate structure still sticking to the sides of the lava-filled neck of the old volcano. Another Sugarloaf mountain, 2 miles north of Antigonish, is a denuded volcanic plug like the other two, though formed of black lava or diabase instead of felsite. It reaches 760 feet, in agreement with the nearest parts of the highland from which it is somewhat detached.

If the altitude of this highland be compared with that of the Cobequid range and the nearest parts of the Southern upland, it will be seen that the upland surface forms a perfect extension of those parts already described, carrying the plane upward in a northerly or northwesterly direction to an altitude of 900 feet. As noted in the case of the Southern upland, this slant is independent of the presence of lowlands and of the great submerged plain which forms Acadian bay and Northumberland strait.

UPLAND BELTS AND NORTHERN TABLELAND OF CAPE BRETON ISLAND

The most remarkable group of fragments of the old Atlantic upland to be found anywhere in the Maritime Provinces occurs on Cape Breton island. They appear wherever the hard crystalline rocks come to the surface, in a series of elongated, irregular belts that trend southwest along the axes of the old Appalachian folds. The largest and highest of these fragments is a great tableland which occupies the northern part of Victoria and Inverness counties—a wild, wooded plateau about 1,200 feet high. As in the rest of Nova Scotia, the upland has been preserved only on the hard rocks; it has been destroyed on the intervening belts and patches of less resistant rocks by the erosion of the later geological periods. The correlation of the fragments of the upland on Cape Breton island is interesting in the light of what we have learned in the region farther southwest, for the upland belts and the tableland when plotted in profile fall into a single very definite inclined plane, which can be traced inland from sea-level along the southeast coast to the 1,200-foot tableland of the north country (Figure 5).

The rocks which have so successfully resisted the attack of rain and rivers since the upwarping of the old lowland are mainly crystalline rocks of great age—commonly granites, syenites, and other coarse-grained types of deep-seated origin; but in some places there are highly altered rocks of sedimentary origin, known as the George River series—old limestones, sandstones, and shales, which have been converted by pressure and heat into marble, quartzite, and slate. That these bedded rocks are older than the granitic rocks is shown by the intrusive contact between them, just as in the case of the Gold-bearing series and the granite of the Southern upland. These bedded rocks appear to be the oldest in the province. Closely associated with them are volcanic rocks of various kinds—old ash beds, breccias, and agglomerates. Some of the volcanic rocks, as at Louisburg, Scatari island, and George River, are variegated in purple, green, red, and grey, and are especially beautiful when seen in smooth, wet beach pebbles or in artificially polished specimens.

SOUTHEASTERN UPLAND

Along the coast from Scatari island past Louisburg and Framboise to L'Ardoise, the low, irregular surface of the Atlantic upland slants beneath

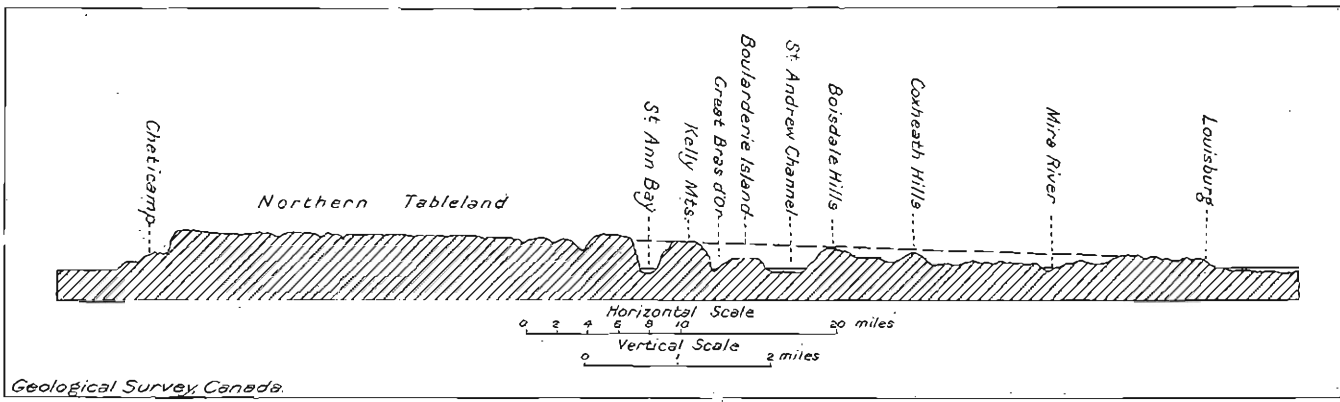


FIGURE 5. Profile of Cape Breton island showing how the upland fragments may be correlated into a single inclined plane.

the sea in ragged peninsulas and islands. These are succeeded off-shore by submerged reefs and ledges that endanger navigation almost as much as the dense fogs that brood on the coast for weeks at a time. Rough, wave-torn ledges and rocky beaches testify to the vigour of frequent storms. Some of the rocky hills near the shore rise to altitudes of over 100 feet, and a few of them to more than 200 feet. There is an endless succession of glacier-worn, rocky knobs, unproductive, boulder-filled pastures, fire-swept barrens, and trackless morasses. Extending inland, this surface rises gradually to an altitude of from 300 to 400 feet in Mira hills, 12 miles from the coast, where it terminates in an escarpment overlooking the Salmon River lowland. Uninteresting and monotonous scenery prevails throughout the region. Lakes with low, marshy banks, generally bordered by forests, occupy the broad depressions. The lakes are due to the obstructing effect of the glacial drift; for ledges are seldom seen at their margins. Long, sluggish streams connect the inland waters with the sea. One lake that lies only 1½ miles back from the shore of Gabarus bay, and is separated from it by no great elevation, discharges northeastward through the lazily-flowing Catalonge river, reaching the sea at Mira bay after a journey of 13 miles. The value of the district appears to rest chiefly on its fishing, which is exceptionally fine. Cascades of considerable size occur in some of the rivers, as on Grand river below lake Lomond, where in a distance of 135 feet three cascades drop 16, 4, and 6 feet in succession, over ribs of hard rock.

On one of the low, boggy projections of this unpromising district are the historic ruins of the old French city of Louisburg. What a poor situation for the costly fortress and city! It had a good harbour, and it stood where the new world stretches farthest out towards the old; but it would be difficult to find a more desolate background for the French capital in North America. A bleak, rough coast, hidden half the time by fogs, with a soil too poor and thin to cultivate, and surrounded by swamps—this site could be at its best only a foothold.

EAST BAY HILLS AND SPORTING MOUNTAIN

Beyond the Salmon River lowland, where soft Carboniferous rocks outcrop in a long, narrow belt, is a range of crystalline rocks called East Bay hills, with an average altitude of somewhat over 500 feet. At one place north of Irish Cove the summit reaches 600 feet. The top of the range looks very even as seen from the Bras d'Or steamer between Grand Narrows and St. Peters. The precipitous northern slope of the range, facing East bay, is well covered with glacial drift, allowing the rocky framework to show through only at scattered intervals.

Nearly in line with the East Bay hills, and overlooking West bay as that range overlooks East bay, is another flat-topped remnant of the Atlantic upland called Sporting mountain. Its rock structure is like that of the other upland remnants. Its summits range from 480 to 630 feet, rising 200 or 300 feet above the surrounding lowland, with an average altitude of about 550 feet.

NORTH MOUNTAINS AND BOISDALE HILLS

The next mountain range is the long, upland belt of which the Boisdale hills constitute the axis and the Coxheath hills near Sydney a minor branch. As shown by the altitudes on Map 2006 the summit of the main range, overlooking St. Andrew channel, rises between 600 and 700 feet, closely approaching the latter in most places. In Coxheath hills, which lie a few miles south of the Boisdales, the smooth summits rise only 550 feet. This seeming discrepancy in altitude proves to be an instance of the orderly arrangement of altitudes on the tilted upland; for the southeastward slant, which appears in the relation between the upland fragments already described, accounts for the descent from the crest of the Boisdales to the lower crest of the Coxheaths. In both these belts volcanic rocks like those of Scatari island are found.

At the opposite end of Big Bras d'Or lake, on the north side of West bay, North mountains occupy a position nearly in line structurally with the crystalline belt of the Boisdales, and have summit altitudes which are comparable, slightly exceeding 700 feet in the three places where measurements have been made.

CRAIGNISH HILLS AND KELLY MOUNTAINS

It is a short step across the lowland, the undulating hilltops of which are crossed by the Intercolonial railway at an altitude of nearly 500 feet, to the next range of hills, which extends from near the straits of Canso northeastward for 20 miles, to Whycocomagh. In this Craignish range, with its higher average altitude, it would be natural to find less perfect accordance of summits; yet the sky-line, as viewed from the railway or from George bay, is no more uneven than that of the lower upland belts. Owing to the fact that this range has a more northerly trend than the foregoing belts, the tilting of the upland has produced greater differences in summit levels and the average elevation of the hilltops rises from less than 700 feet on the south near the straits of Canso to 900 feet or more near Whycocomagh. From the southern end of the Craignish belt, Inhabitants river, rising on the highland, close to its steep western edge, within 3 miles of the shore, descends in a southeast course 17 miles long, reaching the ocean not far east of the strait of Canso. It follows a course which was once common to all the large rivers of the region—a consequent course down the inclined plane of the elevated upland, which is exhibited in a more marked fashion by the drowned valley of the strait itself. Fletcher has thus described the streams of Craignish hills: "These rivers originate among the hills in innumerable tiny streams from marshes and lakes, or bubble out clear and cool from the foot of some rocky cliff, rush down the rugged and precipitous sides of the mountains, plunging over rocks or hurrying through dark and gloomy ravines; and unite to stray in the lower reaches among rich meadows and farms, at different seasons, as clear, winding rivers or turbid, swollen, irresistible floods, sweeping to destruction bridges, hay, or other obstacles. The streams flowing from the steep sides of the hills that look towards West bay and the straits of Canso are short and rapid; those on the opposite side are longer and less turbulent."

An isolated scrap of the upland, near Mulgrave, on the southern side of the strait, is preserved on a solitary patch of the ancient crystalline rocks, the only known occurrence of Precambrian structure on the peninsula of Nova Scotia. This forms cape Porcupine, whose altitude, in harmony with that of the upland just across the strait, is 640 feet. In his geological report on the region, Fletcher speaks of cape Porcupine as wooded and picturesque, with romantic waterfalls, not unlike the larger uplands of Sporting mountain and North mountains.

Far to the northeast of Craignish hills, but appearing in line with them structurally, is the long belt of upland known as Kelly mountains. It stretches along the north side of Great Bras d'Or channel for 20 miles, to cape Dauphin, where it stops abruptly. Its crest rises in this distance from an altitude of about 800 feet in the southwest to 900—and locally even 1,000—in the northeast. As seen from the Intercolonial railway across St. Andrew channel, or from the St. Ann or Ingonish boat which passes by its northern end, the long, low summits, swelling and sinking with little variation, make a plateau-like profile that matches the tableland across St. Ann bay on the west. The precipitous northern end at cape Dauphin is a surface of great antiquity, revealed by the removal of soft sandstones and limestones of the Lower Carboniferous or "Windsor" series which once overlapped it. The Atlantic upland plane intersects this old surface at a definite angle, forming a shoulder.

NORTHERN TABLELAND

Just across St. Ann bay from Kelly mountains stands the bold front of the tableland of Victoria and Inverness counties. Coming out from Sydney harbour on the boat which runs on successive days to St. Ann, Ingonish, and Aspy bay, an impressive view is obtained of the great tableland, with its flat surface ending sharply in a precipitous line of cliffs, 1,000 feet high, which overlook the sea for 25 miles between St. Ann and cape Smoky. At that point there is a deep offset in the shore-line which throws the more distant coast far in the rear of the cape; and 15 miles beyond it is another greater offset at cape Egmont, before the extreme end of the plateau is reached at cape North—a point so far away that it barely shows in faint blue on the horizon. As the boat draws nearer to the coast the cliffs north of Smoky cape vanish behind its angular corner and attention becomes fixed upon the part of the tableland that lies plainly in view. Although the even sky-line of the interior shows it to be a plateau of great uniformity, standing 1,200 feet above the sea, the margin of the plateau is broken by many deep valleys and narrow gorges or canyons, where the rivers that drain its vast interior pass down to the sea. Some of these enter the sea as quiet, deep-flowing rivers, with fiord-like mouths due to a drowning of the coast. Most of them, even the largest, are torrents dashing over cascades and waterfalls down narrow, V-shaped canyons, whose forest-covered sides flare out rapidly as they reach the front of the tableland. As seen from 3 or 4 miles offshore, the sky-line of the plateau takes on a broken or roughly serrate form, because of the depth of these great valleys that are so prominent in the foreground.

PLATE III

Tableland near cape Smoky.

For long distances, the great escarpment or front of the tableland lies a little back from the shore, where narrow remnants of lowland show that the weaker, bedded rocks have not been removed by the combined assault of the sea and of subaerial agencies. Long, sea-carved cliffs, from 200 to 300 feet high, expose the steeply inclined strata that underlie these foothills of the highland. Beyond Wreck Cove the lowland fringe ends, and the face of the tableland itself comes out to the coast. Although heavily wooded in most places, the great cliff has been eaten away by the sea in two places near cape Smoky where pale pink granite shows in huge scars that reach from the water's edge to the top of the plateau. Cape Smoky has been stripped of its soft, green forest cover for a third of its height, displaying a crumbling foundation of granite, from the recesses of which great slides of loosened rock slip into the sea and are consumed by the surf.

Passing under the shadow of these cliffs, the boat rounds the cape and runs into South bay and Ingonish river, affording a wonderful view up the fiord. The harbour, almost completely enclosed by a cobblestone bar, reaches inland about 2 miles between steep, rocky slopes that form a grand natural gateway to the back country. Through this gateway can be seen the high, table-like summits of the interior, around which the branches of Ingonish river head in great gorges. Within sight, though several miles away, are vast stretches of balsam fir forest, wild salmon streams, and the mossy barrens of the caribou country. Dwellings and farms appear only along the shores of the harbour and at the mouths of the valleys that enter it. Beyond and above them the broad intervales lead up to roaring cascades and water-falls. Here the trails stop; and the tableland to the west shore can be travelled only by compass, for 15 miles through the wilderness.

An idea of the appearance of this wild interior is readily obtained by following the post road south from Ingonish toward cape Smoky, until the summit of the plateau is reached, about 3 miles from the harbour. A mile out, the road reaches the brink of a deep, straight valley, and, turning, follows up the side of the valley for a mile or more, until at length it crosses a stream which rushes down its axis; thence the road turns abruptly eastward up a tributary valley. Looking down the main valley from this point one cannot fail to be struck with its extraordinary straightness. The maps of the Geological Survey clearly show that the valley trends parallel to the great outer escarpment of the plateau and this, taken in connexion with other facts, suggests that the valley lies on a fault-line, parallel to the fault that forms the great escarpment. At many points along the road there are outcrops of soft, red sandstone or "arkose," instead of the hard granite, of which the tableland is mainly composed. It seems likely that this soft sandstone is a remnant of a once continuous cover of bedded rocks which, later, were dropped down along the fault-line. Since the uplift of the plateau the sandstone has guided the work of rain and rivers. Indeed, the surface of the tableland as seen from the summit farther out on the road has the appearance of being composed of large blocks with gently tipped tops that slant westward.

On reaching the top of the tableland, 3 miles from Ingonish, the road emerges from the tall, dense forest of mixed growth and passes over a wilderness of quaking peat bogs with alder thickets or of dry, rocky ground where blueberry bushes and scrubby balsam grow profusely. The granite ledges are deeply cracked by glaciation and frost, and along these gaping fissures the rock is crumbling to bits. Scattered all around on the ledges are angular blocks loosened from them by the ice-sheet and by more recent frost action. In some places they are so thickly distributed that walking is difficult, and progress must be made by stepping from block to block.

The rock disintegrates in a peculiar way. As the fragments break down, and the feldspar is separated from the quartz, the feldspar mineral vanishes (presumably by decay and solution), leaving a coarse, rough sand made up of quartz grains, which looks very much like broken rock salt.

The presence of so much local material and of the crumbling ledges has led observers to suppose that the soils of the tableland are wholly residual in origin, and to question the passage of the ice-sheet across it during the glacial period. Glacial drift of characteristic structure and composition occurs along the road where it ascends the valley between Ingonish and cape Smoky. If the ice-sheet approached this part of the province from the northwest, as it appears to have done, its course across many miles of granite highlands would fully account for the absence of debris from other sources.

The more remote interior of the great tableland, west of cape Smoky, is mainly a rocky surface covered by virgin forests of balsam fir. On the main watershed, a chain of great bogs or muskegs discharges into both eastward and westward-flowing streams which rise in them as sluggish brooks, half concealed by alder thickets, and farther down by ferns, spruce, and mountain ash. Caribou are plentiful in this muskeg country. The highest known point in the province, Ingonish mountain, 1,392 feet above sea-level, is visible from the coast in Ingonish bay.

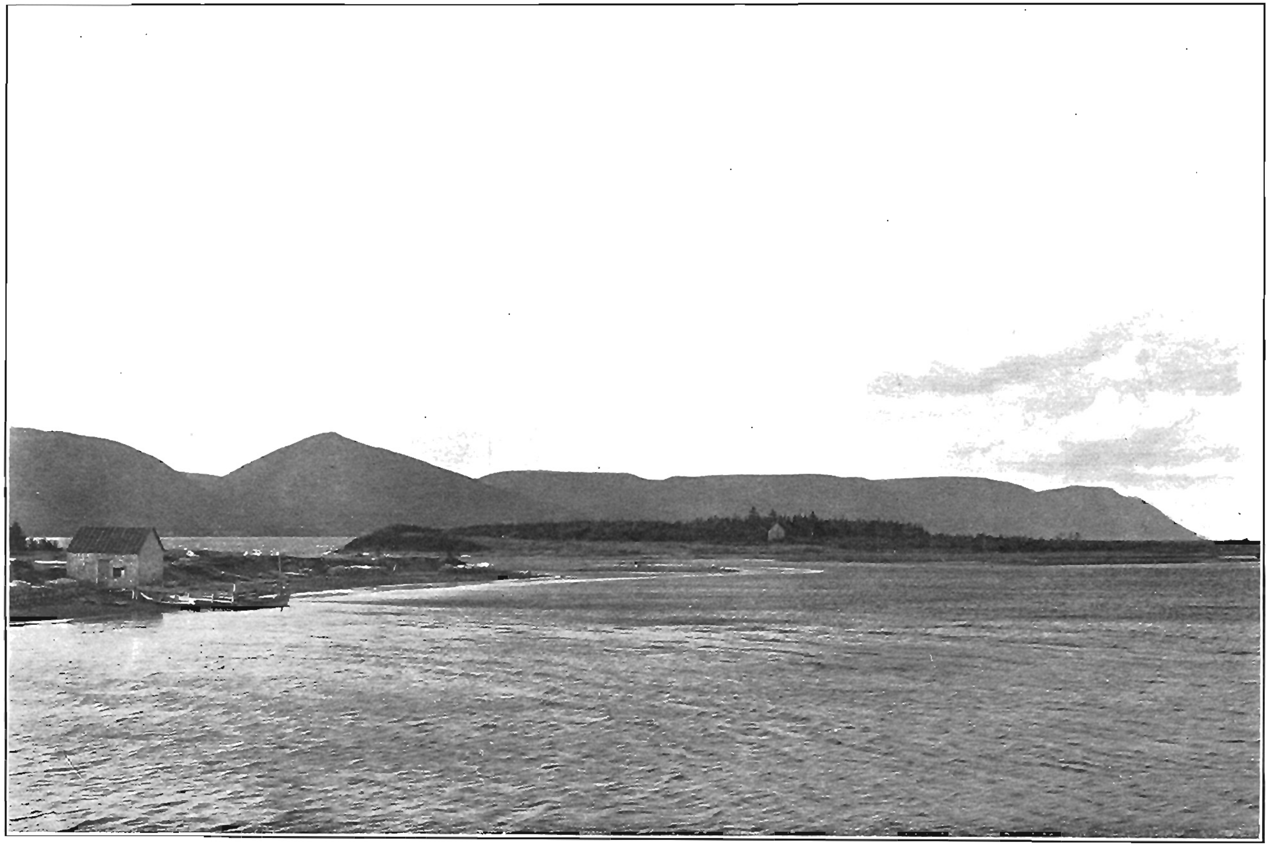
The two bays at Ingonish, North bay and South bay, are separated by a long, narrow, finger-like projection called Middle head, a remnant of an old pre-Carboniferous surface, exposed by the stripping off of the overlying strata, and appearing in many places on the shores of the bay. At the head of North bay great valleys like the one already described offer magnificent views of the distant interior. Northward towards cape Egmont the coast is low, although it is formed of the same hard, crystalline rocks as the tableland. It is difficult to understand why the granite surface of the coast here does not rise as high as that of the interior.

As the boat passes around cape Egmont, another long, straight escarpment meets the view, coming out to the shore behind Aspy bay and extending along the coast to Money point near cape North. This is perhaps the most magnificent view in Nova Scotia. The great 1,200-foot escarpment is slashed by many deep torrent valleys. Between them, in two or three places, peaked mountains known as "Sugarloaves" rise to the level of the plateau, like huge pyramids standing in line. These bold summits are said to be the first sighted by Sir John Cabot.

From the shore of the "North pond" of Aspy bay, it is a moderate climb to the top of Sugarloaf mountain; and one well worth the effort.

The approach to the mountain affords impressive views northeastward along the steep front of the plateau where it forms a magnificent sea-cliff

PLATE IV



Sugarloaf and cape North, from Dingwall.

which ends near cape North. In the opposite direction the escarpment passes along the front of a mighty line of mountain-like spurs, in close order, which extend past Big Intervale to the head of North Aspy river, 15 miles away. On the trail up the mountain through a clearing on its southern side, the view widens rapidly, taking in the wide lowland that surrounds Aspy bay and the highlands behind it (Plate V). The great triangular lagoon or "north pond," sheltered from the ocean by a long bar of sand, and dotted with low islands, occupies the middle distance, and on the right the long escarpment is now hidden by the forest-covered corner of the next "sugarloaf."

Thus far, it might be satisfactory to follow the usage of the people of Aspy bay, and call these summits "mountains." But once on the sharp summit of the Sugarloaf, the impression is different. Behind the peaked mountains stand table-topped summits of equal height, which, though separated by broad, deep chasms in the foreground, merge behind into one broad surface of almost perfect flatness. The origin of these "sugarloaves" is now easily appreciated: they are "mountains of circumdenudation"—sharpened remnants of the great tableland, cut from the plateau mass by rivers whose beds now lie at the bottoms of the flaring valleys. This is the maturely carved edge of a plateau: not a true range of mountains.

Southwest of the Sugarloaf is the deep, steep-sided valley of Wilkie brook, the largest stream of the district. Its straightness is wonderful considering the depth to which the valley has been cut; for it runs without deviation for 3 miles, and no spur projects into it from left or right. Also, it trends parallel to the outer escarpment of the tableland, and lies only a mile behind it— like the straight valley behind cape Smoky. Is not this a fault-line valley? The escarpment is apparently a fault scarp, brought into relief by the erosion of softer rock from the downthrown side. It is not a sea-cliff; for it runs inland 15 miles, past Big Intervale to the very heart of the tableland. The conditions here and near cape Smoky are not without parallel on the west coast. Map 39A of the Geological Survey shows cases of the same sort south of St. Lawrence bay and on the west coast, where the border of the high tableland is straight and has the same northeast-southwest trend. The outline of the crystalline area, shown in colours on the map, is very suggestive of broken and tilted blocks from the exposed sides of which the softer rocks have been stripped to form lowlands and escarpments. Blocked plateaus of this sort are common in other parts of the world, as, for instance, in Arizona and Palestine. By the dislocation of the blocks the angular outline and the pattern of drainage have largely been determined.

Whether the immense gorges and funnel-shaped glens that lie between the Sugarloaves at the edge of the tableland were occupied in the glacial period by local tongues of ice is a question that must be left to a later chapter.

From Big Intervale, 8 miles up North Aspy river, a bridle path mounts the fault scarp, and after passing over 2 miles of the boggy plateau top, descends into the steep valley of Grand Anse river to Pleasant bay. This path, which is used by the mail carrier twice a week, in going from coast to coast, is the only trail across the plateau. Where it passes over the peat bogs on the tableland, corduroy roads alone prevent the traveller or his horse from sinking knee deep.

PLATE V

Aspy bay, from the Sugarloaf.

The west coast is very much like the east. Long, straight escarpments similar to those south of cape Smoky and near Aspy bay extend between Lowland cove and Paulet cove, and between Mackenzie river and Cheticamp river, distances respectively of 8 and 12 miles. These cliffs trend parallel to the cliffs and scarps of the east coast, and probably mark main lines of faulting, which belong to one great system. Narrow strips of the soft Windsor rocks form foothills near Pleasant bay, where the escarpment lies a short distance back from the shore; and farther south, near Cheticamp, these stratified rocks spread over a broad, lowland area behind which the border of the tableland runs far inland. This lowland includes the two coal basins of Inverness and Port Hood, and reaches southward to Craignish hills.

MABOU HIGHLANDS

Only one outlying patch of the crystalline rocks appears to the west of the tableland, between Cheticamp and Craignish hills—the Mabou highlands. This district resembles the other uplands, both in its evenness of surface and its crystalline rock structure. Its average height is 1,000 feet. From the swamps on its summit, streams rush down through deep, steep-sided glens, whose beauty has delighted many tourists and summer visitors.

DEVELOPMENT OF THE DRAINAGE SYSTEMS ON THE ATLANTIC UPLAND

ORIGIN OF THE ANCIENT PLAIN

The ancestry of the river systems of Nova Scotia can be traced back to its earliest beginnings on the newly upwarped surface of the Atlantic upland. If this great surface could be completely restored, by filling up all the valleys and lowlands with the material that has been taken from them, we would see a vast plain unbroken by mountain ranges or sea-filled basins, slanting seaward from the interior of New Brunswick and Gaspe to the outer edge of the Banks. Instead of being isolated by broad bays, Nova Scotia would merge on the northwest without break into the higher country of New Brunswick, and on the far north into that of New Quebec. Indeed, fragments of the upland similar to those in the Maritime Provinces make it possible to trace this sloping plain southwestward across New England and down the Atlantic coast to the gulf of Mexico. How such a broad plain, which truncates the edges of old mountain folds and granite batholiths with no regard for the relative hardness and softness of the rock structures, came to be formed, is a difficult question. Three hypotheses deserve attention: (1) It has long been thought by American students of physiography that this plain was the product of subaerial wasting and river erosion, operating during a long period of quietude and freedom from earth-warping forces. By the close of this period, it is thought, the whole district, whether underlain by hard or by soft, rocks had been reduced to a low, featureless plain or "peneplain" that extended from Saguenay county to the gulf of Mexico. Fossils in the overlying sediments in New England and the region to the southward show that the Nova Scotia plain was completed some time in the Cretaceous period. The conversion of the Cretaceous peneplain into an upland of moderate altitude was accomplished, it is supposed, by an upwarping of the whole region. The upwarp was followed by renewed denudation, which developed broad lowlands on areas of soft rocks and narrow valleys in the hard rocks. This second "cycle of erosion" is thought to have been interrupted long before it was complete, by several elevations and depressions which finally left the region lower than it had been at the beginning and which half drowned its coast. Meanwhile the great North American ice-sheet spread southward from Canada across the International Boundary, advanced and retreated a few times, and at length disappeared, leaving the topography somewhat altered in detail, and the river systems badly disorganized.

Among the objections to this hypothesis of subaerial denudation or "base-levelling" is the fact that there are few peneplains if any at the present time in the low-lying positions which they should have when newly finished. This is not a very weighty objection, however, for geological history is full of instances where long periods of rest have been followed by shorter periods of unrest and deformation; and it appears that conditions of unrest were prevalent not long ago. Some critics have questioned whether periods of tranquillity like the Cretaceous were long enough to allow the base levelling of a region; for although the rate of denudation is rapid at first when slopes are steep and streams vigorous, the rate of denudation must diminish greatly as the slopes become flatter, so that the time necessary to complete the task is inconceivably long.

(2) A second hypothesis which likewise recognizes subaerial agencies as the processes responsible for the shaving away of the structure, but which avoids the necessity of such lengthy periods of quietude, is summed up in the word "bevelling." It supposes that during the Cretaceous period the destruction of the higher summits and steeper slopes by rapid weathering and stream erosion reduced them to an altitude roughly accordant with the lower hills, where the flattening by denudation was proceeding much more slowly; and so a sub-equality of surface was worked out on the hard rocks, and the areas of soft rocks were worn down nearly to sea-level. Thus the hypothesis accounts for two partly developed planes or facets in a single cycle of erosion; and one uplift following the bevelling and the lowland carving period accounts for the cutting of modern valleys below the lowland surface.

It should be noted that the theory of bevelling requires that the bevelled surfaces, along the interstream spaces, should slant seaward in harmony with the floors of the neighbouring lowlands, since they developed side by side. This test, applied to the case of Nova Scotia, puts the hypothesis of bevelling in an unfavourable light. The valleys that traverse the Southern upland are shallow and ill-defined in the interior, but increase in depth downstream until their floors lie far below the upland surface. This is true no less of the rivers flowing southeastward into the Atlantic than of the shorter and more vigorous streams that run northwestward down the South Mountain escarpment. In cross-section these valleys, where best developed, show steep side slopes that rise steadily with little tendency to flare or round off until they stop abruptly at the level of the upland facet. If the uplands had been formed by the organized bevelling of interstream spaces by tributaries to the main rivers, there would commonly be no angle or shoulder where the upland surface meets the valley side. Professor Daly has called attention to the significant fact that the crest of North mountain does not rise and fall in sympathy with the slope of the floor of the Annapolis lowland on its south side, or with the floor of the bay of Fundy on its north side, as it would if the trap range were a bevelled outcrop. From Blomidon to Digby, 80 miles, the mountain holds its altitude of 550 feet with little variation. At its base the bed of Cornwallis-Annapolis lowland rises southwestward to about 150 feet on the drainage divide, near Berwick, midway between Minas and Annapolis basins. If to these slopes is added the descent of the floor below the waters of Minas and Annapolis basins, where these bathe the base of the range, there is at least 50 feet more drop at each end, or a total relief of over 200 feet. The crest-line of North mountain should show a definite ascent and descent in the same distance, if the erosion of the tilted lava sheet has been accomplished wholly by the attack of tributaries of the Cornwallis and Annapolis rivers. So far as the bevelling of the range has been accomplished by drainage on the Bay of Fundy side, the crest of the mountain should show a descent from Blomidon towards Digby; for the floor of the bay descends more than 150 feet in that distance. Furthermore, if the region had been reduced to its present condition in only one incompleted cycle of erosion, the upland remnants near the bay of Fundy and Northumberland strait would have been bevelled to a lower level than those in the centre of Cape Breton and the southern peninsula. The bevelling hypothesis is, therefore, wholly inadequate to account for the increase in upland level northwestward, which is so uniform when the fragments are correlated.

(3) A third explanation of the smooth upland is that it was formed by the shaving back of the seacoast during a period of slow but prolonged subsidence, which let the waves and currents plane away a great submarine shelf, covered with shallow water. As in the first hypothesis, it is supposed that after this smooth plain was formed, it was elevated into a slanting upland, and that during the subsequent period rivers excavated the lowlands and the narrower valleys of the upland districts.

The objection has been made that though rain and rivers act over the entire surface of the land the sea works only along a narrow belt at its border; consequently the sea requires much more time to develop a wide plain of denudation. Be that as it may, there is no question that there have been many periods of long continued, slow subsidence in the earth's history. It has been learned, for example, that the slates and quartzites of the Gold-bearing series of Nova Scotia, originating in shallow water, yet measuring more than 5 miles in thickness, represent a continuous subsidence of the coast, inch by inch, for many thousands of years.

The validity of the hypothesis of marine denudation, therefore, appears to rest chiefly upon the presence or absence of features that would characterize an uplifted sea-floor, such as a wave-carved bluff or cliff at the upper margin, patches of marine sediment remaining on the surface during the later cycle of erosion, and more especially the arrangement of river systems with respect to rock structures. It is obvious that when a broad, submarine plain is elevated to form a slanting upland, the first rivers to form on its smooth surface will choose paths straight down its slope to the sea, irrespective of what hard and soft structures lie concealed beneath the newly deposited blanket of sea-floor deposits. As time goes on, these rivers, which are becoming the master streams of the region, will entrench themselves, and begin to dig into the foundation of the older rocks that lie below. Manifestly, the paths of the rivers will have no relation to these rocks, for they will depend wholly upon the slope of the overlying plain. As the sedimentary cover is stripped from the inter-stream spaces, revealing the old topography and rocky floor, and exposing the softer parts of it to stream erosion, the largest rivers will assume the task of sawing their way through the hard structures, and will try to hold to their original courses, however odd or unfortunate they may be. Such rivers are called "superimposed." Although liable to be cut into segments by flank attacks of more fortunate neighbours, and diverted to other paths, these freaks among rivers will not wholly disappear from the upland until the new cycle of erosion has passed its middle or "mature" stages, and the hills are again approaching flatness. Conspicuous cases of disregard for structure are to be looked for, along with a general absence of adjustment of streams to weak belts of rock.

In justice to the hypothesis of subaerial base-levelling, it ought to be said that a moderate degree of disregard for structure is to be expected on the part of large rivers even on an upwarped peneplain; for low, featureless surface would of necessity be covered with a deep accumulation of soil, which might serve much the same purpose as a blanket of marine deposits, allowing rivers to be shifted by upwarping into paths that would ultimately superimpose them upon resistant rock structures. To discriminate between uplifted and dissected plains of submarine denudation, and uplifted and redissected peneplains is, therefore, no easy matter.

Exhaustive studies by Professor Joseph Barrell of the upland of southern New England have led to the opinion that at least the outer part of this worn-down region, including all Connecticut and Rhode Island, and much of Massachusetts, is an old plain of submarine denudation and not an old peneplain. The evidence of this lies in the existence of poorly preserved escarpments or bluffs that run nearly parallel to the coast without much regard for hard and soft structures separated by broad, terrace-like stretches; also in changes in the composition of the sea-floor deposits which were made at the same time, and which are now exposed on Long Island, although every scrap of them has disappeared from Connecticut.

In the light of this remarkable evidence, so near at hand, it is not wise to draw final conclusions regarding the origin of the Atlantic uplands in Nova Scotia. Nevertheless, there are three reasons for favouring the hypothesis of base-levelling by rain and rivers: (1) the adjustment of rivers to belts of weak rock, throughout the province, is so thorough that it seems to demand the presence of systems already adjusted to structure at the beginning of the present cycle, whereas, on the other hand, there are no clear cases of superimposed rivers; (2) some of the most conspicuous residual mountains—like mount Aspotogan—are near the outer border of the upland in positions which would have been longest exposed to the attack of the sea; and (3) the summits that rise above the upland plane do not show wave-cut cliff profiles, running transverse or oblique to structural boundaries, but have gentle slopes, conforming in outline to the structure.

STRUGGLE FOR EXISTENCE AND ITS RESULTING STREAM PATTERNS

The main rivers on the newly uplifted plain must have run southeastward down the general slope to the sea. Such rivers are known as "consequent" streams, because they follow the guidance of the initial surface. Inasmuch as these rivers were the master streams of their time, and were in a position to dominate the development of river systems as time went on, it may be possible to find traces of them even today, in spite of struggles that have gone on between them, and of obstructions placed in their way by the ice-sheet. During the second cycle of erosion, these master, consequent streams, excavating the rocks on which they found themselves, struggled, with varying success, to maintain their courses. It is indeed evident that not one of the rivers was able to preserve its entire course; for there is not now a single river that rises in the highlands of New Brunswick and flows southeastward across Nova Scotia to the sea. Broad belts of soft rocks intervening between New Brunswick and Nova Scotia, where the bay of Fundy now lies, and other soft belts within the limits of the latter province, have allowed certain stream systems to extend their headwaters inland so far, and to deepen their valleys so rapidly, that the consequent streams have been cut into fragments, piece by piece, and diverted to other courses, leaving only the withered lower parts of their original systems to drain the Southern upland.

Judging from the southwestward slant of the upland in Digby and Yarmouth counties, and from the tendency of rivers there to run parallel to the bay of Fundy, the upland when first elevated was warped in such a way that west of a line between Digby and St. John it slanted towards the gulf of Maine. Of the rivers which took consequent courses down this part of the Atlantic upland, one, whose path is now deep beneath the bay of Fundy, was destined to revolutionize the drainage of Nova Scotia. The fact that it ran longitudinally along the middle of the broadest belt of soft rocks, bordering the gulf of Maine, may account for its rapid growth. It succeeded in excavating for itself a broad trough, and extended its headwaters inland farther and farther towards the northeast, behind the belt of trap rock, and thus captured and diverted those rivers that flowed from New Brunswick across central Nova Scotia to the sea. These diversions took place early in the cycle, and there is little or no topographic evidence to show that the rivers did so run. Presumably the divide shifted first to the belt of trap which was beginning to take on the form of North mountain; but if so, it soon shifted again to the granite area farther south, as tributaries to the piratical Fundy system devoured the soft sandstones which lay between the trap belt and the granite area, and formed the Annapolis-Cornwallis valley.

By these active streams and their branches water-gaps were cut across the trap belt, where it was offset by faulting and earlier denudation, and were deepened as fast as the lowland within the range was deepened.

It is not improbable that some of these offsets had been water-gaps in the earlier period, preceding the reduction of the region to the plain.

The shifting of the drainage divide did not stop at South mountain. As time went on, it was pushed still farther southward, until it stopped near the middle of the granite axis, a position of natural stability on account of the breadth of exposure of the hard rock. There it still lies, though modified in detail by glaciation. The divide of pre-Glacial time in this district was doubtlessly more distinct than that of today. Lakes and bogs were rare where they now exist by the hundred. Long, narrow lakes, like the Ponhook-St. Croix chain which nearly crosses the granite belt and is 14 miles long, and the Liverpool chain near Milford, suggest that through-valleys or wind-gaps, robbed of their rivers, still remained on the summit of South mountain when the ice-sheet settled down on the region.

Not only did the consequent streams of southern Nova Scotia have to contend with the Bay of Fundy river, they struggled for supremacy among themselves. An illustration may be seen on Map 2006. In southern Digby and Yarmouth counties and western Shelburne, the consequent streams had the advantage of following both the seaward slope and the rock structure; for, as it happened, the strike of the rocks here is a little west of south. The St. Mary Bay river, developing rapidly along the sandstone belt between North and South mountains, sent a tributary out at Weymouth which ate headwards along the line of the Sissiboo. Working southeastward towards the head of the ancestral Salmon river, the Sissiboo finally reached it near Riverdale, and by offering it a steeper slope to the sea captured all its drainage above that point. The sharp "elbow of capture" shows plainly on the map. Salmon river yielded likewise to its neighbour on the other side. The evidence of this is seen about 5 miles downstream from Riverdale, where a fragment of the ancestral Salmon river turns at right angles, just above Beaver lake, and enters the Tusket River system through its West branch. Many instances of capture, particularly between the Meteghan and Tusket systems, are found. A rectangular or "trellised" pattern was thus carved by these rivers on the folded strata, where hard and soft beds succeed one another in parallel belts. The irregular deposit of glacial drift has not obscured the trellised pattern, although its obstructing influence is nicely shown in a chain of eight lakes on the Yarmouth-Shelburne county line, at the head of the modern Roseway river.

The consequent rivers of eastern Shelburne, Queens, Lunenburg, Halifax, and Guysborough counties, unlike those just described, had to cross the belts of quartzite and slate; for the strike of the rocks in that part of the province lies athwart the seaward slope. On this account, adjustments of rivers to weak belts are less numerous and less well defined than in the westerly district. Moreover, the glacial drift, especially on the slate belts, where it is thickest, is massed in long hills that trend northwest-southeast, parallel to the direction of ice movement, interfering seriously with the drainage of the longitudinal belts. Chains of lakes appear not infrequently along these belts; but some of the chains are probably due to the thickening of glacial drift along northeast-southwest lines, parallel to the ice front during its recession from the peninsula. Some cases of suspected piracy are to be found, as, for instance, on Liverpool river above lake Kejimkujik, where the alignment of the Liverpool chain of lakes with Port Medway river is suggestive of former continuity. At the narrow place on the Southern upland, north of Halifax, where no granite intervenes between the Fundy region and the Atlantic coast, old consequent channels are not clearly shown. The depth of Bedford basin, at the head of Halifax harbour, suggests a search there for traces of a large southeastward-flowing river; but the only signs seem too obscure to deserve description. It is probable that they have been wiped out by the exceptionally extensive dissection of the surface by tributaries working on the rocks of the Gold-bearing series, for there are no granite patches here to aid in the preservation of the old valleys. The rivers in this district have suffered heavily from the attacks of branches of the Avon and Shubenacadie, both of which were once fast-flowing tributaries to the favoured river of the bay of Fundy, though their former lower reaches are now deeply submerged in Minas basin. This system cuts off the heads of the large rivers that formerly flowed through Porter lake, the gorge of the Musquodoboit, and Ship Harbour lake.

Musquodoboit river is of special interest because of its compound origin. The course below Wyse Corner is consequent on the Atlantic upland, traversing the full breadth of the granite belt in order to reach the sea by a direct southeastward path; the part of the river above Wyse Corner is an adjusted tributary or "subsequent" river, developed by the headward growth of a lateral stream under the guidance of soft rocks which are here folded into a broad syncline between the harder rocks of the upland. For 25 miles on this upper, adjusted branch, Musquodoboit river flows quietly along the floor of the lowland which it has excavated for itself in a southwesterly direction; but near Wyse Corner it turns abruptly at more than a right angle, enters the granite belt through a deep, narrow gorge, emerging 16 miles below, and after flowing over the slate and quartzite belt enters the sea through a drowned estuary. It is impossible to say where the original consequent headwater of the Musquodoboit river lay. Possibly it headed north of Cobequid range, somewhere in eastern New Brunswick; for Folly Lake pass is almost in line with the course of the Musquodoboit below Wyse Corner, and it may be the fragment of the valley that ran without deviation southeastward to the sea, but which was severed by piracy on the Cumberland and Colchester lowlands. The distance across the Colchester lowland, from the Cobequids to the lower stretch of the Musquodoboit, is 40 miles, so that the question of a former connexion between them is quite hypothetical. In cases of this sort in other parts of the world, definite proof of a former continuity of the valley is found on the beheaded stream in the form of rolled stones, whose peculiar composition shows that they came from the watershed of the diverted upper part. Unfortunately, this kind of evidence is of no value in the case of the Musquodoboit; for although gravel known to be derived from the Cobequid range is plentiful along the bed of the river where it enters the granite, this is fully accounted for by the southeastward movement of the ice-sheet across the district in the Glacial period. The ice-laid drift here, as well as the water-rolled gravel, contains many stones from the Cobequids. Since the beheading of the old Musquodoboit by the growth of the Minas Basin system, the divide has been shifted farther southward, so that it is now at the edge of the infolded basin of Lower Carboniferous rocks. Here branches of Gays river threaten to divert the great adjusted branch of the upper Musquodoboit to a northwestward course. This diversion may have been accomplished before the Glacial period, and the southeastward course restored later by the deposition of drift on the present divide, where only low, swampy ground and small lakes occupy the interval between Musquodoboit and Gays rivers.

The Parrsboro water-gap, as has been seen already (page 27), was deserted for a similar reason, after a long siege by the Minas Basin and Chignecto systems, and perhaps yielded at last to the obstructing ice-sheet.

In eastern Halifax county the parallelism of rivers in courses which do not run straight down the slope of the upland, but obliquely to it, suggests a widespread dependence upon the fault zones which in many places have been observed in the rock structure. Faults with large offsets have been reported and mapped along the Sheet Harbour and Country Harbour rivers, and smaller displacements are known to exist on several others, though they are not large enough to show on the geological map (No. 2006). Several of the headwaters of the Sheet Harbour system have a trellised pattern based upon this fault system.

St. Mary river has had a history even more remarkable than that of Musquodoboit. It heads on the highland of eastern Pictou county, flows southeastward down an original consequent course, crossing a lowland 10 miles wide and running on through the Southern upland 20 miles more before it reaches the sea. Where it crosses this last belt, between Melrose and cape St. Mary, it follows the Indian Harbour fault. There are several reasons why this river has so successfully held possession of its headwaters on the Pictou highlands. In the first place, it lies about midway between the flank attacks of rivers tributary to Northumberland strait (the Pictou and Antigonish systems) whose headwaters have been working southward around the highlands on both sides; consequently, the St. Mary headwaters would naturally be the last to surrender. Country Harbour river has given up its old tributaries to the southeast branches of the Antigonish River system. In the second place, St. Mary river has developed a powerful tributary, the West branch, along an infolded belt of Carboniferous rocks, which has brought it large gains of volume from diverted neighbours on the west, and has thus enabled it to keep on sawing down its channel across the hard quartzite beds of the Goldenville formation. Nowhere else in the whole province is there a river which has retained so much of its original course.

The strait of Canso appears to be an old, consequent valley deeply drowned by coastal subsidence of more recent time. Was this long, narrow gap traversed by a river which ran southeastward, or by one which ran northwestward, or was it occupied by streams which headed near the middle and discharged in opposite directions? The last condition seems the most probable, since the divide between north and south-flowing rivers, in eastern Nova Scotia, approaching the strait of Canso, runs quite definitely toward the middle of it. It is noticeable, however, that the width of the strait is nearly uniform, suggesting its occupancy by a single, through-flowing river rather than by two opposed rivers heading within it. Some explanation may be found by looking at the trend of the valleys which enter the strait from its two sides. The largest, Ship harbour at Hawkesbury, opens towards the Northumberland plain. Smaller estuaries at Hastings, Auld cove, and Plaster cove trend at right angles to the strait, and are, therefore, noncommittal. Two small coves near Mulgrave and one at Archie pond open towards the southeast; but they are rather insignificant. On the who.e, the dominating outline of the Ship Harbour branch throws the balance of evidence on the side of a river that flowed northwestward from one end of the pass to the other.

On Cape Breton island, the only river (except on the eastern slope of the northern tableland) that pursues a consequent course for any distance, is Inhabitants river. This rises on Cra gnish hills a few miles north of the straits of Canso, and after descending steeply to the lowland continues southeastward across it in a deeply entrenched valley to a drowned mouth near the village that bears its name. So scattered are the patches of crystalline rocks, and so high do they stand above the sea, that the adjusted rivers of the later cycle have completely broken the original consequents into segments, leaving only rude wind-gaps to mark points where one or another of them once crossed the up.and on its way to the sea. The deep drowning and the glaciation have further obscured the traces of whatever consequent courses may have persisted down to more recent time.

CHAPTER III

LOWLANDS

More or less deeply sunk beneath the uplands, and serving to emphasize their relief are belts and broader areas of lowland. Although they show much diversity of form and variation in height, it is appropriate to group them all together, since they originated at the same time, and under similar conditions. They are underlain in every case by weak rocks, that have been worn low by subaerial decay since the upwarping of the Atlantic upland. During the period which followed that uplift these detached areas of weak rocks were reduced to a fairly smooth surface, interrupted only by a few low, residual ridges, where less easily weathered grit and sandstone strata rose in ancient folds to a level above that of the new plain. Before the lowlands had been reduced to base-level, an uplift occurred reviving the lowland rivers and increasing their eroding power. By the beginning of the Glacial period, these new valleys had been entrenched along both main streams and branches, to depths varying from 10 feet to 300 feet or more, according to their proximity to the coast. Glaciation did not greatly change the character of the surface. The generally decayed, smooth rocks were buried under a blanket of drift which almost completely covered the surface but was not thick enough to conceal the forms of the pre-Glacial river valleys nor even to deflect or obstruct the larger streams. Subsidence of the coast in the more recent periods of geological time has let the sea overspread the outer, lower tracts, particularly in the gulf of St. Lawrence, where Acadian bay covers an old Acadian plain, and in the bay of Fundy, where lowlands tributary to the gulf of Maine lie under from 15 to 50 fathoms of water. This drowning has brought out clearly the forms of the valleys, by converting them into harbours and basins which lie all along the coast.

The prevailing rocks of the lowland areas are sandstones, shales, limestones, and gypsum beds. Though not equally non-resistant, they are all so much weaker than the trap of North mountain, or the crystallines of the other upland districts, that they afford distinct topographical boundaries. Thus, the Annapolis-Cornwallis valley, worn out along the broad belt of Triassic sandstones that lies between the North Mountain trap-sheet and the South Mountain granite, is sharply outlined by escarpments; and the broad, lowland plain of Cumberland county, that stretches from New Brunswick to the foot of the Cobequid range, terminates there in an abrupt slope at the boundary line between the sediments and the crystallines.

When the general slope of a lowland district is studied separately, or when the relative altitudes of the lowland districts are compared, it becomes apparent that the lowlands do not belong to one inclined plane that slants southeastward, like the plane of the Cretaceous upland, but that there are several more or less separate, worn-down districts which slope towards the coast that is nearest, whether it be the bay of Fundy, or the gulf of St.

Lawrence, or the Atlantic. Evidently the reduction of these lowlands was accomplished by river systems that headed on upland divides essentially where they do now.

ANNAPOLIS-CORNWALLIS VALLEY

Between the steep, straight wall of North mountain and the opposing South Mountain escarpment lies the long, trough-like depression known as the Annapolis-Cornwallis valley. The sea has flooded its southwestern end, forming St. Mary bay, and its northeastern end, forming Minas basin. Through Digby gap, also, as through a side entrance, the sea reaches the valley of Annapolis river, converting it into a long, wedge-shaped basin, and the river for miles beyond into a tidal creek. Into this sheltered roadstead the French settlers sailed, at the beginning of the seventeenth century; and there, at the head of the harbour, they founded the historic Port Royal. The length of the valley from the head of St. Mary bay to the Pereau shore is 85 miles; its width ranges from 2 to 7 miles, being least in the middle stretch from Annapolis to Lawrencetown. On its floor are fruitful apple orchards. No other part of the province equals this in productivity.

The rocks that underlie the valley throughout its extent, although generally hidden from view by glacial boulder clay and sand and by tidal flats and marshes, are displayed in sea-cliffs, where waves are eating away the shores of the basins. Brick-red sandstones with occasional pebble beds and, less commonly, beds of shale, appear there in fresh sections, dipping gently northwestward towards the base of North mountain. These red strata form the floor on which the lava sheet was spread out; and with it they have been tilted into an inclined position. The oblique faults that traverse the mountain no doubt cross the valley also; but they are not visible there. Minor displacements, only, are seen in the sea-cliffs. The sand grains and pebbles that form the red rocks are held together by a calcareous substance rich in iron—a cement which is dissolved readily by circulating groundwater, causing the rock to rot and crumble. On this account, it is not always easy to distinguish the decayed rock from overlying sands of glacial age. The brilliant colour of the rock is imparted to the glacial drift that covers it, so that the limit of the red sandstone area can be fairly well determined by observing where the colour of the drift changes.

In the preceding chapter it was explained how the uniform crests of North and South mountains show that the entire region was at one time reduced to a level upland. It follows that this valley, which lies between the two upland belts, has been hollowed out by denudation since the plain was elevated into an upland. The floor of the valley is by no means flat; on the contrary it is decidedly uneven, commonly reaching an elevation of 150 feet in the hills and descending to an equal depth below sea-level in the basin bottoms. There is a noticeable agreement, however, in hilltop altitude on the watershed around Digby and on the Annapolis-Cornwallis watershed near Berwick. In both places the general level is 170 feet. In the Digby district, where the distance between the basin and the bay is only 5 or 6 miles, the relief is fairly strong, owing to the deep and extensive dissection of the 170-foot floor; yet the hills are dome-like in contour. How far this smoothness is due to the full play of rain and rivers on the yielding rocks, and how far to the passage of the ice-sheet across them, it is not now possible to say. In the long tract drained by Annapolis river the valley floor is lower, owing to the reduction it has suffered by the river and by tides. Farther east, between Berwick and Minas basin, the hilltop plane descends somewhat, reaching 100 feet near Centreville where when travelling on the Kingsport branch of the Dominion Atlantic railway a sweeping view over its surface may be obtained. There is reason to believe, therefore, that when the reduction of this weak sandstone belt was nearly finished, a second uplift raised the lowland a few hundred feet and caused the rivers to re-dissect it into hills and valleys. Of the rivers which were thus inspired to renew the task of carving the valley floor, the largest is the Annapolis. Maintaining the course through Digby gap, which it must have inherited from an ancestral river on the Cretaceous plain, this meandering stream dug out a wide, basin-like hollow just inside the gateway, a hollow which was later drowned by depression in the latter part of the Tertiary period or during the Ice age.

When the ice-sheet withdrew from the valley, the sea stood even higher than now, covering the floor at least as far north as Middleton; for the sands there contain starfish and marine shells. Judging from evidence adduced in later chapters, the submergence may have formed a continuous strait from St. Mary bay to Minas basin. Rolled gravels lie on the hillsides near Digby, to a height of 100 feet; heavy cobble and gravel deposits are cut by the railway near Smith cove and Coldbrook; and terraces of gravel at the mouths of Bear and other rivers show where the flooded streams of late Glacial time discharged into a sea the level of which was at least 60 feet above that of today. Tides have been actively at work, since the Ice age, filling in the basins with mud, but not preventing the river and its tributaries from maintaining their channels. The actual mouth of Annapolis river has been extended by these tidal deposits from Bridgetown nearly to Annapolis. These alterations are described more particularly in Chapter V.

The adjustment of rivers to this long sandstone belt is remarkable and significant; for it has a bearing on the question of the origin of the upland surface. Such perfect adjustment would hardly be expected if the rivers had developed on the surface of an uplifted sea-floor. In that case, streams would first have grown up under the influence of seaward slope, alone, and would slowly find it necessary to seek out the softer belts as their branches developed. If, however, the Cretaceous lowland had its origin in the wearing down of the structure by rain and rivers in a complete cycle of erosion, full adjustment to weak belts like the Triassic sandstone would be expected even before uplift occurred and the second cycle began; and those advantageous adjustments would be retained by Annapolis and other rivers as they entrenched themselves. It is this thorough obedience of rivers to structure, in the lowland belts and narrower upland valleys, that particularly supports the hypothesis that the old upland plain was formed by subaerial rather than by submarine denudation.

LOWLANDS OF HANTS AND COLCHESTER COUNTIES

The district immediately surrounding Minas basin on the south, east, and northeast is a lowland that merges into Cornwallis valley on the west, and is separated from the plains of Cumberland county on the north only by Cobequid mountains. Minas basin occupies the central part of the lowland, flooding it to a depth of 150 feet or more, and drowning the main river valleys that drain into it. Eastward this low country extends to the irregular, northern border of the Southern upland, and the highlands of Pictou and Antigonish. Its large, tongue-like extensions invade the Southern upland in Halifax county, where weak lowland-making rocks overlap the hard rocks of the Southern upland with sinuous outlines. The lowlands in this part of the province are developed on three systems of rocks: (1) Triassic sandstones that form the "canoe fold" between Blomidon and Truro; (2) a series of sandstones and shales mapped as Devonian; and (3) a series of marls, limestones, and gypsum beds mapped as Lower Carboniferous—locally called the Windsor series. These three series of rocks are folded and faulted in a complex manner, having yielded to pressures which more resistant rocks could withstand. The oldest series, particularly, has been involved in folds that dip as steeply as 45 degrees. The complex patchwork of structure which has resulted from the repeated folding and faulting is expressed topographically in a somewhat disorderly grouping of the ridges and valleys, with trends as a rule determined by the varying trend or "strike" of the strata. The shapes of the hills, however, are very generally rounded or oval, after the fashion of "drumlins" or hills of glacial drift. That they are not true drumlins is evident from the fact that they follow the strike of the rocks rather than the direction of glacial movement. Moreover, deep cross-sections of some of the hills along the Avon shore and the railway—for instance, that in the cut between Windsor station and the Avon bridge—show that some of the hills that are most like drumlins in appearance are composed of deeply decayed rock, covered with only a thin sheet of glacial boulder clay.

In places where beds of gypsum or "plaster" underlie the surface, an odd kind of topography appears. Round funnel-like depressions and saucer-shaped hollows, some of them occupied by pools of water with no visible outlets, crumbling white mounds of gypsum, honeycombed with passageways, caverns in which small streams lose themselves, or from which they flow freely, show that groundwater is rapidly dissolving the rock. No other rock is subject to so rapid a chemical decay as this plaster. In gypsum quarries where the rock has been stripped of its reddish overburden of residual clay, it is seen to be pitted in all sorts of fantastic shapes, by the erosive action of the water which slowly filters through it after every rain. Joint cracks are enlarged and the intervening blocks attacked on all sides, until one by one they are dissolved, and only the red powdery clay is left. Decay reaches down to the level of permanent saturation of the rocks by groundwater, a depth of 20 or 25 feet and in some places as much as 50 to 100 feet. It sometimes happens that closely spaced joints far below the surface of the ground or a more easily dissolved mass of gypsum offer chances for more rapid corrosion than at the surface, so that a deep subterranean channel comes into existence, which may gradu-

Minas basin and the lowland of Triassic sandstone, from "the Lookoff" near Canning.

ally be enlarged to make a cave of good size. In time the growth of such a cave so weakens the roof that it collapses, and the ground drops in, forming a new sink hole where no cavity was suspected before. Such surprising changes in the shape of the ground and the drainage of it come as a rule in seasons of exceptionally wet weather. Because of them gypsum ground is notoriously treacherous. It is a weird, mysterious sort of country, where those laws of nature which are usually concealed and forgotten are brought forcibly to one's attention.

Fine examples of this odd "plaster" topography are to be seen in the house lots and pastures behind King's college, Windsor. Some of the sinks are elliptical and arranged in lines, where underground waterways have developed along belts of the most easily decayed rock. The pools of water in the sinks range in size from a score of feet across to ponds a hundred feet or more in diameter. Some are surrounded by gentle slopes, others by slopes of 45 or 50 degrees. One of the deepest sink holes, a great funnel holding a shadowy pool of water, is called the "devil's punchbowl." Another fine display of gypsum topography is near Brooklyn station, on the line from Windsor to Truro, where quarries reveal the relation of knobs and pits to the solid rock below.

CUMBERLAND-PICTOU PLAIN

Lowlands occupy all that part of the isthmus of Chignecto that lies north and west of Cobequid mountains. Limited thus on the south by a long upland barrier, this Cumberland County lowland passes northwestward without a break into the still broader plain of eastern New Brunswick. North of the isthmus, the plain has been drowned to form the floor of the Acadian bay; but a curved belt of ground slightly higher than the rest of this plain, along an old watershed, still remains above sea-level as Prince Edward Island.

The rocks whose rapid decay has caused the development of the plain are sedimentary formations, laid down during the Carboniferous and Permian periods. By far the most widespread are the Permian sandstones and shales, which occupy fully three-fourths of the country and have a thickness of about 2,000 feet. Below them are the "Coal Measures," a series of sandstones, shales, and limestones 7,000 feet thick, containing as many as seventy interbedded coal seams. A world-renowned section of this Carboniferous formation occurs in the sea-cliff at Joggins, where the inclined series of beds is seen in unbroken order for a distance of 10 miles. Still farther down in the rock column are the early Carboniferous sandstones and conglomerates, commonly called the "Millstone Grit"—a grey, buff-weathering sandstone about 5,000 feet thick. This has been quarried at Wallace for more than a century and used as a building stone in many parts of Canada and the United States. Grindstones, also, have been extensively quarried from it near Joggins and Amherst. These great stratified formations have been warped into broad open folds, whose flanks seldom dip more steeply than 20 degrees, and which run as a rule east and west. A well-defined anticline whose axis enters the province just north of Joggins runs eastward past Nappan and Salem hills, nearly to Philip river. Another anticlinal belt runs from Springhill to Oxford Junction and Wallace. In these arched folds, as Map 2006 shows, the Millstone Grit appears at the surface, stripped of all overlying strata. This coarse sandstone and its interbedded conglomerate beds, though weak in comparison with the trap of North mountain and the granite and syenite of the Cobequids, is so much stronger than the sandstone and shales of the Coal Measures and of the Permian system that it forms long, smooth ridges that trend east and west across country for many miles, and that swell and sag where the anticlinal axes rise and fall. At Springhill the coal seams appear in concentric loops around the nose of a broad anticline which pitches southwestward. The folded structure has been displaced by many faults which add to the difficulty of following coal seams.

The Coal Measures are full of interesting markings and structures that show the conditions under which they accumulated. Fossil tree stumps, rooted in place and erect, though enveloped in sand and subsequently turned to stone by mineralizing underground waters, mark the sites of coal forests of the medieval stage of earth history. Reptilian skeletons in some of the stumps show that primitive lizards found refuge in hollow trunks. Footmarks on the surfaces of mud layers, now completely indurated, relegate these creatures to the mud flats of long ago. Raindrop pits tell of passing showers, mud cracks of intervals of warm, dry, sunshine during the building up of the deposits. Few sections on the continent have furnished such a clear and realistic picture of past geography as this section at Joggins.

Were it not for these sections in the sea-cliffs and for diamond-drill borings and mine shafts, our knowledge of the structure of Cumberland county would indeed be meagre; for the ground is almost completely covered with a blanket of glacial drift. This mantle is so intermingled with debris from local sources, mostly decayed, that it might easily be mistaken for weathered soil in situ. The lack of hard stones from other districts is natural enough, however; for, as will be seen in a later chapter, the ice-sheet reached this part of Nova Scotia after a journey of scores of miles over soft sandstones and shales just like these, on the floor of the Acadian bay. Although the drift is not thick, it serves to conceal the rock over fully 95 per cent of the lowland area.

The lowland surface truncates the folded structure, after the fashion of the surface of the Southern upland, where it cuts across the folded quartzite and slate of the Gold-bearing series; but in the case of the lowland the truncation is not so obvious, both on account of the more gentle folds in the rock structure and on account of the unequal reduction which has been suffered by the sandstones and shales, which are all weak, but not equally so. In most places the flatness of the lowland is plainly evident, and the valleys cut rather sharply beneath it afford a satisfactory record of uplift since the wearing down of the soft rock area to the plain; but in other places, notably near the upfolded Millstone Grit belts, the surface undulates unevenly in ridges and swells. The average elevation of the lowland is about 200 feet. On the grit ridges it commonly exceeds 400 feet. The more or less isolated summits of Springhill (610 feet), Claremont hill (565 feet), and Salem hills (450 and 390 feet) are too flattish to show as monadnocks in a photograph, although they properly belong to that class of eminences.

The drainage lines have developed in patterns commonly seen in regions of broadly folded strata. Some of the river systems which lie where folds are well defined, as for instance Wallace river, show distinct rectangular or trellised pattern, due to adjustments to parallel belts of rock; on the whole, however, the tributaries have not been guided strongly by either structure or slope, and form dendritic or arborescent patterns. Shinimikas and Pugwash rivers illustrate this, and so does the more deeply drowned Pictou river. All the large streams are graded, and meander in graceful curves, which, by a shifting process characteristic of mature rivers, lead them to trim their banks from place to place, and thus to increase the width of their flood-plains.

The lowland extends eastward across Pictou county without change of character, narrowing out at last at the Arisaig shore in northwestern Antigonish. South of Pictou and New Glasgow, in the gap between the east end of the Cobequids and the west end of the highlands of Pictou and Antigonish, the lowland blends with the higher and more irregular hill country of the Devonian rocks, where the ridges rise to 400 or 500 feet, and the valleys are deeply entrenched. This Devonian district, which occupies a broad belt of very irregular outline, as shown on Map 2006, and forms the main drainage divide in southern Pictou county, must be regarded as a part of the lowland in spite of its stronger relief; for its summits fall short of the 1,000-foot highland plane by several hundred feet, and are themselves not altogether without uniformity.

The main undulations of the surface seem to follow the strike of the rocks, marking belts of unequal resistance to denudation. They consist of long, flattish ridges and smooth drumlinoid hills similar to those of the district around Windsor. The parallelism of these hills to rock structure is distinctly shown in Map 1707 of "New Glasgow, Pictou county, N.S.," by B. R. MacKay. The prevailing trend of both structure and relief is northeast-southwest, but locally the structural belts run southeastward, and the drumlinoid ridges adopt the same course. It is not safe to say just how far the trend of these hills depends upon the direction of the most vigorous glaciation; for ice-sheets have crossed the district in at least two different directions, the earlier glaciation running somewhat north of east and the later one southeastward. The most drumlin-like hills occur near the coast, as on Merigomish island, and some of them seem to be wholly composed of glacial drift. The imperfect drumlin form of the hills of the interior, however, together with their tendency to agree in trend with the strike of the underlying rocks, whether it be northeast or southeast, are reasons for regarding the glaciation as a minor factor in shaping them, and rain and rivers as the chief agents.

On the southeast, the lowland around New Glasgow meets the border of the Pictou-Antigonish highlands at a steep scarp, several hundred feet high. This marks an ancient fault-plane, where hard and soft rocks were brought into juxtaposition in late Devonian time. It extends continuously from Piedmont station northeastward to Malignant Cove, where it reaches the shore and finds still further continuation in a long, straight sea-cliff that reaches 10 miles to cape George.

Hardly less striking than this steep scarp is "the Hollow" or "Bruin's highway," which extends along the foot of the escarpment for 14 miles from near Bailey brook to Malignant cove. This is a wide, U-shaped depression, drained by tributaries of the north-flowing streams, which leave the hollow by sharp elbows, showing the characteristic tendency of adjusted streams to pass across hard belts by the shortest and most direct course possible. The hollow is plainly a valley of denudation, excavated in a soft belt along one side of an old fault line. Its bottom is flattish and inclined to be swampy. The escarpment on its south side rises steeply to the highland level, several hundred feet above it. By a study of the rock structure, M. Y. Williams has found that the original displacement by faulting measured 3,000 or 4,000 feet. The modern scarp, which is only a fraction of that height, represents merely the difference in reduction of the surface by erosion since the elevation of the base-levelled Cretaceous plain.

Between the hollow and the Northumberland coast, in Antigonish county, the lowland surface descends from 400 to 200 feet. The Millstone Grit area here is a flat plain as in Cumberland county, and is traversed by valleys of the dendritic type, whose mouths are drowned. Farther east, around Arisaig, where Silurian and Devonian belts, only, lie between the highland and the shore, differences in the strength of the rocks give rise to a rolling yet well-graded surface, with mature valleys. Below the floors of the valleys, however, the rivers are definitely entrenched, in rock-walled gullies many feet deep. This is evidently the result of a recent uplift, of small amount, steepening and rejuvenating the rivers. Some of the smaller streams have not had time to wear down their courses to grade, and are flowing over rapids and waterfalls; but the larger ones have already secured flat, gravelly flood-plains, on which they meander again, though not so widely as before the last uplift. Near the shore, at the mouths of these valleys, are gravelly terraces 10 or 20 feet above the modern flood-plains, which in some instances, at least, blend with a seacoast terrace that stands about 15 feet above the sea. This appears to register a slight post-Glacial elevation of the coast. Higher beaches and scarps at certain points along the Arisaig shore have been taken to indicate still greater elevations; but that interpretation will be questioned in a later chapter which deals more specifically with changes of level.

LOWLANDS OF ANTIGONISH AND GUYSBOROUGH

South and east of the highlands which reach towards cape George is a considerable area of soft rocks, mapped as Carboniferous. These rocks occupy the greater part of Antigonish county. Sandstones and limestones predominate, as they do around Windsor. They present the same low, undulating surface, traversed by crooked, ramifying valleys. Near the northern border, the Intercolonial railway, emerging from a transverse valley in the Pictou-Antigonish highlands near James river, runs northeastward for 18 miles or more, along a belt of gypsum in which a narrow valley has been worn by solution. Sink holes, honeycombed plaster cliffs, ponds, and disappearing streams indicate the character of the underlying rock. Southward, in the broad Devonian belt of northern Guysborough county, the hills rise to 300 or 400 feet. Even there, the relief is softened by rounded slopes, due in part to the glaciation of yielding sandstones.

The large rivers, like West river at Antigonish, occupy wide, open valleys, on whose broad flood-plains or intervales they meander freely, trimming away the bordering scarps of terraces which mark the old flood-plains spread out by overloaded rivers at the time the ice-sheet was melting away. The coarse, cobbly gravel of which these flood-plains were built appears in railway cuts near Antigonish station. Farther up the valleys, crooked, steep-sided ridges and knolls of gravel, or "hogbacks," mark the courses of temporary rivers which ran between walls of ice when the ice-sheet covered the region.

The Devonian area which lies west and north of Chedabucto bay is a lowland of greater height and stronger relief than that which borders George bay. Its hills, however, are well rounded and smoothed by glaciation, and generally covered with a sheet of drift. At the shore, typical drumlins appear, from cape Argos westward, for many miles. The sea has cut away their outer sides, and has constructed beaches and bars of immense size between them.

To the south of the Devonian belt, in northern Guysborough, a long area of Lower Carboniferous rocks borders the Southern upland—a district known as the valley of St. Mary river. The greater part of it is drained by the St. Mary. The trunk river, properly speaking, rises in the highlands of Pictou county and flows southeastward across the lowland and the Southern upland. The "West branch" is longer than the main stream. It has developed by headward growth and piracy along the Carboniferous rocks, just north of the upland area. The sculpturing effected by this adjusted river and its captured tributaries has reduced the area to low relief, and the structural boundary has been converted into a great north-facing escarpment which sharply defines the limit of the Southern upland. This runs without interruption to the head of Chedabucto bay, and continues in the high, straight coast-line of Halfway cove and Queensport.

LOWLANDS OF CAPE BRETON ISLAND

Somewhat less than one-half of Cape Breton island is occupied by the uplands described in the preceding chapter. The remainder is occupied by undulating lowlands and land-locked lakes. Attention has already been called to the complete coincidence of uplands with areas of hard crystalline rocks, and of lowlands with areas of softer sedimentary rocks—a relation which suggests that the fundamental process of sculpture has been subaerial wasting and river action. The evidence of this is the more compelling because the conformity of topography to structure holds good in spite of the extreme narrowness of some of the hard and soft belts. River valleys are now obscured by drowning, but the adjustment in the past seems to have been so complete, that it is doubtful if the rivers that dissected the lowland were consequent streams on an uplifted sea-floor. They appear rather to have inherited the longitudinal habit from an earlier generation of rivers on a "peneplain" or plain of subaerial denudation.

Viewed from Bras d'Or lakes, the lowlands, which in this central district attain an altitude of over 400 feet, appear as irregular hills, with subdued, well-rounded outlines, and almost without ledges except where waves have gnawed cliffs in them. This green, hilly country forms a charming contrast with the wild, rocky uplands above it, with their dark forests and rough crags. Although from the lake or the railway an upward gaze detects little uniformity in the hilltops, the impression gained from the vantage ground of a summit is different; for whether standing on a 400-foot hill near Grand Narrows or on a 200-foot hill near Sydney, a fair accordance of the surrounding hilltops is observed, in spite of the ramification of valleys among them. From the train going east from Grand Narrows glimpses are obtained of a plateau-like surface on Boulardarie island, across St. Andrew channel. This surface has an elevation about midway between sea-level and the 800-foot level of the Kelly Mountain upland which lies back of it.

The rock structure of the lowlands of Cape Breton island repeats the features of Cumberland, Pictou, and Antigonish counties already described. There are broad tracts of land where the Carboniferous sandstones and Coal Measures lie almost horizontal, their swelling domes and sagging, dish-like folds showing on the geological map as broad elliptical patches. Curiously enough, the synclinal coal basins all occur on the coast, where the structure has been exposed by marine erosion at Sydney, Glace Bay, Morien, Inhabitants River, Port Hood, Inverness, and Cheticamp. They are clearly shown on Map 2006. Faults which interfere somewhat with mining operations in Cumberland county and elsewhere, are exposed here and there in the sea-cliffs. Where the rocks dip so gently that a single formation (for example the Coal Measures or the Millstone Grit) is widely exposed, the valleys form dendritic systems, as in the drowned valley system of Sydney harbour. More commonly, however, the rocks are folded rather closely, bringing up harder and softer members in parallel belts of no great width and encouraging strong adjustments of drainage. The effect is seen in some of the harbours and straits along the coast, for instance, in Cow bay, Bridgeport harbour, and the Great Bras d'Or entrance; and more plainly still in the long, tapering arms of Bras d'Or lakes, for example, East bay, St. Andrew and St. Patrick channels, and the stillwater parts of Mira river.

Wave-action has cliffed the headlands and other exposed stretches of shore on the lakes, revealing snow-white masses of gypsum, red shales, and buff limestones, which, with the ever-changing blue of sky and water and the varied tints of green on the hillsides, make the Bras d'Or country peculiarly beautiful. The depth of these inland lakes is extraordinary. Although there is less than 30 fathoms (180 feet) of water over most of their area, and much less than that at their narrow entrances, in places the depth exceeds 100 fathoms, particularly off the southeast coast of Boularderie island, where a depth of 141 fathoms (846 feet) is recorded. This great depth cannot be due to tidal scour, for it occurs where tides would be particularly feeble. It can hardly be due to excessive erosion by the ice-sheet, for all other signs point to weak glaciation. It is perhaps possible that Bras d'Or lakes are remnants of valleys the mouths of which are blocked by very great thicknesses of glacial deposits; yet it seems incredible that these should be several hundred feet thick, as the soundings would lead us to suppose.

DATE OF THE LOWLAND CYCLE

It has been generally supposed, by those who have investigated the geologic history of uplands and lowlands of the Atlantic coast district, that the plain which now appears in the Atlantic upland was completed in the Cretaceous period, and that the cycle of erosion which followed the uplift of this plain, and produced the modern lowlands and valleys, occupied the next, or Tertiary period. It is known that in northern New England, at least, the larger valleys had already been carved out by the middle of the Tertiary period; for the Champlain valley at Brandon, Vermont, contains clays which hold many and varied remains of vegetation in the form of lignite or brown coal. The age of these plants is certainly Miocene—or Middle Tertiary. By inference, it has been supposed that the low lands and valleys of the Maritime Provinces were carved out during the early Tertiary, and the cycle of erosion has accordingly been called the "Tertiary cycle," in contrast with the preceding "Cretaceous cycle." In the valley of the Shubenacadie and in that of the Musquodoboit, are clays which contain lignite. When these are thoroughly studied it should be possible to fix the date of this period of erosion in Nova Scotia.

At Shubenacadie, the clays are covered with only a few feet of gravelly drift; in fact, in J. E. Ettor's field, near the railway, there is less than one foot of gravel on top of them. Here the clays are mainly white and dove-coloured, with a few grey-black bands. They are soft and very plastic, and contain small bits of lignite, the size of a lead pencil. Fragments as large as a man's fist are said to have been dug up in former years, when the clays were excavated for pottery. Unfortunately, these specimens were not preserved nor examined by specialists in palæobotany, and the exact age of the clays is not known. There are also many large nodules of marcasite, or iron sulphide, a brassy mineral which quickly decays upon exposure to the air; but if these formed around organic remains embedded in the clays, as nodules have been known to form elsewhere, under the action of circulating groundwaters, no trace of the organic structure remains.

At Middle Musquodoboit, splendid exposures of bright red, grey, black, and white clays occur at points on the newly completed railway grade, and in the banks of the river, as far east as Elmsdale. There is no doubt that these clays underlie the valley for several miles, although they are almost wholly concealed by glacial drift. Red or rose-coloured clays seem to predominate near Middle Musquodoboit. Lignite was reported at Elmsdale, years ago, when the clay was prospected, and a deep shaft dug; but the hole has long since been filled up, and none of the fragments of fossil wood are to be obtained.

In the absence of fossil evidence, reliance is placed upon the resemblance of the coloured clays of Nova Scotia to those on the islands off the south coast of New England—clays which are Cretaceous rather than Tertiary in age. The resemblance, particularly in the red clays, is so striking that pending further discoveries and studies, it seems wise not to employ the phrase "Tertiary cycle," inasmuch as the valleys may have been carved out as early as the Cretaceous period.

CHAPTER IV

FEATURES DUE TO GLACIATION

THE ICE-SHEET AND THE GLACIAL PERIOD

The period which followed the excavation of the lowlands and valleys in Nova Scotia was marked in both Europe and North America by the growth of great ice-sheets which have now wholly disappeared. For over a hundred thousand years, according to the best estimates, most of Canada and adjoining parts of the United States were buried by a great sheet of ice similar in character and equal in size to that which now covers the Antarctic continent. Why polar conditions came into existence in Canada is not considered here, for that is a question which climatologists have not yet satisfactorily settled. Whatever may have been the causes for the development of the ice-sheet, its occurrence is unquestionable; for it made many peculiar changes in the topography, soils, and drainage of Nova Scotia and the other territory which it covered.

Some conception may be formed of the appearance and action of the North American ice-sheet from the accounts given by explorers of the ice-sheets of the present day in Greenland and Antarctica. They are vast, flat domes of solid ice, covered with a thin layer of snow, which changes to ice and is replaced by fresh snow. The snow falls in periodic storms at intervals of three or four days and is swept toward the outer margins of the domes by blizzards, which come at the beginning of each storm. Except near the periphery, the sheet covers every inch of ground, concealing mountain and valley alike, and spreading as an unbroken desert of snow over thousands of square miles. Near the margins, where it is thinner, mountain ranges protrude and isolated peaks or "nunataks" rise like islands in a sea of ice. The edge of the Greenland sheet lies on land, and is marked by a series of tongue-like projections, where the inland ice seeks an outlet through valleys that descend steeply from the ice-covered plateau to the level of the sea. The Antarctic ice-sheet, on the other hand, spreads out beyond the shore-line in most places, and terminates in a floating cliff of ice which is distinguished from the pack ice of the polar ocean chiefly by its greater height and its bluish colour. In the interior the ice-sheets appear to be stationary, though really they move radially outward a few inches a day; near their margins the rate of movement increases to a foot or more a day. In very exceptional cases—in steeply descending outlets from the Greenland sheet—it is as much as 100 feet a day. The movement appears to be a rigid mechanical thrust, acting slowly and continuously towards the ice border, and generated by the addition of new snow, which packs down under its own weight, undergoing a series of changes in texture and structure as it solidifies. The behaviour of the ice is such that while it moves forward almost like a viscous or plastic mass, it holds its load of rock debris firmly in its grasp; consequently, it works in an entirely different way from rain and rivers, and its effects are easily recognized. Not an acre of ground covered by such an ice-sheet is without some record of glaciation after the sheet has retired, although these marks may later be concealed or obliterated by other agencies. The evidences of glaciation are varied, and each in its own way is of interest.

Careful study of the glaciated region for two generations has brought out the fact that the great North American ice-sheet spread from three or four centres—districts that were at first the gathering grounds of heavy snowfall, and from which the sheets grew outward by the accretion of blizzard-swept snow. At least, it is known that there were centres of movement from which the ice-sheet spread radially outward; and it is believed that the centres of snowfall coincided in a general way with them. These centres were not regions of great altitude. The two main centres were upland districts of moderate height, east and west of Hudson bay (Figure 6). From these the ice mass extended outward by its own forward movement and by continual additions of snow blown to its margin, advancing without

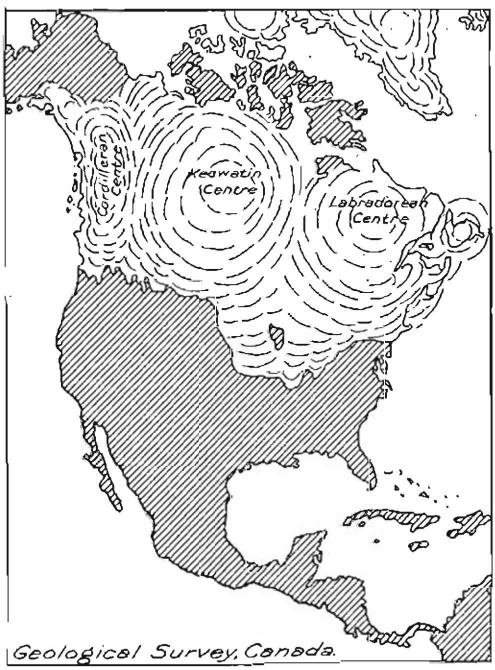


FIGURE 6. North American ice-sheet.

hindrance across regions much higher and more mountainous than those where it originated. In the White mountains of New Hampshire, summits which stand 5,000 to 6,000 feet above the sea, and from 4,000 to 5,000 feet above the valleys, became completely covered, and across their tops the currents of ice swept southeastward without deviating from their path except where high knobs or ledges deflected the ice locally for very short distances. Geologists of earlier days, familiar only with glaciers of the alpine type, which descend like rivers from snow-capped mountain tops, were generally unable to conceive how ice could have moved over Canada and the northern United States except by energy gained locally from the accumulation of snow on mountain ranges and upland districts. To escape the difficulties which mystified them, the fact must be borne in mind that this is not a group of thin, river-like streams of ice, moving by gravity and guided by the topography, but one vast ice-sheet, which advanced with little regard for inequalities of surface, especially where the relief was low.

No means are available of telling how thick the ice-sheet was on Nova Scotia. Inasmuch as its marks are found on the Cobequids, the highlands of Pictou and Antigonish, and the mountains and tableland of Cape Breton island, it is evident that the sheet was at least 1,200 feet thick; and since it is known to have covered all the mountains in this part of North America, including mount Katahdin in Maine (5,150 feet) and mount Washington in New Hampshire (6,293 feet), it was probably a few thousand feet thick in Nova Scotia. Accordingly, when glaciation was at its height, the ice-sheet would have been uninfluenced by the shallow water of the bay of Fundy, the gulf of St. Lawrence, and the Banks, if indeed the sea then covered these parts of the Maritime Provinces. The bay of Fundy attains a depth of 600 feet near its mouth; Acadian bay, which occupies the southern half of the gulf of St. Lawrence, is not over 300 feet deep, and the Banks off the southern coast as far as Sable island and the edge of the continental shelf are covered by less than 600 feet of water. These are extreme depths; the coast charts show that over the greater part of these regions the water is less than 300 feet deep. There is no reason to suppose that these areas were farther below sea-level at the beginning of the Ice age than they are now; in fact, the land probably stood higher. How would these shallow bays and shelves have affected the ice-sheet? As the glacier advanced into the sea it would not float until about seven-eighths of its thickness was under water; hence it is clear that the sheet need have been only 700 feet thick to have entered and crossed the bay of Fundy as it would enter and cross a lowland. Seven hundred feet additional would have allowed it to overtop North mountain and the Southern upland; 1,200 feet to cover the Cobequids and all except the highest summits of northern Cape Breton. It would have needed to be only 700 feet thick over the south coast of Nova Scotia to have advanced to the edge of the continental shelf before floating. There is danger, therefore, that maps which show only the outline of Nova Scotia with its encircling bays and gulfs, may give the impression that these bays and gulfs checked the extension of the ice-sheet, or remained open as great re-entrants in its border. They are much too shallow to have done so. But it is not necessary to depend upon indirect evidence and theory to reach the conclusion that the ice-sheet advanced across the gulf of St. Lawrence, the bay of Fundy, and the Banks. In the trend of the grooves which it engraved upon hilltops and ledges while it was advancing. in the paths taken by stony fragments which the ice bore from their parent ledges to new situations, and in many other facts which will presently be described, direct proof exists that the ice-sheet filled the gulf of St. Lawrence and the bay of Fundy and covered the banks off the south coast of the province.

It is possible that the ice-sheet advanced over Nova Scotia and retreated from it two or three times during the Ice age. On Long island, south of Connecticut, the deposits of sheets of glacial drift form a complex series which is interpreted as a record of three or four distinct advances, separated by intervals of unknown duration. In the Great Lakes region, and especially at Toronto, interglacial beds contain fossil plants and animals which indicate that during one of the intervals between glacial epochs living forms migrated somewhat farther north than they have done since the last glacial epoch. The inference, of course, is that the ice-sheet completely disappeared and grew up again; and that there may be a return of glacial climate in the remote future. But in Nova Scotia, as in other parts of eastern Canada and throughout northern New England, there is no clear evidence of the recurrence of ice-sheets during the glacial period.

EROSION BY ICE-SHEET

STRIPPING AND SMOOTHING OF THE SURFACE

As the ice-sheet moved across the surface of Nova Scotia, it gathered up nearly all of the decayed mantle of rock waste or soil, and a great deal of solid rock besides. The ice when freezing incorporated material from the fractured upper surface of the rock and on moving tore it away from the solid part beneath. In the granite country the mantle probably consisted of loose earth which graded downwards through round residual boulders into solid ledge and resembled that of granite regions in the southern states and the arid regions of the west. From this deposit the ice-sheet gathered a rich supply of coarse quartz sand and of large rock masses, whose weathered shells or skins soon cracked away or were scraped off, leaving the round cores to make the boulders which now lie scattered so plentifully over the barrens. But the ice-sheet acted also as a quarrying agency, plucking out joint blocks from ledges below the weathered zone, and adding them to the round boulders and cobbles which it had secured from the decayed mantle. Quartzite, split by joints like the granite, but less subject to decay at the edges and corners, provided thousands of large, angular blocks. The slate regions, covered originally with a thick, muddy blanket of clay soil, were completely stripped of their covering, and the ledges were scraped down as the rock-shod ice moved heavily over them, gathering up slabs or sheets here and there and crushing them to bits. Limestone and sandstone areas suffered in like fashion, as the ice-sheet dragged the surface mantle long distances and mingled with it foreign stony material, moulding the surface into new shapes.

In the regions of soft rock, at least, the ice rounded or smoothed off the hills and ridges, using the plastic mantle as a medium with which to glide over the obstructing summits or to fill such small irregularities as it encountered. In consequence, the hills of the lowland districts where shales and limestones occur extensively came to possess gracefully curving profiles, both lengthwise and crosswise. These are spoken of as "drumlinoids" or "false drumlins" because they imitate the form of arched hills of glacial drift or "drumlins," which are presently to be described.

ROCHES MOUTONNÉES

High ledges or knobs of rock over which the ice passed were usually steepened on the far side by the plucking away of joint blocks and rounded and scoured on the near side by the rasping action of the debris which the ice pushed vigorously against and over it. Unsymmetrical ledges of this character, known as "roches moutonnées," are in places well developed and make it possible to determine the direction in which the ice moved, but more commonly the rock exposures are flattish and the whole surface is merely rounded.

GLACIAL GROOVES AND STRIÆ

The most characteristic effect of glaciation on bedrock is the scouring and grooving of its surface. These unmistakable marks of an ice-sheet are found in all parts of the province; but more abundantly on certain kinds of rock than on others. The granite ledges, for instance, seldom exhibit distinct grooves or "striæ." The granite is so hard that the ice could scour and scratch it only with fragments of its own composition, or with quartzite fragments, and then only to a limited degree. Moreover, the rock has disintegrated rather fast since the ice-sheet retired, so that the exposed surfaces of granite on the barrens are rough, and well-glaciated surfaces are to be seen only in places where the soil has recently been removed, as in roadside ditches, cellars, and borrow-pits. Needless to say, care must be taken in such places, to discriminate between bona fide striæ and the scratches left by ploughshares and road scrapers. Quartzite holds the striæ better, except that where the rock is thinly bedded the glaciated surfaces are not continuous. The trap of North mountain exhibits well-glaciated surfaces in many places, though its tendency to be torn out along the lines of columnar jointing, leaving knobs and pits of hexagonal pattern, and to decay on exposure, makes it necessary to search carefully for the ice marks. Slate ledges are most distinctly scored by the glacier; for slate is of inferior hardness, as well as fine-grained and compact. As the ice-sheet passed over slate ledges, the clay which filled its basal part scrubbed and polished the rock, and the corners of granite, trap, or quartzite blocks, forced against the ledge, cut long, straight scratches and ruts. At the ledges near the Prince of Wales tower in Halifax, grooves of this character are plainly seen, running like wheel marks on a soft road, in one direction (Plates VII and VIII). Though this is a particularly good illustration of glaciated ledges, it is by no means unique. Thousands of such ledges are seen in various parts of the province. Naturally the most distinct and numerous grooves occur where the ice-sheet reached a belt of soft rock like slate, soon after it had passed over an area which provided many hard fragments like quartzite or granite, as was the case at Halifax.

Some of the rocks of Nova Scotia, however, are too soft and crumbling to retain any grooves or striæ. The red sandstones of the Triassic belt have afforded not a single record of glaciation, although large areas of that rock have been mapped in detail, and its cross-sections have been studied by several observers. The rock seems never to have been thoroughly consolidated, so that its sandy surface was roughly scraped instead

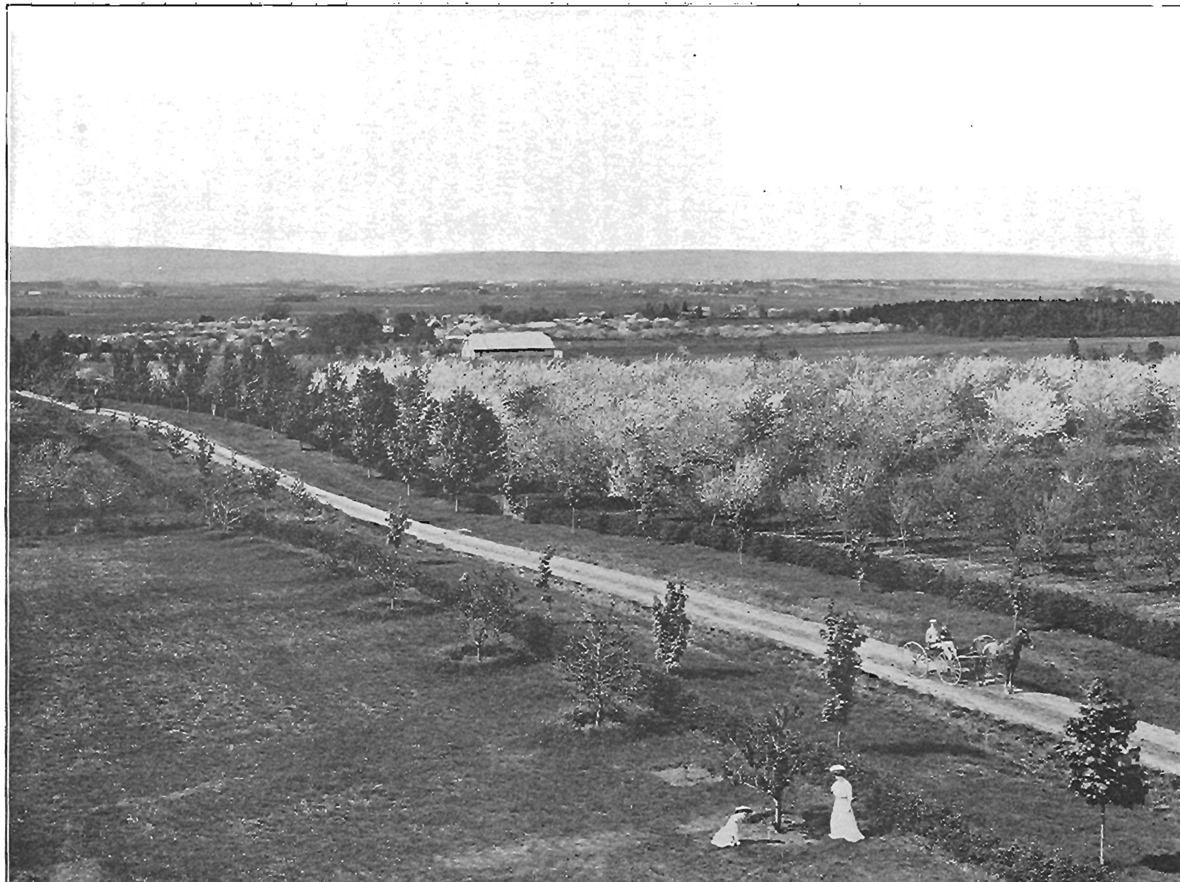
Plate VII

Scoured and grooved ledge in Point Pleasant park.

Plate VIII

Glacial grooves, deepening southeastward.

PLATE LX



From Hillcrest orchard looking over Cornwallis valley.

of polished and scratched. It is immaterial that striæ are not preserved in the Annapolis-Cornwallis valley, for they are plentiful enough on the rocks of both North and South mountains; but it is unfortunate that none of the rocks around Cobequid bay is of a kind that retains many records of ice action.

The shales, limestones, thin-bedded sandstones, and gypsum beds of the Devonian and Carboniferous systems, which occupy large parts of Hants and Colchester counties, afford little evidence of glacial movement either in grooved surfaces or in dispersal of drift. Their weakness accounts for the lack of striæ arrows on the map, between the Cobequids and the Southern upland. Farther east, in southern Pictou and northern Guysborough counties, glacial grooves were found by Fletcher on the Devonian sandstones and conglomerates and are indicated on Map 2006. The Millstone Grit, a brown sandstone which covers most of Cumberland county and northwestern Pictou, forming the great Cumberland lowland, shows almost as few striæ as the weak rocks just described. Very little foreign, hard material occurs in its drift, a fact which will be explained presently; exposures of rock are scarce and are much decayed except where they have been protected by a covering of soil and only recently stripped as in railway cuts and roadside trenches. Moreover, most of the exposures are so loosened along bedding and joint cracks that it is usually impossible to tell whether they are ledges of rock, in place, or masses which have been shifted from their places. Most of the observations of striæ hitherto reported from this Permian area are of uncertain value on that account, and a large number are admittedly on loose blocks. In the course of their journey such blocks as these must have turned from time to time, and given new sets of striæ, finally settling into position with the scratches oriented in many accidental directions which have no significance. If all these questionable data were accepted and plotted, only confusion could result; hence on the accompanying map (No. 2006) only a few of the observations of *bona fide* bedrock localities—four reported by Fletcher, one by Ells, and six by the present writer—are used to indicate the directions of movement of the ice on the lowland north of the Cobequid range; for at least two distinct movements have taken place. In the lowland rocks of Antigonish county and Cape Breton island there is also a scarcity of grooves. Around Sydney and Glace Bay, where the splintery shale and thin-bedded sandstones of the Coal Measures cover scores of square miles, it is almost impossible to find glacial scratches. A few have been observed on ledges at the shore of Sydney harbour; but as a rule they occur in the outcrops of volcanic and crystalline rocks.

It is usual to find a divergence between the striæ on a glaciated surface of 5, 10, or even 15 degrees. In places these discordant striæ seem to fall systematically into two or more sets, a phenomenon which is easy to detect if there is a wide angle between the sets, and only a few well-defined grooves on the exposure; but less apparent where the two sets average only 15 or 20 degrees apart in compass direction. Where there are two or more sets of grooves, their importance may be very great, since the chance for destruction of earlier grooves or striæ by abrasion during a later striation is so great, particularly if the later movement is long maintained, that it is probable that the later of two recorded movements represents merely a

A. Crescentic gouges.

B. Annular scar.

short stage of the same epoch of glaciation, not a second epoch of equal magnitude. However, there are well-established cases where marks of two or even three successive epochs are engraved on a single ledge. In western Ontario, two sets of striæ have been correlated with two sheets of glacial drift, one of which is composed of materials brought by ice moving southeastward from a centre west of Hudson bay and the other of materials brought by ice moving southwestward from a centre east of Hudson bay. These two sheets overlap so far that it is clear that a considerable interval of time elapsed between the retreat of one ice lobe and the advance of the other; yet the striæ made by both are well preserved. In northern Nova Scotia and Prince Edward Island criss-cross striæ are so widely divergent and so definitely grouped with reference to one another and to probable centres of deployment as to make it evident that there were successive movements from places as far apart as central New Brunswick and the region north of Anticosti. It is, of course, desirable always to discover which of two sets of grooves was the last one made, the later set crossing the earlier set. In some cases the question of relative age is a difficult one, demanding close scrutiny of many examples and corroborative evidence of various kinds.

The question not infrequently arises whether the ice moved in one direction or in the opposite one. It cannot as a rule be answered satisfactorily by studying the grooves alone. Some grooves show a tendency to grow wider and deeper in the direction of glaciation, ending more abruptly than they began, as if the graving tool had cut in more and more deeply until the resistance which it encountered caused it to jump ahead and start a new groove, or crushed its cutting edge, but other grooves taper out in the direction of ice movement, as if the pressure on the tool had been slowly relieved, or its cutting edge had been slowly worn away. A more reliable criterion is the shape of the glaciated ledge, if this is not too flat or irregular; for the "struck" side, which opposed the ice movement, is usually severely abraded and scoured, whereas the lee side is more likely to be angular and rough.

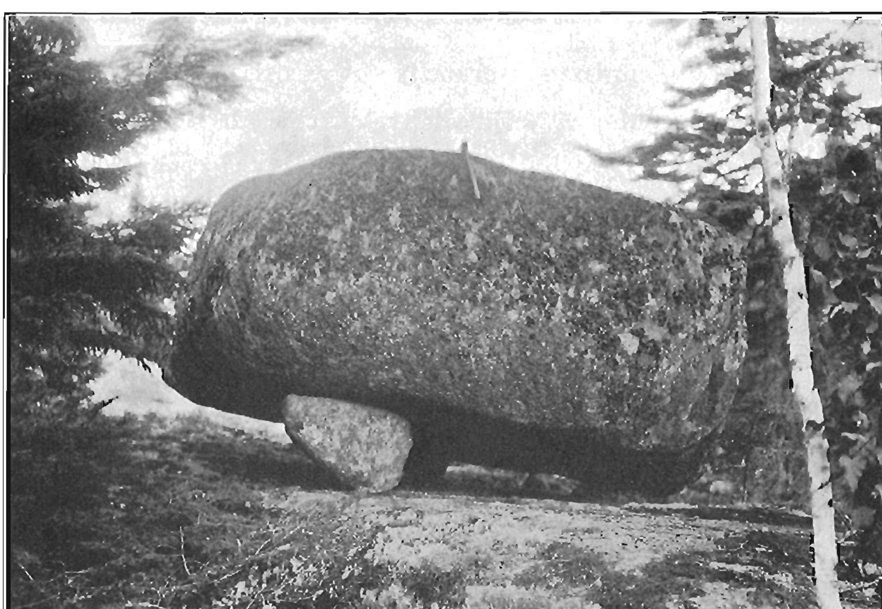
ICE SHADOWS

Even where this last-mentioned test fails because the exposure of the rock is too flat and too continuously scoured, it may be possible to tell by examining the glaciated surface more closely how the ice moved. If the rock contains hard bodies or lumps, as, for example, a slate containing hard quartz pebbles, or a limestone with silicified fossils, the hard substance will project above the ice-worn surface, protecting some of the soft matrix, which stands behind it like a shadow. These "ice shadows" vary in size from those which can be seen only with a lens, under concentrated light, to those which rise an inch or two above the surface. If all these signs fail, recourse may be had to the direction in which the stony material was transported from parent ledges to its present resting place in the drift.

CRESCENTIC FRACTURES

Certain firm, compact rocks such as quartzite and granite exhibit glacial marks of a still more peculiar kind, known as crescentic fractures or

A. Crescentic fractures, lake Rossignol.



B. Table rock, Spryfield.

gouges. One type is a curved depression on the otherwise well-smoothed rock surface, where a large, crescent-shaped piece of the ledge has been chipped out (Plate X A). This mark is left only where ice carries large boulders and has been forced to ascend a hill. The pressure due to crowding against the ascending rock floor was concentrated through boulders at points of contact between them and the rock surface, giving a tendency to dent in the rock, in much the same way as one might make a dent in the top of a bowl of jelly, by pressing the thumb obliquely down on it. Since the rigidity of the rock was too great to allow the dent and the partly encircling ridge to develop far, it yielded to the strains by the formation of a nearly vertical, semicircular crack in front of the point of contact, and a gently inclined crack intersecting this in such a way as to separate a crescent-shaped chip. These crescentic fractures or "lunoid furrows" mostly occur in lines, following the glacial grooves, as if the same boulder had been pressed against the rock repeatedly as it moved forward, catching on the surface at short intervals and then jumping or sliding forward to the next point. The outer side of the crescent is always in front, with reference to ice movement. The fractures commonly measure 1 or 2 feet in diameter. In a few places the pressure of the boulder on the ledge appears to have been quite vertical, causing a complete circular or elliptical crack from which a circular or elliptical disk was flaked out. These are called "annular scars" (Plate X B).

The quartzite of Nova Scotia also shows crescentic marks of another kind known as "chatter marks"—fractures that stand almost vertical, with the concave side forward (just the reverse of the "lunoid furrows"), and that occur in such large numbers and so closely spaced that they intersect. Since they, too, show a definite tendency to follow lines of glacial grooves, they appear to have been caused by the pressure of the passing ice-sheet; but in what manner is unknown. Fine examples of this sort were seen on deeply grooved quartzite ledges at the east end of Lockeport beach, and on an islet near "The Screecher" in lake Rossignol (Plate XI A).

SYSTEMS OF STRIÆ IN NOVA SCOTIA

The arrows on Map 2006 indicate the directions of glacial grooves at many localities and show that the general movement of the ice-sheet across the province was southward and southeastward. At first glance the map seems to show that there was one great movement from a centre east of Hudson bay, coming southeastward, but allowing the ice to deploy to the southward and southwestward in Digby and Yarmouth counties, and to the eastward in Cape Breton island. Closer inspection discloses a positive discordance between a southeastward system of striation over the western part of Nova Scotia and a southward system over the northern part, a discordance which is particularly plain on the isthmus of Chignecto, and occurs also in Prince Edward Island and New Brunswick.

The grooves on North mountain between Digby and Blomidon run southeastward, showing a seaward push from New Brunswick; the striæ at the head of the bay of Fundy, in Cumberland county, show a strong southwestward movement which merges into a southward movement farther east, on the Cumberland lowland and the Cobequids, and into a southeastward movement on the Arisaig highlands and Cape Breton island. This divergent system appears to have originated in a southward movement from the region north of Anticosti island, which spreads radially over the now submerged Acadian plain, producing a great lobe in which movement at all points was towards the semicircular margin of the plain—the present coast of Northumberland strait and western Cape Breton island.

At two of the localities north of the Cobequids, shown on Map 2006, the movement from New Brunswick and the movement of the Acadian Bay lobe are recorded by cross striæ. Many other cases, both in northern Nova Scotia and on Prince Edward Island, were reported by Dr. Chalmers, but they are not entered on the map because some are known to be on erratic blocks, and these lead to bewildering disagreements. The angle of discordance is usually over 90 degrees. There seems to be an overlapping of the two sets for 20 or 30 miles, in southeastern New Brunswick and northern Nova Scotia. This is seen on the map in the observations recorded at Pugwash Junction, Pictou, and Arisaig. The grooves cut during the southward advance of the Acadian Bay lobe seem to be the later of the two sets. South of Minas basin, on the Southern upland, two sets of striæ, less markedly divergent, are seen around Grand lake and in the vicinity of Windsor Junction. These striæ seem to show that at the time the ice front stood on the Southern upland the division into lobes was just beginning; and that the New Brunswick and Acadian Bay lobes took definite form only after the ice had withdrawn into Cumberland county. Scattered instances of cross striation appear in northern Queens county and elsewhere; but they are not sufficiently numerous or related to indicate more than very local and temporary changes in the direction of movement. On Cape Breton island there is evidence not only of the southeastward movement of the Acadian Bay lobe, recorded at several places in Inverness, Victoria, and Richmond counties, but also, in Cape Breton county, of a northeastward or a southwestward movement which it seems impossible to attribute to ice moving from a centre in either New Brunswick or from a centre in Labrador. Furthermore, these striæ run too nearly north and south to be due to a movement outward from a centre in Newfoundland, or to a movement northeastward from a centre in Nova Scotia, a fact which makes it difficult to hypothecate a third centre of glaciation. The possibility of a local centre on Cape Breton island is equally remote. The interpretation of these strange conditions may best be left for a later page after other observations bearing on the source of the ice have been presented.

TRANSPORTATION BY THE ICE-SHEET

DISPERSION OF STONES IN THE DRIFT

As it moved forward, the ice-sheet carried enormous loads of rock debris across the province; and, melting, left it scattered over the surface. By studying the present distribution of these rock fragments and the areas where the same types of rock are known to outcrop, it may be discovered whence the rock fragments were derived and the direction of the movement of the ice. This study of the dispersion of the drift is a matter of practical interest. In prospecting for gold, tungsten, coal, and other mineral resources in Nova Scotia, the first signs of the mineral sought have usually been fragments in the drift; and in many cases the main deposit has been found by carefully tracing this drift or "float" back along the direction of glacial grooves to the parent ledges.

Whereas grooves and striae furnish a record chiefly of the direction of movement at the close of the period of occupancy of the region by the ice-sheet, the dispersion of the stones which it carried and dropped indicates more clearly the general drift of ice currents through the entire period. Striæ of an earlier stage of movement would generally be erased by erosion during later movements; but the drift material carried and deposited in an early advance might be picked up again during later stages or epochs and moved in a somewhat different direction. Therefore, a less simple and orderly arrangement in the paths followed by drift stones might be expected than in the direction of striæ in the same region. If the successive movements were very different in direction, or nearly opposed, it would be hard to analyse the result.

Among other difficulties which must be faced in determining the courses of stones which have been carried by the ice-sheet are the following. (1) The stones must have some strong peculiarity of composition which enables one positively to identify them as having come from a particular place; otherwise they are of little value. Fossils of rare kinds, uncommon rock types, for example the North Mountain amygdaloid and jasper, are usually easy to identify. (2) Only well-defined trails can be helpful. Many of the areas in which rocks of the several types outcrop are very large, and so placed in relation to the direction of glacial movement that trails from different areas of the same rock overlap. (3) In order to know the source of a certain type of rock, not only the outlines of the areas where it outcrops must be known, but the possibility must be admitted of its occurrence in places where it is now concealed from view by water or soil. All possible sources must be considered. (4) Certain fragments may have been transported by rivers, shore ice, tides, or waves before the ice-sheet advanced and incorporated them in its drift. This contingency cannot be ignored, inasmuch as there are known to have been times in the Pleistocene (or Glacial) period when the land stood much lower than it now stands. (5) Pebbles, cobbles, and boulders of certain types of rock occur outside the areas of rocks of that type, in coarse conglomerates which were formed from debris brought together by rivers, waves, or tides, in geological periods long before the Glacial period. Some of these conglomerate formations are widely distributed, reaching far beyond the limits of the areas from which their pebbles came; and by their decay in pre-Glacial time, as well as by breaking down under glaciation, they must have contributed to the drift millions of pebbles which have the appearance of having been brought directly from their parent ledges by the ice-sheet. (6) At the coast, the beach material, which is in some cases studied to determine the composition of the drift, is liable to be adulterated by ballast dumped from schooners. At North Sydney, for instance, thousands of tons of cobblestones from Newfoundland, Wales, Denmark, and other distant countries have been dumped along the water front. Even docks at small ports have had these artificial contributions of stone; and not infrequently a schooner thus ballasted has been wrecked on the shore and has contributed fragments of strange foreign rocks to the beaches. The discovery of three or four black flint nodules on a little beach at Yarmouth bar led the writer to inquire from the occupant of a homestead close by, where such stones had come from—since they looked like specimens from the chalk formations of Texas or of Dover. The explanation promptly given was that an old sea captain used to bring flint pebbles home as ballast from the West Indies. (7) Though certain types of rock like granite, trap, and quartzite are so resistant that they do not wear out or become crushed in a journey of scores of miles, others, such as limestone, shale, slate, and crumbling sandstone, quickly vanish or are converted into small particles which, though they may form an equal volume of the matrix, are not easily discovered. Accordingly, certain types of rock vanish, making others the more conspicuous. Even so, trails of the softer rocks are valuable as indicating the ice movement, and because of their shortness do not demand such extensive field studies.

Of all the rock types occurring in Nova Scotia the most easily traced by fragments in the drift are the trap and amygdaloid of the North Mountain belt. These two types of rock, outcropping together along the range for 120 miles, and appearing also in small islands on the north shore of Minas basin, shed a broad trail of drift stones, which is unrivalled in its extent and in the sharpness of its outline. The durability of the trap fragments is so great that large numbers of them were carried across the southern peninsula of Nova Scotia without being destroyed, though mingled with granite rubbish on the way. The composition of the amygdaloid, with its odd amygdules and bright colouring matter, makes its fragments conspicuous, and easy to identify. Moreover, unlike many of the other hard rocks, the trap does not occur as pebbles in the conglomerates; for it is of later date than any of them.

The movement of ice across Nova Scotia appears from observations of the courses of striæ to have consisted in: (1) a southeastward movement from New Brunswick; (2) a southward movement from the gulf of St. Lawrence; (3) possible local movements; and (4) a movement in eastern Cape Breton which at first sight seems unrelated to the others. The subject of drift dispersion will be treated under the four heads.

Dispersion of Stones by Ice Moving Southeastward from New Brunswick

The glaciated ledges of North mountain, so far as seen, do not indicate whether the movement of the ice was southeastward or northwestward. No well-developed roches moutonnées and no good ice shadows have been reported. In one or two places, where the columnar jointing of the trap allowed the ice to tear out angular blocks, the pits thus formed are scoured more severely on the southern wall than on the northern, as if the ice had moved southeastward; but this evidence is by no means convincing. It is fortunate, therefore, that the path of North Mountain trap-stones can not only be traced southeastward, but that in the North Mountain district stones are found which have come southeastward from New Brunswick. In the northern part of Digby county, at Bear River, Smith Cove, Digby, Rossway, Weymouth, Tiverton, Freeport, Salmon River, Meteghan River, and elsewhere, the drift contains boulders and smaller stones of a mottled red and grey conglomerate, so different from the other rocks that they attract the attention of anyone who examines a number of beach pebbles. The red conglomerate stones occur not only on the beaches at these places, but in the glacial drift from which the waves have washed them to the beaches. They are found on both North mountain and South mountain. On the beach at Digby and at the sea-wall near Rossway, boulders of the conglomerate over a foot in diameter are not uncommon. The matrix of the rock is usually red or greyish green; the pebbles are of many colours and angular or well rounded. It looks like a moderately coarse gravel, firmly compacted by pressure and cementation. Thousands of the red conglomerate pebbles and boulders must occur in the drift on this side of Nova Scotia; for scores of them have been counted at the localities mentioned, where by actual count they compose from 1 to 3 per cent of the stones in the drift. Although conglomerates occur in the red Triassic formation of Annapolis valley, they are not well cemented like these and differ from them in composition and general appearance. No similar rocks are known to occur in place anywhere in Nova Scotia, nor is it likely that ledges are concealed, or remain undiscovered. Ledges of hard, red conglomerate are widely exposed, however, in southern New Brunswick, outcropping on the shores of Kennebecasis bay and near Mispec. There are two formations, both red, but differing considerably in composition. The Redhead conglomerate is mainly a water-worn gravel, containing boulder beds, firmly consolidated, but with a matrix much softer than the pebbles. The Mispec conglomerate is a "breccia," consisting largely of angular fragments, mostly of volcanic types, set in a hard matrix, thoroughly compressed and badly sheared. Boulders of both rocks are common on the shore near St. John, and pebbles of both kinds have been collected at localities in Nova Scotia. Towards the west end of the North Mountain district the Mispec appears to be the only type of red conglomerate present; but in the vicinity of Digby the pebbles of the Redhead conglomerate are plentiful. Fragments are found as far south as Yarmouth harbour. Along with the red conglomerates there is always a small percentage of other stones foreign to Nova Scotia, or at least to those parts of Nova Scotia which lie along the lines of striæ; in this section—felsite, diorite, syenite, and granite of various types. Although these are not so confidently identified as having come from New Brunswick, they lend additional weight to the evidence from the red conglomerates.

Nothing is plainer than the southeastward movement of trap and amygdaloid fragments from North mountain. In the Annapolis valley, where red sandstones underlie the drift, angular and waterworn fragments of trap constitute from 80 to 95 per cent of the stones in it. The fields along the base of the mountain are dotted with thousands of the black blocks, and the red drift that appears above the red sandstone in the cliffs of the sea-wall is full of them. Across the valley, on the lower slopes of South Mountain hills, where slate, quartzite, and granite outcrop, trap is still common in the drift, but at a distance of 4 to 5 miles from its occurrence in place the trap boulders form only 10 per cent of the fragments.

Since the granite ledges are so easily broken into fragments it is rather surprising that the trap forms so large a proportion of the debris in the drift. It forms about 5 per cent of the glacial material in the middle part of the peninsula, and from 1 to 3 per cent on the south coast. At some points on the coast the percentage is much higher. A count of the stones in a borrow-pit near the railway station at Mahone Bay disclosed the surprising fact that 27 per cent of them are trap and amygdaloid. The presence of the amygdaloid in numbers equal to the traps is important because although trap might have come from small dykes, which are known to outcrop in a few places on the Southern upland, the amygdaloid could come only from North mountain. The journey from North mountain to Mahone bay, measured in the direction of striæ, from Middleton, is about 50 miles. Many pretty fragments of amygdaloid may be found in the cliffs at Chester, where the sea is cutting away the ends of the drumlins or drift hills. A score or more fragments of trap and amygdaloid and a few pieces of red jasper were seen at Peninsula point. In the Provincial museum at Halifax are a number of Indian arrowheads from Bockman beach near Lunenburg, which are made of North Mountain jasper and flint. Since the rocks occur in the drift near Lunenburg there is no necessity for supposing that the trap arrowheads were traded by Indians dwelling in the two places. Most of the arrowheads from Lunenburg are of vein quartz and slate, which are abundant in the local rocks.

The presence of the North Mountain rocks on the south coast was first noticed by Dr. Honeyman in 1873. His curiosity was excited by a fragment of amethystine quartz in the museum collections, said to come from Cow bay. Visiting the shore at that place in search of evidence to confirm this report, he found not only a large number of North Mountain traps and amygdaloids and a few fragments of jasper and agate, but a number of other stones from other sources far northwest of Halifax, for example, fossil tree fragments from the Carboniferous rocks of Hants county and syenites and felsites from the Cobequids. He collected similar specimens from the drift hills in and near Halifax. An exhibition of these erratics at the Philadelphia exposition, in 1876, won for him a well-deserved prize. The specimens may still be seen in the Provincial museum; but anyone who cares to make a collection of his own can easily do so by searching on the beaches east of Halifax or on the islands of the harbour. The distance from Blomidon to Halifax, in the direction of striæ, is about 65 miles.

On Map 2006, localities are plotted where trap and amygdaloid like that of North mountain have been found in the drift. The proportion of the North Mountain rocks to other types, in the stones of the drift, is shown by figures. It will be seen, on examining the map, that whereas the traps constitute over 50 per cent of the stones in the first stretch of the southeastward journey, across the Annapolis valley, there is a rapid falling off in percentage as soon as the drift reaches the granite, or the quartzite belts of the Southern upland, where the ice found a multitude of hard fragments of those rocks. Dr. Honeyman explored the country northeast of Halifax in an attempt to find the eastern boundary of the boulder trail from Blomidon. Judging both from the course of striæ and by the observations of drift which he secured, he finally set the limit of the trail at a line running from Blomidon to Enfield and thence through Goff and Preston to Threefathom harbour, near Lawrencetown. He conceded, however, that similar fragments might be found in much smaller numbers farther east, fragments derived from the small exposures of trap and amygdaloid at Partridge Island and Five Islands. The new boulder counts which furnish the percentages of trap for the map attest the accuracy of Dr. Honeyman's conclusions; for they show a sudden decrease in percentage of trap and amygdaloid between Scotch Village and Clarksville; and east of that line traps occur only sparingly, varying from 2 per cent down to a fraction of 1 per cent. This is remarkable, since in some places no rocks capable of supplying hard pebbles outcrop between the trap and the drift locality and hence the total number of fragments being less the percentage of trap pebbles should be greater. The occurrence of amygdaloids at Kennetcook may be explained by a southeastward movement from the outcrops at Five Islands, which lie only 20 miles away. The amygdaloids found at Truro, however, seem to demand an eastward movement from the trap localities. The only alternative is to suppose some other source of material indistinguishable from the rock of North mountain; but inasmuch as the occurrence of eastward-running striæ shows that at some time in the Ice age the New Brunswick ice advanced as far east as Pictou, N.S., and to the eastern end of Prince Edward Island, it seems more probable that the Truro amygdaloid pebbles are relics of that eastward movement from New Brunswick, not destroyed by the later southward movement of the Acadian Bay ice lobe. The occurrence of trap at Hopewell and Ferrona Junction is not as acceptable evidence of this eastward moving ice, because the trap found in the drift at these places is not accompanied by amygdaloids, and might, therefore, have come from local dykes. At Hardwood hill, near Pictou, however, one amygdaloid stone containing zeolites was found, together with a very high percentage of crystallines from the Cobequid range The amygdaloid appears, therefore, to have come from one of the Minas Basin localities. Without this corroborative evidence of Cobequid rocks it would be hard to settle the question of identity of the amygdaloid at Pictou; for there are other small areas of amygdaloidal lavas about 30 miles east of Pictou, on the coast at Arisaig, where the drift is locally well supplied with fragments of it. Moreover, the Magdalen islands contain volcanic rocks not altogether unlike the North Mountain amygdaloids.

The dispersion southeastward of pebbles from the granite of the southern upland is evident from the composition of the drift south of the granite areas. Thus the drumlins of the slate district around Caledonia, 10 miles south of the granite boundary, are dotted with granite boulders from 2 to 6 feet or more in diameter, and boulder walls enclose the cultivated fields and pastures. At Chester the percentage of granites is 48 to 51 of local quartzites and slates, though the granite is 5 miles away. Granite is an abundant component of the drift at every locality southeast of the granite axis. The quartzite of the Southern upland shows evidence of the same movement towards the southeast, in southwest Digby and Yarmouth counties, although rock outcrops are so plentiful in the region that the drift fragments are widely scattered and lose much of their significance.

It has been seen that in conformity with the eastward course of striæ in the district north of the Cobequids and on Prince Edward Island a few fragments of trap and amygdaloid appear in the drift as far east as Pictou, Hopewell, and Ferrona Junction. Since these might be confused with fragments brought from other sources, however, it is fortunate that a trail of crystalline boulders extends eastward from the Cobequids over this district. On Hardwood hill, 5 miles west of Pictou, where three distinct sets of striæ are registered on ledges of sandstone, granite, and syenite boulders are exceedingly numerous in the pastures and stone walls. A count of drift stones here showed 45 per cent of granite, syenite, diorite, or other rocks derived from the Cobequids, and 50 per cent of local sandstones. A movement of the New Brunswick lobe in a direction 10 degrees north of east would have brought a plentiful supply of these crystallines from the Cobequids to Hardwood hill. A subsequent movement southward of the Acadian Bay lobe might not have removed this drift and in case of mixture with drift from that direction the pebbles of crystalline rocks would still be noticeable, since the drift of Prince Edward Island and the Northumberland lowland generally is almost wholly composed of soft, crumbled sandstone and contains no hard boulders. This explanation of the occurrence of large numbers of Cobequid rocks on Hardwood hill is corroborated by the fact that in a roadside ditch near where the count was made, there is a section showing 2 or 3 feet of red drift like that which covers the red sandstones of Prince Edward Island, above a grey drift in which granite and syenite boulders are very abundant. In the district between New Glasgow and Hopewell, granites and syenites are fairly common in the drift; but at New Glasgow a coarse conglomerate which comes to the surface furnishes a plentiful supply of quartzite pebbles, so that the proportion of syenites and granites in the drift is reduced to less than 5 per cent.

The discovery in 1915 of a fossil-bearing pebble, in the glacial drift near Pictou, raises an interesting question. The shell impressions in the piece of stone have been identified by Professor Charles Schuchert of Yale University as those of two brachiopods *Dalmanella lunata* and *Dalmanella orbicularis*—species which belong to the higher Silurian strata of Nova Scotia and England. They occur in the "Stonehouse formation" near Arisaig and New Glasgow and it might hastily be concluded, therefore, that they had come to Pictou by a westward movement of the ice-sheet. But inasmuch as a geological map (No. 39A), issued by the Geological Survey, shows small exposures of the same Silurian strata west of Pictou, near the eastern end of the Cobequid range, and inasmuch as the drift at Pictou is so well filled with granites and syenites from the Cobequids, there can be little doubt that the fossil-bearing Silurian pebble, also, was brought by an eastward movement.

Dispersion of Stones by the Acadian Bay Lobe

Indications of the great southward movement of glacial ice across Prince Edward Island, Northumberland strait, and the northern part of Nova Scotia are varied and interesting. Sir William Dawson reported the presence on the Arisaig shore of a number of peculiar types of rock foreign to the region, including a few which resemble rocks of the region north of the gulf of St. Lawrence. Among them he speaks in particular of boulders of labradorite, a rock composed of bluish grey feldspar. Dawson refused to follow the glacialists of his time, and assigned these far-travelled boulders to the drifting of pack ice during a former submergence of the lowlands of Nova Scotia by the sea; but the evidences of a continental glacier are now so clear that the 300-mile journey may be attributed to the great ice-sheet. Some of these foreign boulders at Arisaig may have come from the Cobequids, as Dawson suggested. This district is in line with the eastward movement towards Pictou. Honeyman reported, in 1878, that boulders from the fossiliferous section of the Arisaig shore had been transported south 30 degrees east. This was later confirmed by Fletcher and Faribault, who reported fragments of the Silurian in the drift near Ecum Secum river, 30 miles south of Arisaig. More recently, Williams has called attention to the fact that the fragments from the volcanic plugs of the Arisaig highlands trail southeastward, in some places to points much higher than their source.

It has been said that the drift on Prince Edward Island is composed almost wholly of local sandstone with no boulders from other rock areas except near the western part of the island, where crystallines like those in the highlands of New Brunswick make their appearance. The absence on the island of pebbles of crystalline rocks indicates a lack of available crystalline material on the submerged plain over which the Acadian Bay ice advanced to Prince Edward Island and agrees with the idea that the southward movement followed the eastward one. On the Cumberland lowland the southward movement of the ice is clearly indicated by the presence of boulders of Millstone Grit and other lowland rocks on the top of the Cobequid range, where they have been found by all who have searched for them since Dawson first described them. At Amherst and Joggins mines, the drift is made up wholly of rocks from the lowland—sandstones, grits, and conglomerates, with little or no material from New Brunswick—showing, as the southwestward striæ of that district also show, that the last movement was a strong southward advance of the Acadian Bay lobe deploying over Cumberland county. Locally on the lowland, near conglomerate outcrops, the drift is full of quartzite pebbles derived from the conglomerate. Even as far south as Canning, in the lee of the North Mountain trap range, quartzite pebbles constitute 23 per cent of the drift stones. Near Wallace it is noticeable that fragments of conglomerate are plentiful to the south of the conglomerate belts; but not to the north of them.

The movement of the Acadian Bay ice across the top of the Cobequids is shown not only by the presence of sandstones on the top of the range, but by the southward dispersion of Cobequid rocks into Colchester, Hants, and Halifax counties. Granites, syenites, diorites, felsites, and other igneous rocks which outcrop along the Cobequid Mountain belt are strewn all over the country to the south and southeast, as Honeyman discovered, forty years ago, at Halifax. At Middle Musquodoboit, these boulders are plentiful. At Truro, 10 miles south of the range, coarse crystalline rocks from the Cobequids constitute no less than 34 per cent of the stones in the drift.

The movement on the east side of the Acadian Bay lobe is best shown by the greater and greater easterly divergence of striæ across Cape Breton island. At the lighthouse near Hastings, in the strait of Canso, beautifully striated roches moutonnées show a southeastward movement of the ice. Fletcher's observations on Craignish hills, Sporting mountain, Madame island, the Middle River-Margaree divide, and near Mabou, and those of the writer at L'Ardoise, Whycocomagh, Pleasant Bay, Neil Harbour, and Ingonish, plotted on Map 2006, agree in showing a southeastward movement of the ice, so strong that it overtopped the upland belts and tableland, and reached the south coast, in Richmond county, at least. The glaciated ledges at L'Ardoise show plainly by their form that the movement was towards the southeast and not towards the northwest. It is difficult to get satisfactory evidence, however, from the dispersion of the stones in the drift, because crystalline rocks occur not only in the scattered upland districts, but also as pebbles in a coarse conglomerate that outcrops in the lowlands and at certain points on the west shore. On this account, the presence of syenite, felsite, and granite boulders in the drift northwest of Craignish hills and west of the plateau escarpment near Pleasant Bay signifies nothing. There is a sea-cliff near the steamboat landing at Pleasant Bay where the coarse, red conglomerate contains boulders of granite and purple felsite, which, when weathered out and incorporated in the drift, might easily be mistaken for boulders that had been transported by the ice from the plateau in a northwestward direction.

Movement from Local Centres

It remains to consider whether certain features which have generally been supposed to indicate movements of ice from small local centres in Nova Scotia need to be thus interpreted. What has already been said concerning the thickness of the ice-sheet in the mountains of New England should be kept in mind; as also the positive evidence of the two great movements so clearly shown by the striæ and the dispersion of stones—the eastward and southeastward movement of ice from New Brunswick and the southward movement of the Acadian Bay lobe.

On the top of North mountain, from Digby eastward, pebbles and boulders of granite are common. It was thought by L. W. Bailey that these must have come from the granite area of South mountain, being carried out from a local ice cap which survived the sheet from the Labrador centre. However, coarse granites of several types are widely exposed in southern New Brunswick. Moreover, the granite stones in question are associated with the "red-head conglomerate" stones, and felsites and diorites which have evidently come from New Brunswick. Since all of these together constitute as a rule from 3 to 6 per cent of the drift stones in the district around Digby, it is most reasonable to suppose that these granites came from the northwest rather than by a local movement in the opposite direction.

Granite boulders appear in much larger numbers on the floor and sides of Annapolis valley, between Clementsport and Lawrencetown, where they are conspicuous objects in the fields and pastures, likely to be noticed from a passing train. Their coarse porphyritic texture and their abundance leave little doubt that they came from the granite area of

Annapolis county. It is not necessary, however, to suppose that there was a northward movement of the ice in this district, for granite ledges extend down to the bank of Annapolis river in one or two places, and it is not unlikely that they underlie the marshes and drift-covered ground at other points in the valley. Moreover, there is the possibility that granite boulders from these lowest outcrops were distributed by tides and shore ice in the basin when it was more deeply submerged than now, and that they were allowed to remain, in large measure, when the ice-sheet, later, advanced across North mountain, overriding the deposits that lay behind it. The diagram of drift stones at four localities near Bridgetown (Figure 7) shows how plainly the southeast movement is indicated by the dispersal of trap from North mountain, and by the relative scarcity of granite boulders that lie north of the supposed boundary of the granite in South mountain.

Where boulders of South Mountain granite rest on ledges of slate or quartzite at points north of the granite area, it seems evident that the

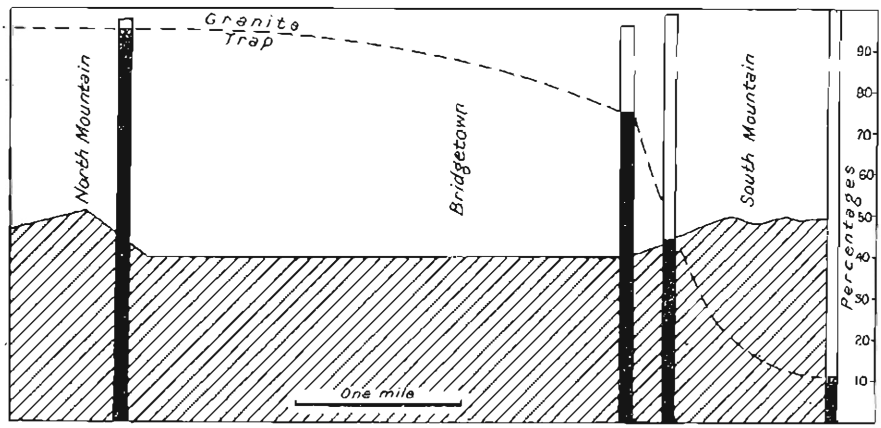


FIGURE 7. Profile and curve at Bridgetown, showing proportionate dispersion of granite and trap boulders in the drift.

movement must have been northwestward; for example, on the New Ross road south of Kentville, granite boulders are conspicuous near South Alton, forming 24 per cent of the stones in the drift, although this is 3 miles north of the boundary of the granite as mapped, and there are glaciated ledges of quartzite. The granite is coarse and porphyritic like that of the South Mountain type, and the boulders are too numerous to have come from a distant source. The abruptness with which they appear suggests, indeed, that they may have come from local patches of granite *north of the main area*, not yet discovered, and perhaps concealed by drift. Outlying patches of granite have been mapped near Nictaux and Weymouth; and it is not improbable that others of the same kind exist there. If so, the boulders at South Alton may have been brought by the same southeastward movement that brought the traps and amygdaloids, which here constitute 10 per cent of the stones. It seems significant that the boulders of the South Mountain granite are absent or nearly absent from the drift in the district around Windsor and Mount Uniacke. Boulder counts at several localities just north of the granite boundary in this district show only a few granite pebbles like felsites and diorites, presumably from the Cobequids; and a host of traps and amygdaloids from the northwest. At South Uniacke, barely 2 miles north of the granite border, only one stone of one hundred and thirty-nine counted was a granite. The evidence in the dispersion of stones seems, therefore, to be very much against a local movement northward from the granite area, and there are no striæ whatever to support it.

The interpretation of the glaciation of the isthmus of Chignecto has been much confused. Partly because of the divergent systems of striæ and the acceptance of striated boulders as evidence of the direction of movements, and partly because of a failure to appreciate the fact that a great ice-sheet could advance over the gulf of St. Lawrence, cross the Cobequid mountains, and continue over the Southern upland to the coast, it has been supposed that the Cobequid mountains acted as a local centre of dispersion, and indeed that the low, isolated hills and insignificant river valleys directed the "sliding" of ice at the close of the period of glaciation. It has been shown that the systematic divergence of striæ on the borders of the Acadian bay points to the existence there of a great lobe, whose axis lay north and south; that the southward transportation of sandstones from the lowland to the top of the Cobequids and of the Cobequid rocks to the country south and southeast of that belt, indicates that this great lobe of ice reached at least as far as Minas basin.

What evidence is there, then, which requires a local centre? In the first place, it has been said that the top of the Cobequids is covered with residual soil and shows little or no glaciation. This is not so. The mountains are covered rather thinly with drift, in which, as usual, local material is the most prominent, and residual material not absent. Pebbles of Carboniferous sandstone from the lowland on the north, and fragments from the Millstone Grit, are not uncommon. Ice-worn and striated stones are to be seen; and although the bedrock is as a rule too much sheared and cracked to show distinct grooves there are plenty of well-smoothed surfaces. In Folly Lake gap, drift is banked up against the sides very thickly, and massed in great kames and morainic hummocks at both ends of the lake. There can be no question that the Cobequids were glaciated by ice passing over them from the north. In the second place, it has been reported that syenites, felsites, and granites like those of the Cobequids occur in the drift on the lowland north of the range. So they do; but to a very limited extent. At a distance of more than 1 or 2 miles, boulders of the Cobequid types are so scarce that it may reasonably be doubted whether they did not come from areas of similar rocks in the Caledonia highlands during the eastward advance of the New Brunswick ice. At Westchester, Wentworth, and other localities within 1 or 2 miles of the foot of the range, granites, syenites, felsites, and other types are so abundant that they probably did come from the Cobequids; but it should be noticed that the movement from New Brunswick sufficiently accounts for them. The ice moving eastward across Cumberland county would collect granite, syenite, and other crystalline rocks from the spurs of the range, like that near Collingwood Corner, and would sweep along whatever crystalline stones had accumulated at the base of the mountains in the fans and flood-plains of northward-flowing torrents. The crystalline boulders near Pictou are explained also by the eastward movement of the New Brunswick ice, and have no value as evidence of a local centre on the Cobequids. At points 5 or 6 miles north of the Cobequids, the scarcity of crystallines in the drift is remarkable. Thus at Springhill a count showed only 3 per cent, at Oxford Junction 6 per cent, and at Thompson station, 1 per cent. It is thought that all these came from New Brunswick, like the boulders, reported by Dawson and Chalmers, at the western end of Prince Edward Island.

Of all the districts in the province, the one where a local ice cap would have been the most likely to form is the high tableland of northern Cape Breton. Its great, flat top, 1,200 feet above sea-level, overlooking the gulf on one side and the Atlantic on the other, would seem to have afforded ideal conditions for a local ice cover; and its deep valleys, descending steeply near the coast to fiord-like mouths, would have made good paths for fast-flowing ice tongues or "outlets" like those of Greenland. It must be considered, therefore, whether this condition seems to be indicated by the evidence thus far discovered. Striæ have been seen at only four places on or near the tableland: near Pleasant Bay; at Ingonish on North bay; at Neil Harbour; and on the watershed half-way between Middle River and Northeast Margaree—the last being an observation by Fletcher. At Ingonish, roches moutonnées show distinctly that the movement was southeastward. This would be expected, however, in either case—whether the glaciation came from the middle of the Acadian bay or from a nearer centre on the tableland. The same is true of the direction at Neil Harbour. The striæ at Pleasant Bay, on ledges at the mouth of Mackenzie river, are not accompanied by roches moutonnées, nor by ice shadows; consequently, when taken alone they do not show whether the ice moved toward the tableland or from it. Fletcher did not state whether the southeastward movement at Middle River was plainly marked or not; but that would fully agree with the evidences from striæ and dispersion of drift on the south shore of Northumberland strait, and on the contrary a movement either northwestward or southeastward would be hard to account for if the glaciation of northern Cape Breton had been from a local centre. It would be expected, in that case, to find the grooves running southwestward. The dispersion of the drift in northern Cape Breton, so far as studied, does not help to settle the question, because of the sources of crystalline boulders in the ledges of coarse conglomerate on the west shore, which make it impossible to determine whether the drift came from the interior or from the shore section. On the trail across the plateau, between Aspy bay and Pleasant Bay, smoothed ledges were seen, which are glaciated, although their surfaces are too weathered to bear distinct striæ. The drift on the tableland is filled with stones of local origin. Inasmuch as the striæ in western Cape Breton, including not only the four localities mentioned, but also those at Mabou, Whycocomagh, and Craignish hills, when plotted together with those west of the strait of Canso, all conform to a single great lobe of ice that filled the Acadian bay, it is reasonable to suppose that the glaciation of the northern tableland, also, was accomplished by the continental ice.

Any local glaciation in northern Cape Breton should have left a record in the larger valleys, making them more trough-like in form, more U-shaped in cross-section, and truncating spurs, since glacier ice cannot accommodate itself to the windings of river valleys. The valley of Ingonish, Clyde, North Aspy, Mackenzie, and other rivers of the tableland are steep sided; but they are V-shaped rather than U-shaped, and usually have winding courses. The only straight-sided and trough-like valleys are those whose straightness seems to be dependent upon fault-lines (*See* page 40). Although a few short, funnel-shaped gorges between the "sugarloaves" of Aspy bay appear to broaden upwards to blunt heads, somewhat after the fashion of hollows scooped out by cliff glaciers, their form is not at all convincing, and without more positive evidence seems worthless.

Movement in Eastern Cape Breton

All striæ thus far reported from the eastern part of Cape Breton island show a strange northeastward-moving tendency. West and south of Sydney, on the Boisdale and Coxheath hills, near Grand Narrows, the trend is only 10 or 20 degrees north of east; but at Sydney, Mira, Louisburg, cape Gabarus, Framboise, as well as on Kelly mountain and at Englishtown, the direction is more northerly than easterly. The striæ of these ten or twelve localities are so out of harmony with the striæ of the rest of the island that they call for special study. If the grooves were made by ice moving southward or southwestward, it was probably from a local centre on Newfoundland, as some have supposed; if it moved eastward and northeastward, the ice must have come either from the New Brunswick centre or from a local centre south of the strait of Canso. The fact that Newfoundland is less than 100 miles away inclines one to favour the theory that the movement was southwestward. Curiously enough, however, the roches moutonnées, ice shadows, and dispersion of stones, without exception, indicate a northeastward movement.

Near the old city of Louisburg the strongly glaciated ledge known as Black Rock point has the appearance of a roches moutonnées with its stoss side on the southwest and its plucked or lee side on the northeast (Plate XII). On several outcrops within the limits of the old city or just outside its ramparts, particularly at the eastern point, ledges of volcanic breccia seem to show a scouring from the southwest; and minute ice-shadows developed on the hard fragments confirm that opinion. At Mira bay, glaciated surfaces of Millstone Grit in the bluff behind the railway station, with striæ running north 31 to 41 degrees east, dimly show ice-shadows of a northeastward trend; and the drift, though carrying 73 per cent of local material, contains 14 per cent of mottled breccia and felsite like that of the crystalline area on the south. On the north there is no known source of volcanic rocks in the whole district between here and the coast at Glace Bay. The region around Glace Bay and Sydney is occupied by the Millstone Grit and Coal Measures, and these are known to extend out to sea. Glaciated ledges of agglomerate beside the Intercolonial railway west of George River station show striæ averaging north 68 degrees east, and small ice-shadows like those at Louisburg, indicating a northeastward, not a southwestward movement. The drift in the district

PLATE XII

Black point; roches moutonnées at Louisburg, seen from the northwest.

northeast of here, around Sydney Mines, Little Bras d'Or, and Westmount park, near Sydney, carries a noticeable percentage of agglomerates and other crystallines like those of the Boisdale belt, although here, as at Mira bay, there is no known source of such rock on the north. At Leitch Creek station, at the head of the southwest arm of Sydney harbour, where the underlying rocks for 3 miles in every direction are sandstone, limestone, and shale, a count of boulders showed 78 per cent of granites, syenites, diorites, felsites, agglomerates, and gneisses, for which there is no adequate source on the north, but an abundant supply in the Boisdales, only 4 miles to the southwest. A similar assemblage of Boisdale rocks appears in the drift at the limestone quarries of Point Edward. At Englishtown, a conspicuous granite knob at the site of the old French fort has its southwest side heavily scrubbed and rounded, and its northeast side plucked. Near it other ledges show striæ running north 36 degrees east. At none of the localities in eastern Cape Breton are there indications that the movement was towards the south or southwest. The conclusion, accordingly, is that this part of the island was crossed by ice from New Brunswick or from a local centre south of the strait of Canso. Of these two alternatives the latter faces the objection that the striæ near the coast run so nearly due northward that they seem to require a centre far out on the Banks, near Sable island, an unlikely place for a local ice cap, particularly as no local ice cap appears to have developed on Cobequid mountains or the tableland of northern Cape Breton. The idea that the northeastward glaciation of Cape Breton county was a part of the movement from New Brunswick finds support in the eastward and east-northeastward striæ at Pictou and Arisaig, and the eastward trail of drift from the Cobequids to Pictou, New Glasgow, and perhaps Arisaig. The marked veering of striæ towards the north, over Louisburg and Sydney, might be taken as a sign of deployment of the ice towards the deep waters of Cabot strait; the obscurity of evidence in Guysborough and Antigonish counties and in western Cape Breton island might be explained by the vigour of the later, southeastward glaciation from the Acadian Bay lobe. If these two movements overlapped as far as the evidence would seem to require, they must have been separated by a very considerable interval of time.

DEPOSITION BY ICE-SHEET

DRIFT

All the loose material which the ice-sheet gathered, transported, and finally deposited is known as the "drift." On account of the fact that it was borne along without any regard for size and weight, and consequently travelled long distances, the drift is composed of a great variety of rock materials, gathered from widely separate sources, and jumbled together in great confusion, usually with no separation of large fragments from small ones. Only where the drift was worked over by rivers, or waves or tides, when the ice had let go of it, does it show any assorting or bedding. In spite of the fact that the ice was able to carry its load long distances, the drift at most localities is very largely of local derivation. As a rule, from 65 to 85 per cent of the stones resemble the underlying rock formation;

and the finer material, by its sandy or its argillaceous character, shows dependence upon purely local sources. So, on the granite areas the drift consists of a mixture of boulders and sand; on the Millstone Grit it is composed mostly of sand and crumbling boulders, and on the slate and shale areas it is chiefly clay.

The drift is of two distinct sorts: the unstratified drift or "till," which was deposited directly by the ice; and the stratified drift, which was deposited by water, mainly during the recession of the ice from the region.

Unstratified Drift

Erratic Boulders. Thus far boulders have been considered as a part of the drift, and as an indication of the paths which the ice currents followed. It is time now to examine some of their more obvious peculiarities. There is practically no limit to the size of boulders which an ice-sheet can carry. Blocks 10 or 20 feet in diameter are not uncommon, and much larger ones are on record. The only reason blocks much larger than this are not found frequently is that the ledges from which the ice-sheet gathered them were already cracked by such closely spaced joints that they rarely furnished sound fragments of larger size. The boulders that lie on the ground were not dropped by the ice-sheet because of their great weight, but simply because the ice melted and left them. Inasmuch as this melting usually allowed the blocks and boulders to settle slowly downward until they came to rest on the ground, it left them in all kinds of odd, unstable positions. In many places a boulder, instead of settling flat-side down, lodged on one of its narrower sides, or on an end, or even a blunt corner. "Perched boulders" are fairly common on the granite barrens, where boulders are numbered by the thousand. Occasionally boulders are found so delicately poised that they will rock when pushed. The great "rocking stone" of Spryfield, near Halifax, is a wonderful example of this class—perhaps the largest one in the world. A photograph of this huge boulder appears as Plate I. The boulder is approximately 30 by 24 by 15 feet in extreme dimensions, but angular and irregular in shape. It rests on a glaciated surface of granite like itself, in so delicately balanced a position that by using a pole for a lever a man can rock it back and forth. The boulder is estimated to weigh between 475 and 500 tons. Although to anyone who stands on it while it rocks, the boulder seems to move up and down a foot or more, the actual displacement, at the extreme end, is only about 1½ inches. Mr. Kidston, the owner of the property, says that it used to be possible for him to rock the boulder without using a lever, by putting his shoulder to it; but a party from the garrison at Halifax, several years ago, moved it so vigorously that it edged along into a position where it is more stable. This seems to have been the fate of other rocking stones, at least one hears similar stories about them. This great boulder still rocks well enough, however, to make it an object of great curiosity. In the days when it was supposed that all the drift had been swept to its place by the deluge, perched boulders and rocking stones were objects of contention; for to an inquiring mind it was not easy to see how powerful floods, transporting huge blocks, could leave them in such unstable positions. The point is well taken; and it is recognized now that most rocking stones reached their present positions through transportation on a glacier. Some, however, are residual boulders left by the cracking away or shelling off of the surrounding structure.

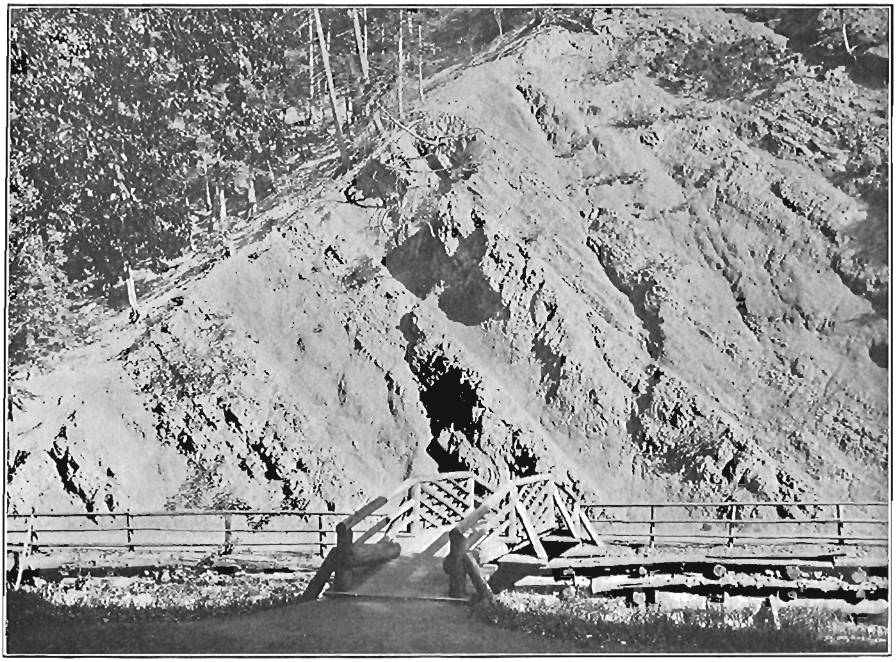
A few hundred yards from the rocking stone, on the far side of a small marsh, is a boulder, called Table rock, which is less well known, but is almost as much of a curiosity as the other (Plate XI B). It is flattish in form, measuring 15 by 14 by 5 feet, and rests on three smaller boulders, which hold it clear of the ledge by distances of 18, 10, and 6 inches, respectively. The Table rock and two of the small boulders are coarse, porphyritic granite like the ledge below; but the third (and smallest) boulder is a grey quartzite. Thus the fact that Table rock was brought and set in place by the ice-sheet is shown both by its perched position and by the presence beneath it of a foreign boulder.

Among thousands of boulders which attract attention merely on account of their large size and easy access, are Sentinel rock and Thrumcap rock in Yarmouth harbour. These isolated cases are uninteresting, however, in comparison with the masses of boulders on the granite barrens of the Southern upland, between Pescawess lake and lake Kejimkujik (Fairy lake) which have been described as follows by Mr. W. C. Prest:

"The land is strewn with immense masses of granite, with thickets of alder, laurel, blueberry, white birch, and poplar, with occasional spruce and hackmatack. Exploration here is very difficult, the whole country being covered with huge granite boulders. One of the latter projects like a pyramid 35 feet from the underbrush at its base, and another, standing on the top of a high ridge, is 47 feet long, 22 feet wide, and 15 feet high, with a probable weight of 1,050 tons. Progress through this boulder-strewn country, involving incessant climbing over huge blocks, separated only by moss-covered crevices serving as pitfalls, and overgrown with a jungle of alder, laurel, and scrub pine, is very exhausting."

Huge blocks of trap appear on the bluffs on the southwest side of the gaps at Sandy cove and Petite passage. These were probably picked by the ice-sheet from the crags on the northeast side, and dropped on the southwest side before they could be carried farther.

Ground Moraine. The greater part of the covering of drift which is spread out over the surface is of the kind known as "ground moraine." The ground moraine was laid down chiefly while the ice-sheet was still moving, but was completed by the dropping of more drift to the ground when the ice melted. Ice-laid material in general is called "till." The ground moraine consists of "lower" and "upper" till. The lower till, being of subglacial origin, is firmly compacted by pressure, and well supplied with ice-worn stones, distinguished by their flattened, scoured, and striated faces (Plate XIII B). The upper till is looser than the lower till and is composed of more angular fragments, with a larger percentage of far-travelled stones. This is natural, for the material highest in the ice-sheet would be the last to reach the ground. When studying the dispersion of stones in the drift, shallow sections by the roadside or in brook beds afford the very best material, because they contain fragments from the most distant sources. The percentage of purely local stones in the till varies according to conditions and is especially dependent upon



A. Tilted sandstones and shales, Victoria park, Truro.

B. Glacial till over limestone, North Sydney.

the character of the local bedrock. It ranges from 50 to almost 100 per cent, but is usually as high as 75 per cent. The matrix is sandy or clayey according to the composition of the underlying rock; and it likewise varies from red to grey, blue, or buff. The red Triassic sandstones of the Annapolis-Cornwallis valley and Minas basin impart a bright red colour to the drift of that belt, whereas the drift of the areas of granite and quartzite is grey. The red sandstones of the Devonian, Carboniferous, and Permian systems, also, affect the colour of the drift; and in some places there is enough iron in the slates of the Gold-bearing series to make the drift reddish. This seems to be the case near Bridgewater and Halifax, though in the latter district it is possible that the drift of red colour has been carried across the peninsula from the Triassic area, through the wide gap in the granite belt between Blomidon and Halifax. Conglomerate belts locally supply the drift with multitudes of well-rounded pebbles, which, as already explained, make the direction of dispersion somewhat harder to determine. In the valley of Musquodoboit river, the red Cretaceous (?) clays that underlie the drift give to it a brilliant red colour. Included masses of the red clay look as if they had been frozen at the time they were incorporated in the drift, so little have they been distorted.

Drumlins. In several parts of Nova Scotia the till thickens from ground moraine into hills of a peculiar dome-like form, called "drumlins." Citadel hill, at Halifax, the military centre of the province, and the fortified hills of George and McNab islands are all drumlins. By a curious coincidence a similar condition appears at Boston, where the fortified islands in the harbour are all drumlins. These "whale-backs," as they are sometimes called, are hills of boulder clay, elliptical or oval in plan and arched in profile, with very smooth slopes that seldom exceed 15 or 20 degrees. Although elliptical forms prevail in Nova Scotia, ovoid and cigar-shaped drumlins are common in other places, notably New York state and Wisconsin. In size, drumlins range from knolls 100 or 200 feet broad and 10 or 15 feet high to hills over a mile long and over 150 feet high. In Nova Scotia they are commonly from 40 to 100 feet high, and from one-half to three-quarters of a mile long. The ratio of length to width is commonly about 2 to 1, although in some cases the drumlins are more nearly circular, and in others the ratio is as much as 3 to 1. The top of the hill as a rule occupies a central position, but is always flattish, giving it the appearance of an inverted saucer. The long axis invariably runs parallel to the ice movement. Drumlins occur in groups that vary in number from fifty to many thousands. Ordinarily, drumlin districts have fairly definite limits, owing to the fact that the conditions necessary for them to form are of rather local occurrence. They grow up beneath the moving ice-sheet, under a combined "plastering on and rubbing away process." One of the requirements for their growth is that the drift must contain a large amount of clay, which acts both as a lubricant, allowing the ice to slip over the drift, and as a cohesive agency, causing the clay to stick to the mound which is already started. The building up of a drumlin beneath the ice has been aptly compared to the work of a sculptor who slaps a handful of clay on to his model, and smooths it by passing his hand over the surface. Drumlins are believed to mark a stage of weak erosion, reached late in the period of glaciation, when the ice has thinned down so far that vertical pressure is much reduced although full forward movement is still communicated from behind as a rigid thrust, causing the ground-contact ice to slide gently over its own deposits. In Wisconsin it has been found that the drumlins were built from 7 to 14 miles behind the ice border of their time; and in every region where they have been studied it has been found that they occupy a position near the periphery of the ice-sheet during a late stage of occupancy. It is highly significant, therefore, that we find a great drumlin district in the heart of Nova Scotia, in northern Queens and Lunenburg counties. If the province had been glaciated from a centre of its own, as some have thought, this district would have been the gathering ground of the ice, and would have no drumlins; but if it was glaciated by ice that came from New Brunswick, this district lies far out near the periphery, where drumlins are to be expected. Although this central district has not been fully mapped, and its size is not known, it has been observed that the drumlins are rather closely limited to the areas of slate. Where quartzite appears, drumlins commonly decrease in number and soon vanish entirely. From the top of the drumlin behind Caledonia Corners, seventy-five or more can be counted, rising all around like a school of fish. Most of them are cleared and farmed; but in lake Kejimkujik (Fairy) farther west, along the same slate belt, wooded drumlin islands are numerous. The slate, besides furnishing the plastic clay matrix of the drift, provides a large percentage of the small stones, but almost all the cobbles and boulders that litter the fields are quartzite and granite, imported from adjoining districts. With some considerable interruptions by quartzite areas, this drumlin region extends southward to the coast near Lunenburg and Bridgewater.

A drumlin district only partly detached from the one just described occurs in and around Mahone bay. From Chester to Lunenburg, and from the shore to the outermost islands and shoals of the bay, drumlins are the most prominent element in the scenery. Their graceful curves have been altered in a score of ways by the attack of the waves against their bases, giving them pleasing individuality. Their exposed ends and sides have been sawed off, forming bare cliffs of clay. Spits trail from their submerged ends and sand-bars tie them together in pairs and larger groups. More than 200 drumlins are shown on the map of this district (Figure 8), in various stages of destruction by the sea. It will be seen that with few exceptions they follow the same general southeast course as the striæ. The wide spacing of drumlins around Chester allows the beauty of their outlines to be fully seen. The deep water in which they lie makes ideal conditions for sailing and boating, which are not present at Lunenburg, where the drumlins are crowded on a ragged rock platform which is only slightly below sea-level. The submerged condition of the drumlins near Chester, of course, does not mean that the coast has sunk since it was built. The ice-sheet ran far out to sea and was thick enough to rest on the bottom for a long distance from shore, so that it undoubtedly deposited its morainic material there just as above sea-level. Since the retreat of the ice-sheet, the drumlins most exposed to the sea have been completely cut away, leaving elliptical shoals that show plainly on the Admiralty chart. Between the complete, unmodified drumlin and these ghosts of drumlins, illustrations occur of all stages (Plate XIV).

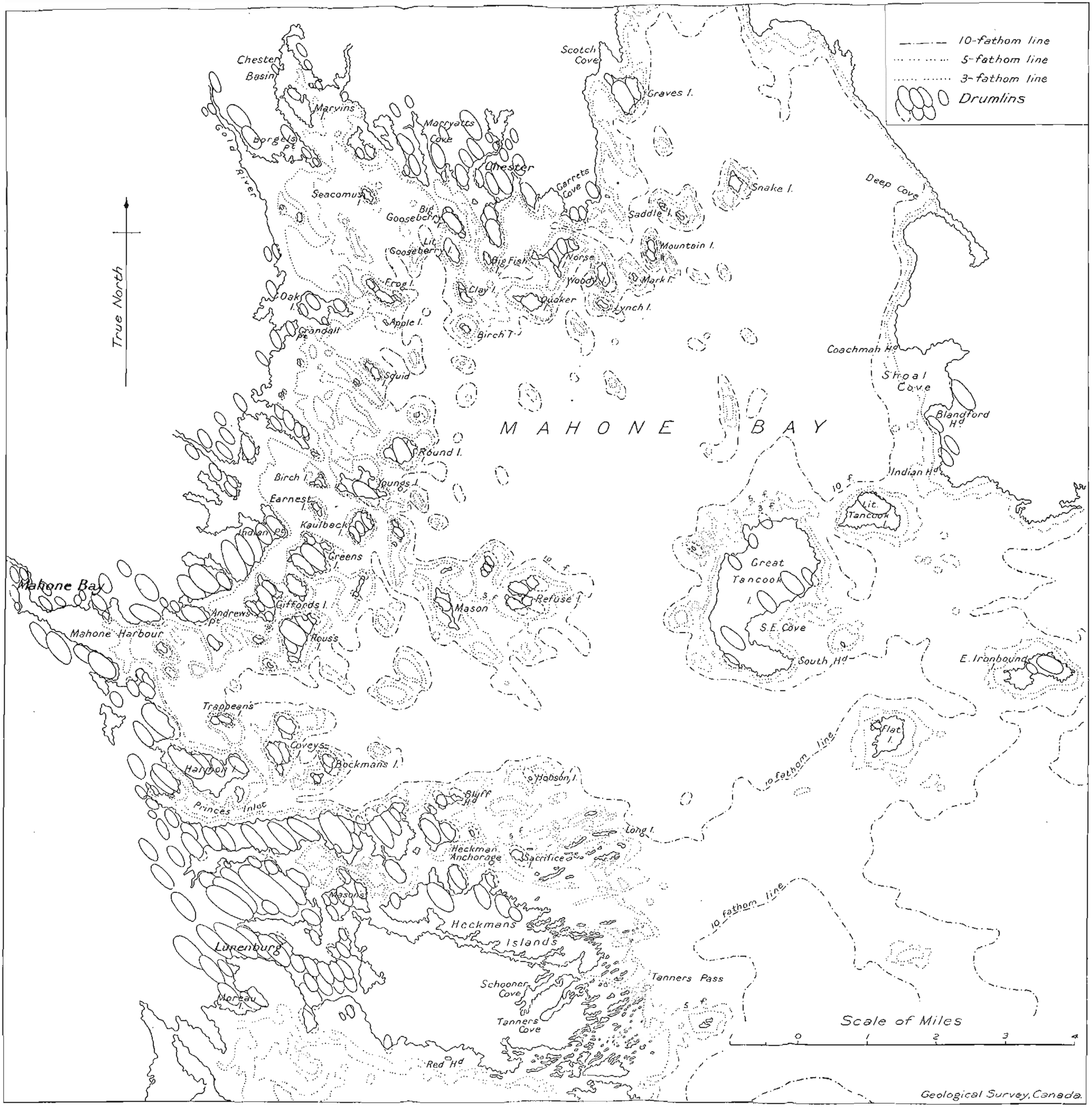


FIGURE 8. Drumlins near Mahone bay.

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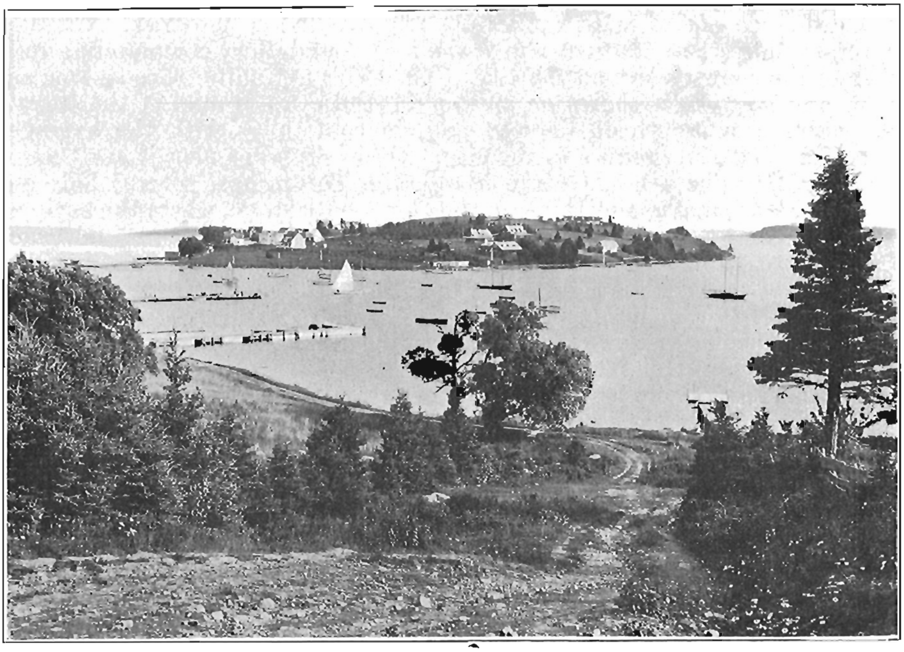
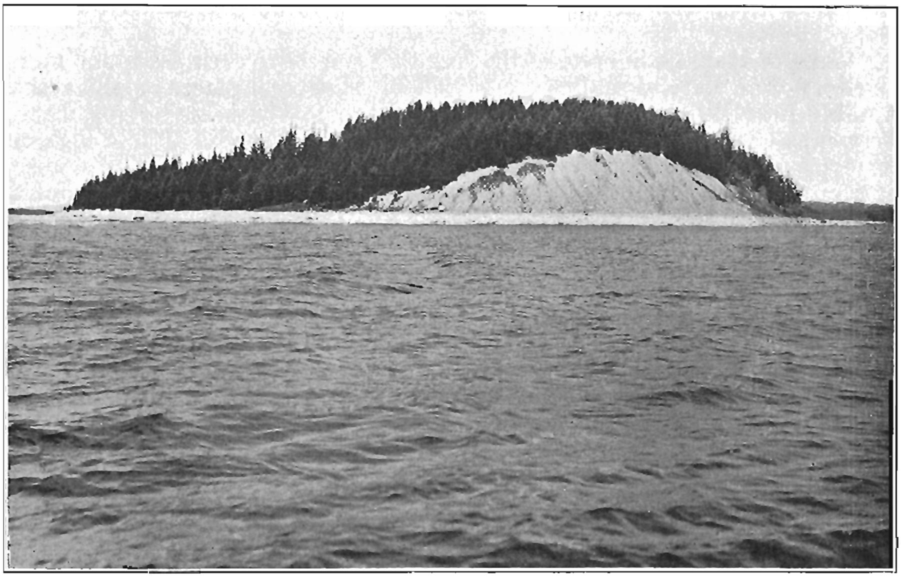


A Drumlins at Chester.



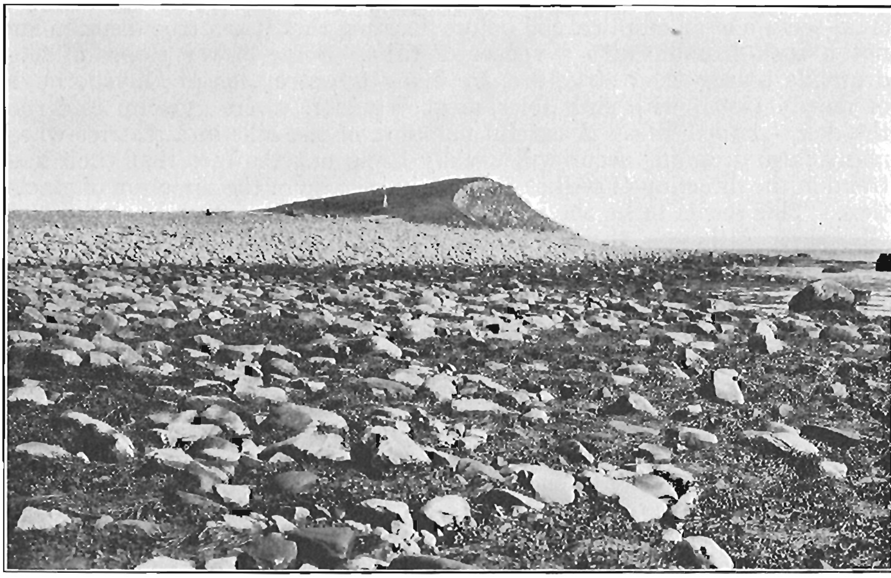
B. Clay island, a cliffed drumlin at Chester.

The drumlin district of Halifax is of very limited extent, though it includes some of the finest individual drumlins in the province. Citadel hill rises more than 100 feet above the rock foundation, commanding full view of the country around the city. The hill is not quite twice as long as wide, and its axis, as shown on an unpublished contour map of the Royal Engineers, runs south 45 degrees east, in conformity with the average direction of glacial grooves in the city. Other drumlins near it are Camp hill, Fort Needham hill, George island, the Thrumcaps, several hills on McNab island, and mount Hope on the Dartmouth shore, where the asylum stands. The smooth, round slopes of Citadel hill and George island have been altered to unnatural, angular forms, by the construction of fortifications. The outer islands have suffered severely from wave-action, particularly Little Thrumcap, of which only about one-third remains (Plate XV A). Their average height is about 80 feet. From all these hills Dr. Honeyman collected North Mountain amygdaloids and other erratic stones. All the drumlins trend parallel to the glacial striæ.

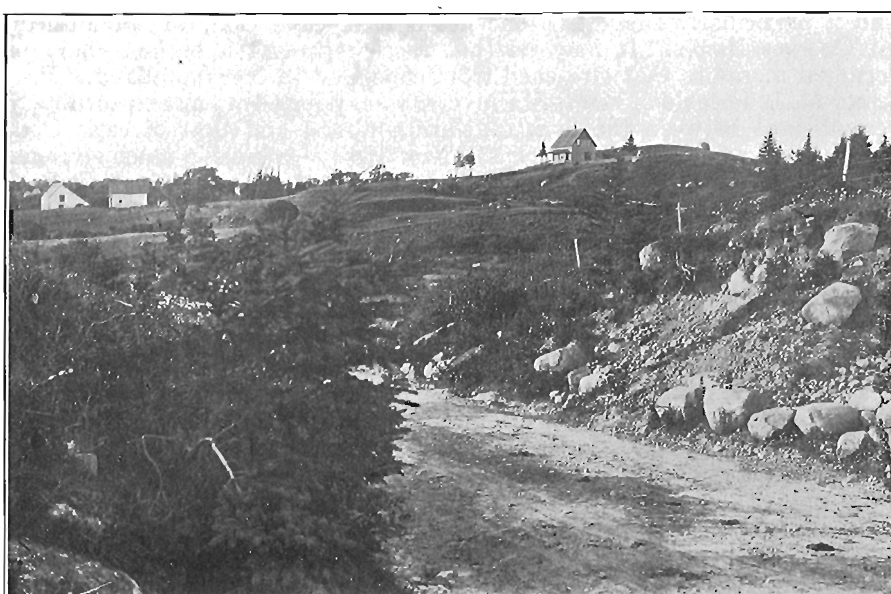
In Yarmouth harbour and elsewhere along the coast of Yarmouth county where slate belts appear, drumlins are conspicuous: one hundred and fifty were counted in that district. Bunker island, close beside the channel of the harbour, consists of a group of drumlins of which the central one, a dome-shaped hill 60 feet high, is the most conspicuous, and is marked by the marine hospital. Most of the Yarmouth drumlins are small and somewhat broader in proportion to length than those of the other districts. They trend almost due south, like the striæ of that district. A little farther down the coast, a "school" of drumlins appears in Tusket islands. The Admiralty chart shows their typical outlines and their cliffed condition. Some have been wholly consumed by the sea, showing only in the elliptical form of the 3 and 5 fathom lines. The drumlin axes swing somewhat to the eastward in this group, reaching south 22 to 32 degrees east on the Bald Tuskets.

East of Halifax, in spite of the fact that quartzite occupies much more territory than slate, drumlins are to be seen at several places on the coast, notably near Wine cove and on the approach to Canso. Glasgow head, near cape Canso, is a splendid half drumlin, with a sea-cliff 50 feet high on its exposed northeast side. Drumlins also occur at the town of Canso, and on the north shore of Chedabucto bay. Cape Argos, a prominent landmark near the south entrance of the strait of Canso, is another half-consumed drumlin. Around St. Peter, on the southeast coast of Cape Breton island, drumlins are numerous, forming cliffed headlands at cape Round and Brickery head. One particularly fine drumlin is crowned by a tall church at River Bourgeoise. Its axis runs south 58 degrees east, in agreement with Fletcher's observations of striæ in this part of Cape Breton. Carboniferous shales and limestones are responsible for the development of drumlins here. The isthmus at St. Peter, which separates Bras d'Or lakes from the sea, is largely composed of drift, massed into fairly complete drumlin forms; but St. Peter canal crosses the isthmus at its east end, where bedrock comes to the surface.

It is not easy to distinguish true drumlins from those imitative forms described on page 52, which have been called false drumlins or "roc-drumlins." These drumlin-like hills of shale occur in many parts of the



A. Little Thrumcap, Halifax harbour.



B. Morainic drift deposits, Shelburne.

province, being extensively developed around Windsor, Truro, New Glasgow, and Guysborough. It is usually necessary to see a complete cross-section of an elliptical hill before deciding that it is a true drumlin and not a rock-drumlin with a veneer of drift. Some of the slopes of false drumlins betray their structure, by being too steep, as at Guysborough, or deeply pitted with sink holes, as at Windsor, where gypsum underlies the dome-shaped hills. A careful mapping of the hills in a district where many false drumlins occur will usually bring out the fact that their axes trend in the direction of strike of the rocks instead of the direction of glaciation. This seems to be the case in the Windsor district and around New Glasgow. Although there is a fundamental difference between a true drumlin and a typical rock-drumlin, examples of all sorts of intermediate types can be found; for the process which has moulded the hills into their arched forms is the same as that which shaped the drift; and decayed shale is almost as plastic as boulder clay. It is not uncommon to find both true and false drumlins in the same district.

Terminal and Recessional Moraines. Glacial drift and scoured and striated ledges are to be seen on all the islands off the south coast of Nova Scotia, and on even the highest hills in that district, and it, therefore, appears probable that the ice-sheet was thick enough on the coast to continue its advance far out to sea. Unfortunately, it is not known just how far out this movement continued, or whether the ice front halted at its outer limit long enough to build a terminal moraine, like that traversing Long island, Marthas Vineyard, and Nantucket, off the south coast of New England. Certain long ridges or swells on the banks, which are imperfectly shown on the charts, because of the scarcity of soundings, appear both off the mouth of the bay of Fundy and the gulf of Maine; and a particularly suggestive one lies east of cape Cod, Massachusetts, on Georges Banks. It may be that these represent a broken chain of terminal moraines that stretched from cape Cod to Newfoundland. Professor M. L. Fernald of Harvard University has pointed out an extraordinary resemblance between the flora of Newfoundland and that of cape Cod, Long island, and the sandy barrens of New Jersey—a kinship much stronger than that between the flora of Newfoundland and that of Cape Breton, although these two islands are separated by a strait only 70 miles wide. Certain small mammals on Newfoundland, also, resemble those of New Jersey more than those of the Maritime Provinces. This is regarded as good ground for the belief that there was a land connexion between cape Cod and Newfoundland at some time since the last glaciation—a connecting chain of sandy ground, along which plants peculiar to sandy soils had a chance to migrate northward into Newfoundland. The rapid destruction of Sable island by the sea during the last century suggests that it is the last remnant of a long line of sand-bars which formed on a moraine during its destruction by the sea. It is possible, too, that there has been a sinking of the coast or a rising of the sea-level, since the last glaciation, which has aided the sea to cover and plane away the higher parts of the moraines. It is well known that gravels from distant sources occur on the banks. Formerly it was supposed that the Grand Banks owed their existence to stony material that was dropped by southward-drifting icebergs meeting the warm waters of the gulf stream. Though contributions of this kind have undoubtedly been made to the surface of the Banks, it is certain that fundamentally they are a continuation of the coastal plain that extends up the Atlantic coast from the gulf of Mexico to New Jersey and dips beneath the sea in southern New England. In view of the seaward movement of the ice-sheet, both in the New Brunswick and the Acadian Bay lobe, it is probable that much if not most of the crystalline pebbles found on the banks off Nova Scotia and Cape Breton were brought there by the continental glacier and not by floating ice.

Terminal moraines, when well developed, appear as belts of hills running in a course nearly perpendicular to the glacial striæ, and characterized by extreme irregularity. The short hills and deep hollows that distinguish them have been likened to potato hills, but they are without straight alignment. No such moraines have been seen by the writer in Nova Scotia. Deposits suggestive of morainic conditions are very fragmentary, and poorly developed. Near the coast in Shelburne county, particularly around Shelburne and Port Clyde, there are many ridges and hummocks, chiefly of coarse gravel, but in some cases abundantly strewn with boulders (Plate XV B). They suggest the "knob and kettle" topography of terminal and recessional moraines; but as far as discovered, they are not grouped in lines that would conform to ice borders. In several parts of the province, including Cape Breton island, one may see hummocky topography of quite another origin, the kind that characterizes the gypsum districts. These false "plaster" moraines are in some cases hard to distinguish from true terminal moraines; but a useful criterion is the presence of very small pits and hollows, less than 20 feet in diameter, which never occur in glacial moraines but are just as likely to appear in gypsum ground as are the larger ones.

In the water gaps of the Cobequids and North mountain are thick deposits of gravel that appear to be somewhat morainic in character, but these may be more appropriately treated under the heading of "kames."

Stratified Drift

Much of the debris contained in the ice-sheet was sorted by running water. Rivers issuing from the stagnant decaying ice as it melted away washed out large quantities of gravel, sand, and clay, dropping the coarser material along their beds, both within the ice-sheet and beyond its borders. Where temporary lakes occupied depressions between the ice-sheet and surrounding hills, the sediment delivered through these overburdened streams accumulated in deltas or bedded deposits of less definite form; and in those places where the ice was withdrawing from estuaries, extensive tidal flats of sand, not unlike those of the bay of Fundy, were spread out. There is, therefore, a great variety of stratified drift deposits, consisting of waterworn material assorted according to size, but carrying stones of the same types as are seen in the boulder clay. The greater part of this stratified drift occupies the low ground, where water was operative. Among the types of deposits found in Nova Scotia are eskers, kames, kame terraces, deltas, and estuarine plains.

Eskers, Kames, and Kame Terraces. Eskers are narrow ridges of gravel and sand, some several miles long. They are steep-sided and narrow-crested, somewhat resembling a railway embankment, but more crooked and uneven. They are commonly from 15 to 30 feet high, but may exceed 100 feet. As a rule they follow the valleys, in courses that trend parallel to the striæ. A good description of an esker or "boar's back" that runs along the west side of Hebert river in Cumberland county, north of Parrsboro pass, is given by Sir William Dawson in his "Acadian Geology."

"It is a narrow ridge, perhaps from 10 to 20 feet in height, and cut across in several places by the channels of small brooks. The ground on either side appears low and flat. For 8 miles it forms a natural road, rough indeed, but practicable, with care, to a carriage, the general direction being nearly north and south. What its extent or course may be beyond the points whereon the road enters or leaves it, I do not know; but it appears to extend from the base of the Cobequid mountains to a ridge of sandstone that crosses the lower part of the Hebert river. It consists of gravel and sand, whether stratified or not I could not ascertain, with a few large boulder stones."

Eskers are stratified, although the bedding can be seen only in a fresh cross-section, being quickly obscured by sliding of loose gravel. Their origin is made clear by studies of living glaciers in Alaska and other regions where eskers can be seen under construction. They mark the channels of heavily laden rivers flowing through the ice-sheet either in ice canyons, open overhead, or in tunnels concealed by an ice roof. Ordinarily these rivers run on the ground, at the base of the ice, although they are fed by streams from higher levels, which pass down through holes and crevasses. As the ice walls melt away, leaving the channel deposit unsupported, the gravel slides or caves, until it has assumed the angle of repose. This is from 30 to 50 degrees, according to the coarseness of the material. Eskers in many places unite or branch, as did the rivers which built them, and in many places begin and end abruptly. They bend from side to side like crooked streams and rise and fall, as a result of differences in the height of filling of the stream bed, or because of local reduction of the crest-line by caving. In a distance of a few miles, an esker usually has several gaps or interruptions. Some of them are original gaps in the deposit, due to spasmodic growth from season to season; others are due to erosion which they have suffered since the Ice age, from streams attacking one side or the other. Their tendency to follow natural lines of drainage plainly shows that the rivers issuing from the ice-sheet were guided beneath it by the topography which the ice covered. It is a common condition for an esker following a valley to run up to its head, pass across the watershed, and descend a valley on the opposite side; for while the watershed was still covered by the ice the larger subglacial rivers crossed it at the lowest points; and as the ice front retired from the divide the same line of drainage came to be marked by a line of esker building.

The question whether an esker which runs, say, north and south, was formed by a river which flowed toward the north or toward the south, is not always easy to answer, where doubt exists as to the source of the ice and the direction in which its front retired. For instance, the Hebert River esker already described, which lies on the north side of the Cobequids, in line with and extending to the head of Parrsboro pass, must have been made by a northward-flowing river if the Cobequids constituted a local centre of glaciation at the close of the last glacial epoch; but it must have been formed by a southward-flowing river if the Cobequids were uncovered by ice which retired to form the Acadian Bay lobe. If, therefore, the source and mouth of this esker river are determined, additional evidence bearing on the much discussed question of the local ice cap on the Cobequids will have been obtained. Now, the Hebert River esker lies on Carboniferous sandstone and conglomerate throughout its length, although at the end nearest Parrsboro pass it is only 3½ miles from the felsite and granite belt of the Cobequids. As Dawson and Chalmers have testified, the waterworn stones in the "boar's back" are wholly of sandstone and quartzite from the local formations; no Cobequid felsite or granite is to be found in it. Moreover, the gravels in certain mounds or kames at the northwest and southwest corners of Halfway lake, only 1 or 2 miles from the crystalline area, are wholly of rock types from the north. The river which built the kames and the esker, therefore, evidently flowed southward, *showing that the ice sheet was retiring northward* from the Cobequid range across the Cumberland lowland. In the pass are other deposits presently to be described, which indicate clearly the southward flow of this ancient river.

Another line of kames or "boar's backs" occurs north of Pictou, reaching from near the mouth of Mill brook 3 miles in a southeasterly direction to near McKeen's quarry. It contains some pebbles of granite, syenite, diorite, and felsite from the Cobequid range, as well as the local grits and sandstones, which is to be expected from the fact that this locality lies within the eastward trail of Cobequid rocks, and that its boulder clay is well supplied with them. The southeast course of the esker, however, is evidence of a final movement of the Acadian Bay lobe from the north, and corroborates the evidence of the cross striæ and two drift sheets at Hardwood hill, and the dominance of north-south striæ and southward drift dispersal over this part of the province. Hundreds of eskers occur in Nova Scotia, and undoubtedly there are many whose length equals that of the few examples here described.

On Cape Breton island, likewise, eskers are well developed in lowland belts where glacial rivers were confined. A long chain of esker ridges and less regular kames follows Sydney river from Fork lakes near East bay to Sydney bridge, making long, narrow points and islets in the South arm. If the last movement of ice here was towards the northeast, in the direction of striæ and dispersion of stones, the river which made this esker flowed northward into Sydney harbour. Near Sydney bridge the ridge merges into a kame terrace.

Kames are steep-sided mounds or banks of gravel and sand which accumulated in contact with the ice edge. The most conspicuous of these are the mounds and terraces which appear in water-gaps, where there was concentrated drainage during the melting out of tongues of ice. In Parrsboro pass, some kames near Gilbert lake which are linear in form and run parallel to the gap are probably esker-like in their origin. Just south of Gilbert lake, however, the mounds seem to be grouped in an irregular line, transverse to the gap, forming the present drainage divide between Hebert and Parrsboro rivers. It looks as if a tongue of ice had rested in the pass for a while, during the withdrawal of the ice-sheet from the Cobequids, so that an unusually large accumulation of gravel got banked up in one place, in a rudimentary terminal moraine. On the sides of the pass are several distinct though discontinuous terraces, formed by the deposition of gravel along the hillsides, draining southward to the head of a great gravel plain at Parrsboro. This plain is a large delta, spreading over several square miles. It declines steadily towards Minas basin, reaching it at an altitude of about 60 feet. Parrsboro river has cut a step-like series of broad terraces in it, after the manner of rivers whose deltas have been raised above the level of the water in which they formed. The terraces have been mistaken for sea-cliffs; but the concave outline of their escarpments and the way in which these face the meandering river instead of the coast make their origin certain.

In Folly Lake pass the conditions resemble those just described, although no great delta has been formed at the south end of it. Several small kames appear near Wentworth, in line with the gap, suggesting a former river course through it. Farther up the valley larger kames take form, developing into a great mass of mounds and ridges at the north end of Folly lake. The mounds in the middle of the gap are sandy and gravelly; those on the side where cut by the railway are stony but unstratified. The whole group has the appearance of a rough moraine, damming up the lake at its north end. There must be considerable seepage of water from the lake through the kames; for large springs with rather constant flow feed the head of Wallace river only a few hundred yards from the lake. There is a similar moraine at the south end of the lake, through which the outlet runs into Folly river.

Deltas and Other Outwash Plains. The city of Truro stands on a broad, gravelly plain about 60 feet above sea-level, which appears to have been spread out by Salmon river and other streams at a time when they were overfed with gravel from the melting ice. Judging from the flatness of the plain, Cobequid bay was then about 60 feet higher than now. The great delta at Parrsboro, mentioned above, corresponds closely in height to this plain. As will presently be shown there are other reasons for thinking that this part of Nova Scotia has risen as much as that since the departure of the ice.

The most interesting example of stratified drift in the whole province occurs at Sandy cove, on Digby neck. This broad gap in North mountain, instead of being swept by tides is blocked by a great gravelly plateau, whose flat top stands about 125 feet above the sea. On the Fundy shore, in a great 125-foot cliff, behind the beach, the stratified structure of the plateau is plainly shown. Sand, composed of fragments of pink chalcedony and red jasper, is arranged in strata that dip south 50 degrees west at an angle of 20 degrees. This stratified structure looks like that of a deep delta built in the gap as the ice melted away from it. Near the middle of the gap this great plateau is interrupted by a huge hollow of irregular outline and steep sides. A pond occupies the bottom of the hollow, oddly-shaped kames rise around its borders, and one esker-like ridge projects far into it, nearly bisecting the pond. Plainly, this is a great ice block pit or "kettle hole," marking the site of a mass of ice which was enveloped by the deposit. What makes the deposit most interesting is the fact that shells are reported to have been found in it at two places in the village. The ground where the shells were found, at a depth several feet beneath the surface, is only 20 or 30 feet above the present sea-level; but the continuity of the plateau structure, the flatness of its top at 125 feet, and the presence on Brier island of marine beaches at 120 feet leave little doubt that the deposit was originally marine. The preservation of the steep side slopes of the kettle-hole, and of the kames around it, seems to require that the mass of ice lingered until the deposit had been elevated to its present position. If the ice had melted out from the depression while it was still beneath the sea, only a short period of submergence would have sufficed to erase the details of kame topography, by washing down their side slopes. It appears, therefore, that the emergence of the region, at the close of the Glacial period, was rather rapid, coming immediately after the ice-sheet retired.

COMPLEXITY OF THE GLACIATION

In the opening paragraphs of this chapter, mention was made of the occurrence in Ontario and elsewhere of a number of drift sheets of different ages, separated by deposits whose fossil contents suggest that there were long intervals of temperate climate between successive advances of the ice. In the states west and south of the Great Lakes, detailed investigations have led to the view that there were three or more distinct epochs of glaciation; and that during the last one the ice-sheet spread first from a centre west of Hudson bay, and later from a centre in New Quebec. In New England the record is not nearly so complex. Over most of that region only one great southeastward movement of the ice is recorded by the drift and erosional forms. The last advance of the ice over New England seems to have wiped away the records of earlier epochs. But on Long island and others off the south coast of New England, the last, or "Wisconsin," drift is seen lying on top of at least two earlier drift sheets which are commonly assigned to earlier epochs. In White mountains of New Hampshire, "cirques" or amphitheatres were carved by local glaciers, like those of the Alps, chiefly, it seems, before the last advance of the "Wisconsin" ice over the region. This condition of local mountain snowfields may have occupied merely the early part of the last glacial epoch, or it may have occupied an entire epoch of earlier date, when there was no general ice-sheet over New England.

In Nova Scotia the record is still more obscure, for the terminal moraines have been destroyed or drowned by the sea, and thus the most promising key to the solution of the question of successive epochs has been lost forever. Within the limits of the land as it is now seen, there are only a few very obscure indications of more than one drift sheet. Mr. W. C. Prest has called attention to an iron-cemented glacial gravel which he calls the "Bridgewater conglomerate," and which he regards as the remnant of a drift older than the last. This is exposed in many places near Bridgewater, Maitland, Greenfield, and Halifax. Wherever it occurs in the Southern upland it lies on top of a ledge of iron-stained slate, and is composed largely of pebbles of this slate. There seems to be no reason why it should not be regarded as simply part of the glacial gravels which, because of an unusually high content of iron, have been cemented into rock. The slate is known to be rich in iron; and the formation of a cement in gravels of "Wisconsin" age is by no means uncommon in New England. There are many cross-sections where this Bridgewater conglomerate is overlain by unconsolidated kame gravels, but none in which typical ice-laid drift appears above it. Even if there were such a section, it would justify the conclusion merely that the gravels antedated the last advance of the ice-sheet; and this does not require an earlier glacial epoch, since gravels are likely to be spread out in front of an ice-sheet, when it is advancing, as well as behind it when it is retreating. A section that illustrates this point can be seen in a cliff on the shore just west of Arisaig. At the base of this cliff, behind a narrow beach, slate outcrops to a height of 10 feet. Above it is a 30-foot thickness of stratified sands and gravels that are full of pebbles of the underlying slate. They rest on a nearly horizontal surface that truncates the edges of the upturned slate beds. They appear to be beach sands, recording a time when the coast was submerged to a greater depth than now, but no shells have been found in them. Next above the gravels and sands is a sheet of glacial boulder clay, 20 feet thick. It is red, and contains many ice-worn stones, including types foreign to the locality. It is the characteristic drift of this district, and appears from its red colour and its association with the southward striæ to have come from the north, over Prince Edward Island. This ice-laid drift is capped by about 8 feet of coarse, cobbly gravel and sand, entirely unlike the lower gravels in that they show abrupt alternations between coarse, cobbly beds and very fine sands—a feature which marks them as deposited by temporary glacial waters during the withdrawal of the ice from the coast. The details are given here chiefly to show that such sections as this can not fairly be used as evidence of more than one ice advance.

The section of drift at Hardwood hill, described on page 79, may be of greater significance. The reddish drift at the top of the section suggests a source in the north, in agreement with the observation that the southward striæ on the hill are the most recent. The grey drift which underlies this and contains a large number of Cobequid stones appears to have come from the west, at the time the earlier, eastward striæ were engraved. There is a danger, however, of mistaking the oxidized soil zone, at the top of the section, for an upper sheet of drift; and more observations of this kind are highly desirable.

If the striæ in the various parts of the province have been correctly correlated, and the dispersion of the drift correctly analysed, they agree in showing that both the eastward movement and the subsequent southward one were of great extent, the earlier advance from New Brunswick reaching to the eastern end of Cape Breton island and the later advance of the Acadian Bay lobe covering the northern part of the province from northern Cape Breton to the head of the bay of Fundy. Although the overlapping of these two lobes in Cumberland, Pictou, and Antigonish counties, and on Cape Breton island, is very considerable, it cannot be asserted that on that account the two movements mark two separate epochs. It is interesting to find, however, that here in Nova Scotia, as in the middle west, the later movement sprang from a centre farther east than the earlier one.

EFFECTS OF GLACIATION ON DRAINAGE AND SHORE-LINE

The extensive dissection of the surfaces of both uplands and lowlands in a pattern which shows that the sculpturing was done mainly by rain and rivers, and that glaciation was only an incident, indicates that at the beginning of the Glacial period river systems everywhere became maturely developed. Few lakes can have existed under those conditions; for lakes quickly disappear while river systems are growing to maturity, being either drained away by the deepening of their outlets or filled up by the deposition of sediment and the growth of vegetation. The ponded condition which characterizes so much of the Southern upland today, where bogs, ponds, and stillwater stretches occur in endless repetition, is a direct result of the passage of the ice-sheet across the region, leaving its load of ill-assorted rubbish scattered without respect to the operation of running water. The old drainage lines were dammed at thousands of places, and the rivers thoroughly disorganized. Thus the present unsystematic and inefficient systems of drainage were substituted for the earlier ones. Though it rendered large tracts of country unfit for use, by converting them into shallow lakes or morasses, the ice compensated for it somewhat by directing the streams over ledges and thus developing hundreds of waterpower sites. The possibilities of this waterpower are just beginning to be realized.

Innumerable cases of diversion of river branches from one trunk to another, by blockades of glacial drift, might be discovered in Nova Scotia. It is not likely, however, that there is any more important case than that which has been described as occurring in Parrsboro pass, where the diversion was caused by a low kame moraine.

The evolution of the shore-line is treated in Chapter V. The idea that the ice-sheet carved out the valleys which indent the southern coast is, it should be noted, a mistaken one. These valleys are plainly the work of rain and rivers during the period preceding the Ice age, drowned and subsequently altered in detail, only, by the activity of the ice-sheet. They are not true glacial fiords like the famous fiords of Norway and Alaska.

CHAPTER V

SHORELINE

The history of the development of the shoreline of any region is more complex than that of its surface; for at the shoreline the surface, fashioned by rain and rivers and glacial action, has been brought into intimate contact with another group of agencies, of which waves, tides, and currents are chief. In the main, the shoreline of Nova Scotia has been produced by a subsidence (relative or actual) of the coast, which caused the sea to advance over the outer part of the maritime region until it reached the present level. Lowlands have been submerged to form shallow banks and bay floors; valleys have been drowned, so that the sea extends far up their trunks, in long estuaries, and isolated upland areas and summits have been converted into islands. But close observation shows that the shoreline is more than this. Its irregularities, estuaries, bars, islands, and other details show forms not fashioned by rain and rivers or by ice-sheet. These are products of the sea, operating through waves, currents, and tides.

INITIAL FORMS DUE TO SUBMERGENCE

First, picture Nova Scotia as it would look if the sea were to return to the outer edge of the continental shelf, where it was before the Ice age, that is, to the 100-fathom line. The province would then appear as the central, elevated part of a great triangular region which may be called the Acadian peninsula, occupying the space between the great, deep estuary of St. Lawrence river and the gulf of Maine, and merging westward into New Brunswick. The bay of Fundy would be represented merely as a short arm of the gulf of Maine. Across the narrow mouth of this gulf, to the south, a broad, spoon-shaped plain, now George banks, would reach out from the coastal plain of New Jersey and southern New England, almost meeting Browns bank off cape Sable. On the other side, across the broad estuary of Cabot strait, an island of grand proportions would include Newfoundland and the Grand Banks. To represent correctly the original relation of land and sea in this region, it must be imagined that the sea falls still lower; for the continent at one time stood so high, in this region, that the St. Lawrence reached the sea at the outer end of Cabot strait, now 1,500 feet below sea-level. The evidence of this great change of level lies in the form of the St. Lawrence itself. The submarine St. Lawrence canyon has the same flaring form as a river-carved valley. Tides sweeping up and down the mouth of this river could never have so greatly deepened it. The only adequate explanation is that a change of about 1,500 feet in the relative level of land and sea has flooded hundreds of miles of the lower St. Lawrence valley that were once dry land. Nor is the valley form of the great estuary, alone, the basis for this belief in a great submergence. On each side of it are branches similar to the main valley in outline, just as branch valleys resemble the main valley in a river system. These submerged valleys head at the mouths of rivers shorter and smaller than the St. Lawrence and in nearly every case the estuary is the seaward continuation of a visible river valley. So, off the Gaspe coast, where the 50-fathom line shows a valley as clearly as if it were 300 feet above, instead of 300 feet below, the sea, it is evident that this is merely the outer part of the Chaleur Bay estuary, the mouth of the old Matapedia River system. A similar drowned valley appears off the northwest coast of Cape Breton island, heading near the east end of Northumberland strait; and a third lies north of Sydney. Naturally, only the very longest drowned valleys are apparent on the Admiralty charts, since submarine contour mapping is a science that necessarily deals with a limited number of plotted measurements, and the topographer cannot see the forms that he is drawing. If there were half as many measurements on the sea-floor as are required on the land, to make a contour map, the chart would have infinitely more detail than it has, and would reveal smaller, drowned valleys, all around the coast. It is true, however, that the sea has smoothed its floor a great deal; and consequently some of these drowned branch valleys would be obscure even if exposed to view. Since there is a lack of satisfactory illustrations of the totally submerged parts of the smaller river valleys, the half-submerged parts which show plainly on the coast-line as mapped on the Admiralty charts will have to be observed. A variety of valley patterns will be found among these estuaries. Take, for instance, a group of which Avon river at Windsor is a good type.

DROWNED VALLEYS OF THE AVON TYPE

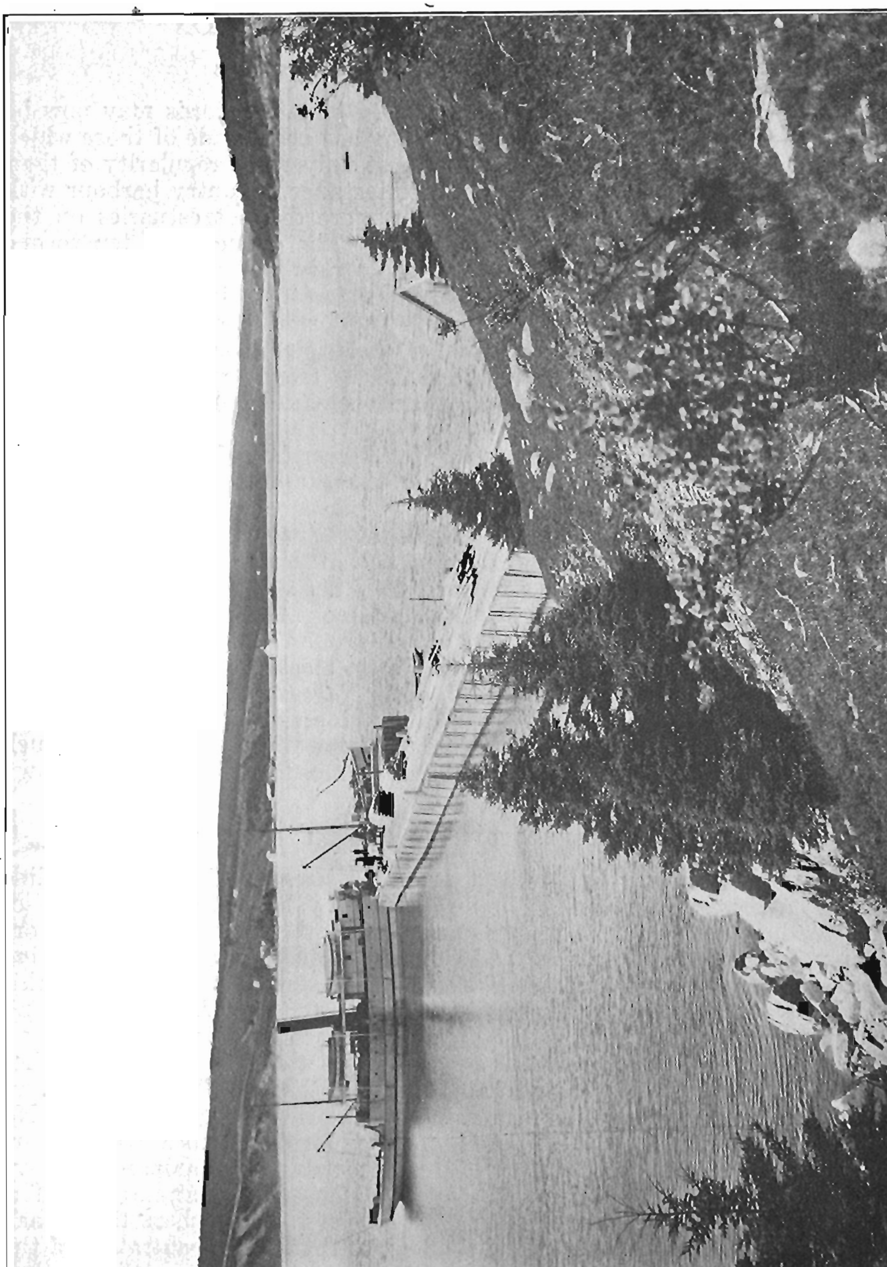
Although this "river" and its branches are not rivers, properly speaking, but tidal estuaries, their resemblance to a river system is unmistakable. Moreover, the system has its source in the real river valleys of the Kennetcook, St. Croix, and Avon. Like valleys in a normal river system, the estuaries meander in graceful curves, become wider and deeper toward their mouths, and join with their axial lines converging slightly down-valley. At the head of each branch estuary, whether large or small, is a river valley of proportional size. Were the sea-level to be lowered 50 feet, the present shore-line would make a perfectly typical 50-foot contour for the branching system of river valleys. Obviously, the modern Avon is the half-drowned trunk of a well-developed river system. It is not possible to say how great a change of level it registers, inasmuch as the estuary has been partly filled up with mud by the tides, and its floor is doubtless much nearer the surface now than it would otherwise be. Lest it be objected that the Avon system has been eaten out by the 35-foot tides which sweep in and out of it every day and night, with extraordinary vigour, let us look at other systems which show the same characteristics, though they occur where tides are relatively weak.

Sydney harbour, Cape Breton, with its northwest and south arms, bears a close resemblance to the branching Avon. At its upper extremities, to be sure, the outlines of the arms are less perfect in form; owing to obstructions of glacial drift described on page 99. There is the same seaward enlargement of the estuary and the same convergence of branches in a direction down valley, where they come together like the two arms of a letter "Y," with the sea at the bottom of the letter. Yet in Sydney harbour the tides have a vertical range of only 4 or 5 feet, and their work as scouring agencies is negligible. Finally, to settle the question beyond dispute, estuaries of the same pattern can be found around Bras d'Or lakes, where the range of tide is only about 18 inches, as at Denys basin. This cannot possibly be assigned to tidal agencies. Obviously, it cannot be supposed that these estuaries have been carved out by the seaward flow of upland rivers which enter their heads, for the discharge of the rivers is small and their seaward flow is so weak that it appears to be utterly inadequate for so great a task. The estuaries increase in width seaward, at a rapid rate, without any accompanying increase in discharge of water through them. Evidently, neither tides nor river sculpture, alone, can explain them; and the explanation must be adopted that they are river-carved valleys, into which the sea has risen during some period of submergence of the coast.

DROWNED VALLEYS OF THE COUNTRY HARBOUR TYPE

Inasmuch as river valleys develop a variety of patterns, under different conditions of structure and slope, so the drowned valleys or estuaries of Nova Scotia exhibit many variations from the typical arborescent pattern of the Avon, Sydney, and Denys. Thus Country harbour and Indian harbour (Plate XVI) in Guysborough county appear on the map as long, rather straight valleys which increase steadily in width, seaward, and have few branches or none at all. This straightness and simplicity are due in some cases to the fact that the valley is located on a fault-line. In the case of Country harbour its floor is flattish, but its sides are steep and high. Along its northeast side, a chain of low, gravel mounds or kames makes the shore-line ragged. Guysborough harbour is another drowned valley of this single, simple type, but it is less regular in outline, owing to drumlinoid hills that partly block its path, and a wave-built barrier at its mouth. Lahave, Port Medway, Liverpool, Sable, and other rivers west of Halifax belong to the Country Harbour type. It is indeed characteristic of the south coast estuaries that they are single instead of multiple, whereas the estuaries of the lowlands, like the Avon, Pictou, Wallace, Antigonish, Sydney, and many others have a marked tendency to be arborescent. In these two contrasted habits—the arborescent and the simple—the influence of rock structure on river sculpture is apparent, as suggested in an earlier chapter. Where rocks are so gently warped that a single formation or a group of formations of uniform hardness outcrops widely, the headward growth of river valleys is likely to be attended by frequent branching, and if the general slope be moderate, by growth along winding and divergent paths. An arborescent or dendritic system is the result. But when closely folded structures are crossed by the river systems, as the Gold-bearing slates and quartzite are crossed by the rivers of the Southern upland, these streams are likely to be held to their original courses by the resistant belts, and to develop branches only along the weak belts, so as to produce a trellised pattern. Since glaciation here has not wiped out nor buried the trunk valleys, but has generally obscured the trellised network of tributary streams, converting it into a confused patchwork of bogs, the "posts," only, of the "trellis" remain, in the simple form already shown.

PLATE XVI



Drowned valley harbour, Port Hillford.

INITIAL FORMS DUE TO GLACIATION

IRREGULARITIES DUE TO DRIFT DEPOSITS

The more marked eccentricities of these so-called fiords may now be examined—for until now, a careful selection has been made of those which are simple and symmetrical, and the almost universal irregularity of their outlines has been ignored. Compare, for instance, Country harbour with almost any other one of the hundred or more distinct estuaries on the coast between cape Canso and cape Sable. The chances are ten to one that an estuary chosen at random will show very pronounced departures from the type. It may have the same general form, but it will be extremely ragged and broken. For instance, there is Porter lake 15 miles east of Halifax. The elliptical form of some of the projections and islands near the south end of this "lake" and the southeast trend, even as seen on the small scale map (No. 22A), issued by the Geological Survey, suggest that they are drumlins.

The irregular isthmus that separates Porter lake from Threefathom harbour, with curiously scalloped outline, consists of a group of drumlins, so distributed as to close the mouth of the drowned valley. The larger scale map-sheet (No. 39A) of the Geological Survey discloses the fact that the lower end of Porter lake lies in a belt of the drumlin-making slate, and that one of the peninsulas referred to is named "Boars Back point." Here is a cause for great diversity of shore-line. Deposits of glacial drift in a concentrated form of drumlins in and around these drowned valleys lead to individualities of outline which almost mask the form produced by drowning. The slight variations of outline due to kames in Country harbour and Sydney harbour, drumlins and drumlinoid hills in Porter lake and Guysborough harbour (Figure 12), give the reasons for the much greater variations which are to be found in most of the estuaries shown on Map 2006.

IRREGULARITIES DUE TO GLACIAL EROSION

By erosion, also, the ice-sheet produced irregularities in the outline of the bays. It was pointed out in Chapter IV how the stripping off of the weathered mantle from the upland surface, the hollowing out of more deeply decayed spots, and the reshaping of projecting knobs by plucking and abrasion gave a new aspect to the hills and valleys. Where this glaciated topography stands knee deep in water, its abnormalities and eccentricities find expression in odd, rocky projections, indentations, and islets, which are more prevalent on this coast than drumlins and other drift forms. In these features are seen the last touches which were applied to make the coast as ragged in detail as in its larger outlines. No very large amount of glacial erosion is required for it, no more than appears on the unsubmerged part of the surface. Probably the topography above and below sea-level suffered just the same amount of alteration. The relief along the south coast is low; most of the valleys, where they reach the sea, are broad, wide open, and shallow, so that no concentration of the ice-flow will be looked for in them, and hence no local deepening like that which shows plainly in the glaciated fiords of Greenland, Norway, and Alaska. Of the estuaries whose depth and steepness would be most likely to favour fiord carving, Country harbour is perhaps the best on the south coast. The soundings on the Admiralty chart reveal the fact that the floor of this deep estuary slopes very steadily seaward, exhibiting none of those rock basins and intervening ledges which a local glacier leaves when it deserts a glacier-carved fiord. Even such deep, canyon-like valleys as South bay, Ingonish, and Mabou harbour show no local over-deepening by ice.

The estuaries that lie on the granite areas are somewhat less systematic in plan than those on the bedded rocks. The valleys are less definite in trend; their outlines seem accidental. Granite seems to encourage a certain ragged outline on account of the difficulty which rain and rivers have in excavating the massive structure. The irregularity is increased, under glaciation, because of the removal of the residual mantle, which reached down to different depths, and because of the quarrying action of the glacier on massive, jointed rock. But care must be taken not to attribute too much of the irregularity to glacial erosion. The existence of typical drowned river valleys like the Avon, Sydney, Pictou, and Country harbour makes it unlikely that the ice-sheet did more than alter the minor details of valley and coast-line. Even certain trough-like hollows in the drowned water-gaps at Digby and cape Blomidon, which look suspiciously like the work of accelerated ice currents within the great ice-sheet, prove to be the product of tidal scour, as will presently be seen.

Among the abnormal features of the south coast, none is more strange or difficult to account for than Bedford basin, which drains through the narrows into the head of Halifax harbour. Unlike the Northwest arm, which is a typical narrow, drowned valley, the basin is shaped like a shallow, elliptical bowl. Its width is 2 miles, whereas that of the narrows is only a quarter of a mile. Its depth in the middle is 216 feet; the depth in the narrows is only 5 feet. The symmetry of this deep basin is very remarkable. Tides, surely, cannot have formed it; for tidal currents are weak, ordinarily not exceeding half a knot an hour; and tides have not acted in that way elsewhere on the coast. The discharge due to upland drainage, likewise, is insignificant; for no rivers worthy of the name flow into the basin. It is of possible significance that the widest part of the basin lies on the axis of an anticlinal dome (Figure 2 b). Anticlines are not infrequently places of inferior resistance to weathering and other agencies of erosion, owing supposedly to the cracking of the strata which are bulged up by the folding. One is tempted to consider glacial erosion as the cause of the excessive depth; but in the absence of evidence of local ice erosion in places much more favourably situated for it than this, the view cannot be regarded with much favour.

SEQUENTIAL FORMS DUE TO WAVES, UNDERTOW, AND WIND-DRIVEN CURRENTS

A coast which has been made ragged by drowning and glaciation cannot long remain unchanged. The sea, attacking it with more or less vigour, according to whether the shore is openly exposed to the surf or sheltered from it, begins at once to re-form the shore-line. Irregularities of outline and of profile are conditions not tolerated by the sea, whose well-organized movements operate smoothly and consistently at its borders, constantly seeking greater efficiency. Accordingly, waves and currents lose no time in making those alterations which lead to better adjustments of profile and more connected relationships between neighbouring points on the coast.

AGENCIES AT WORK

The alteration of the shore is accomplished by the united action of three chief agencies—waves, undertow, and shore currents.

Waves. Waves are "travelling shapes of water," accompanied ordinarily by a much slower, subordinate drift of the water itself, in the direction in which the wave is running. On the crest of an advancing wave, a particle of water is moving forward; in the trough, backward; in front, upward; and in the rear, downward. In the ground-swell—a wave that has run out beyond the reach of the storm which created it—the particles revolve in closed orbits, which are circular or elliptical. Here the shape, alone, travels forward, and the water itself returns to precisely the position from where it started. In the wind-driven wave, however, which is seen at its best during severe storms, the forward movement of the crest exceeds the backward movement in the trough, so that a particle at the surface instead of returning in a closed orbit to the point whence it started, returns a short distance farther forward, and thus in successive waves describes a spiral which carries it slowly toward the shore. Moreover, as a wave runs ashore, the distance between it and the next wave decreases, it becomes sharper, higher, and steeper in front, until it breaks. When this takes place, the water is flung forward from the crest, converting the wave from one of oscillation and slow drift to one of vigorous translation; consequently, the waves which spring up between this breaker-line and the shore are more translatory than those from which they sprang. As they run up on the shore, they bring quantities of stones and sand which they fling up as far as they can reach, at the margin of the sea. The large streamers of kelp, called "devil's aprons," so common along the coast, play an important part in the economy of beaches, for they help to buoy up cobblestones and pebbles which the waves would otherwise be powerless to sweep ashore. After a heavy storm great masses of the kelp can be seen on a seabeach, in which an occasional "apron" may be found with a stone still tied to its roots, although as a rule the seaweed is torn loose as soon as the stone pounds on the beach. This uphill, landward sweeping of beach material is obviously easier on a gently shelving shore than on a steep one.

Undertow. The undertow is a current which creeps in a direction more or less straight down the slope of the beach out to sea. In it as much water returns to the sea as is drifted forward in the waves. Since the waves are strongest in time of severe storm, the undertow, also, finds its best development then. The undertow is a pulsating current—not a steady one; because it is fed by and dependent on the passage of successive waves. By a series of jerks, cobblestones, pebbles, and smaller particles are pulled or rolled down the submerged beach or shelf until they reach water so deep that the diffusion of the current weakens it to the point where it can no longer carry them, and they come to rest, aggrading the sea-floor. Since it works downhill, in conjunction with gravity, the undertow is strongest on a slope that dips steeply towards the sea.

It will be seen from the foregoing account that on a coast which is initially steep, transportation of material will be chiefly seaward, and on a coast that is initially gentle, transportation will be mainly towards the land.

Shore Currents. Shore currents are movements of the water along the coast. Some are dominated by tidal movements. These are very important, but will be considered on a later page, under tides. Others are generated by waves which approach the coast in an oblique direction, producing a bodily movement of water more or less parallel to the coast. Where the coast is nearly straight the current is continuous, and its parallelism to the shore is rather perfect; but where the shore is very irregular, the current is broken up into many separate currents working in nearly opposite directions from headlands, and its momentum is likely to carry it across re-entrants in courses by no means parallel to the shore at that place. Like waves and undertow, the shore current works most strongly in time of storm; and since successive storms may come from different quarters, the direction of the shore current at a given point is liable to be reversed frequently. The circumstances may be such that in the long run the efficiency of the shore current from one side exactly balances that of the current from the opposite side; but at most places the drift from one of them dominates the movement of material to such an extent that the occasional reversals of current may be overlooked, and it may be considered as if it were constant in direction. The effects of shore currents are most plainly seen in changes of horizontal configuration; but it must be borne in mind that such currents co-operate with waves and undertow, delivering detritus to them or receiving it from them and locally and temporarily, at least, controlling the behaviour of the sea. This is particularly true in the early stages of the life history of a shore-line.

Although waves, undertow, and shore currents co-operate in altering the shore in all three dimensions, it will be in the interest of clearness to consider the changes as they appear in two dimensions only, taking first the changes in profile, and second the changes in ground plan.

FORMS CONSIDERED IN RELATION TO ON- AND OFF-SHORE MOVEMENTS

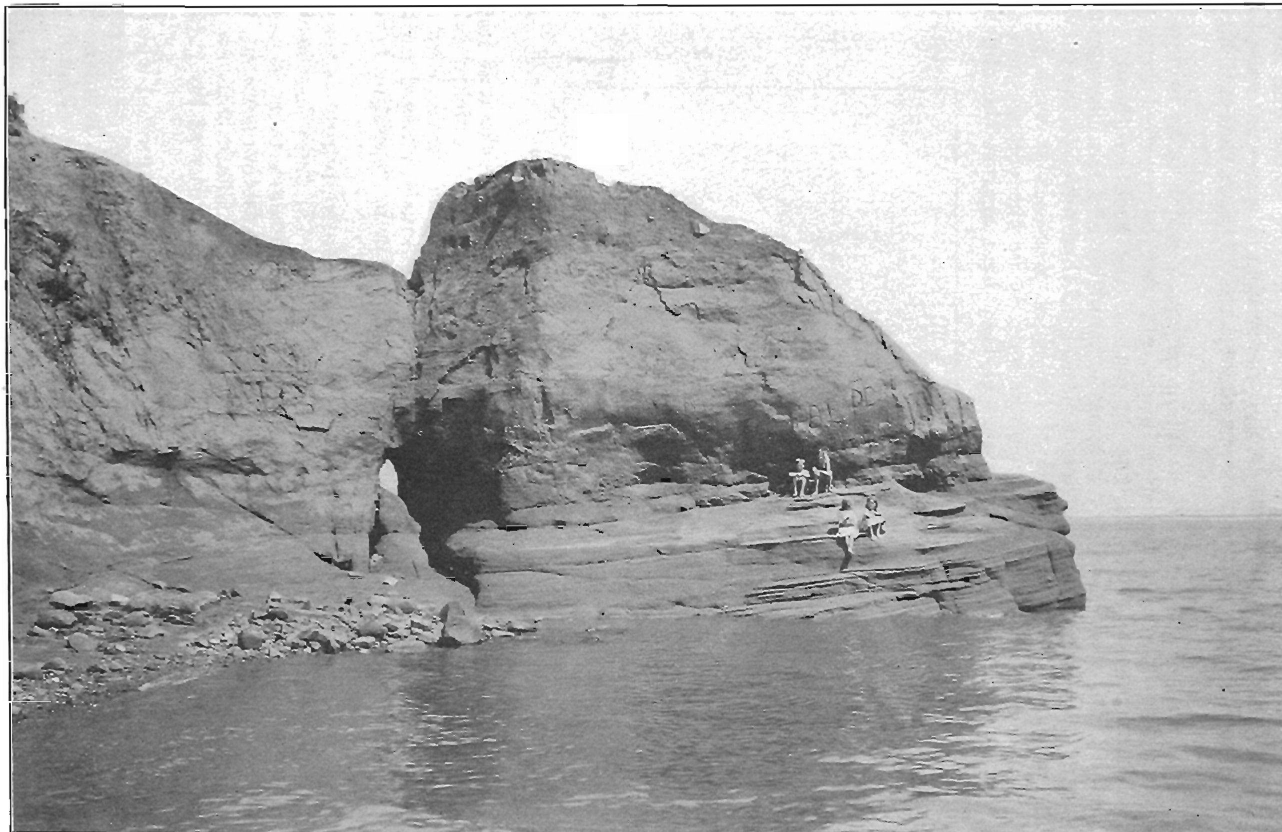
In profile, the new shore may be steep and the undertow may thus be favoured, so that it will sweep more loose material down and off-shore than waves can bring up. Or the slope of the new shore may be gentle, in which case, incoming waves will be stronger than the undertow, and more material will be brought in than is swept out. In either case the opposed forces will tend to construct a profile on which the on-and off-shore movements are balanced—an ideal, adjusted curve called the "profile of equilibrium." Rarely will it happen that the initial slope is itself the profile of equilibrium, requiring no alteration.

Sea-cliff and Terrace. If the initial slope be steeper than the profile of equilibrium, the waves strike the shore forcibly and cut away the material at the water's edge. This is then delivered to the shore currents and the undertow, which promptly separate it and carry away the debris. The coarser part of it is drifted along shore and the finer is carried off-shore in suspension until it settles in deep water. The stones thus gathered are used by the waves as tools by which to cut away the coast. The process is an horizontal sawing at the water's edge, by which the slope above it is steepened into a cliff, and the slope below it is replaced by an inclined terrace or bench that is flatter than the initial slope (Plate III). The width and the slope of the terrace, the depth of water covering its outer border, and the height of its upper border above sea-level vary according to the strength of the wave-action, the time during which the wave and currents have been at work, and the resistance of the material. The longer the process goes on, the broader will the terrace become and the deeper will be the water on its outer edge; for while the cliff is sawed back, the terrace will be planed down. The greater the "fetch" of the waves, the farther up the slope will erosion extend, and the higher the upper limit of the terrace will be. On abrupt, rocky shores the terraces are mostly narrow and steeply inclined; on more shelving shores, particularly in glacial drift, where the sea has had time to make great inroads, the terrace is wide and flattish. Needless to say, the range of tide will also affect both the width and the slope of the terrace. Sea-cliffs cut in boulder clay are common features along the coast of Nova Scotia, particularly where drumlins have been attacked by the waves (Plate XIV B). The recession of these clay bluffs is accompanied by land slips of considerable size, particularly in the spring, when the thawing of the frozen clays and the percolation of water supplied by spring rains lubricate the structure and increase its weight, so that the great blocks slide down to the beach. Fresh landslides of this kind commonly form high, sod-covered terraces on the bluffs. In many places, also, the loosened and lubricated clay slides down the cliff face in a plastic condition, forming steep cones of sticky mud. Much material creeps down the steep cliff face in small amounts, and very much is washed down by rains, developing innumerable gullies, from which the waste is spread out on the beach in fan-like deposits. Wave-action during storms trims away all this fallen debris, steepening the lower part of the cliff and encouraging a renewal of the slipping. Successive masses are thus pulled down by gravity as the waves cut in.

Although the cutting away and removal of debris is the chief process in operation below the cliff, it must not be thought that the shore terrace is wholly a wave-cut form. It is commonly covered with a shifting sheet of gravel and sand and its outer margin is as a rule extended by deposits of waste carried out by the undertow.

Sea-cliffs cut in solid rock take various forms, under the influence of different types of structure encountered. If the cliff be composed of stratified beds that dip into the land, the cliff is likely to be vertical or overhanging, on account of the tendency for waves to undercut rapidly the base of it. If the beds dip towards the sea the steepness of the cliff will depend largely upon the angle of dip of the rocks, for the sliding of loosened masses of rock is most likely to occur along the stratification, so that the cliff face is itself an exposed bedding plane. Rocks such as the crumbling red sandstone of Annapolis valley, when cliffed, are prone

Plate XVII



Sea-cliff in sandstone at Kingsport.

to crumble along the weakest beds, forming fantastic niches and alcoves like those so common in arid lands; and the sawing of waves into the base of such a cliff in many cases develops arches and caverns that are highly picturesque (Plate XVII).

Caves are likely to be eaten out in any rock which is so broken by joint-planes or bedding-planes that fragments may be quarried from the cliff without wholly removing the support of the rock overhead. The columnar jointing of the North Mountain trap-cliffs and the cleavage and jointing of the slate of the Southern upland lend themselves to the carving out of caverns or "ovens." One of the chief processes at work in the tearing out of joint-blocks from cliffs is said to be the compression and subsequent expansion of air by waves as they beat against the cliff and

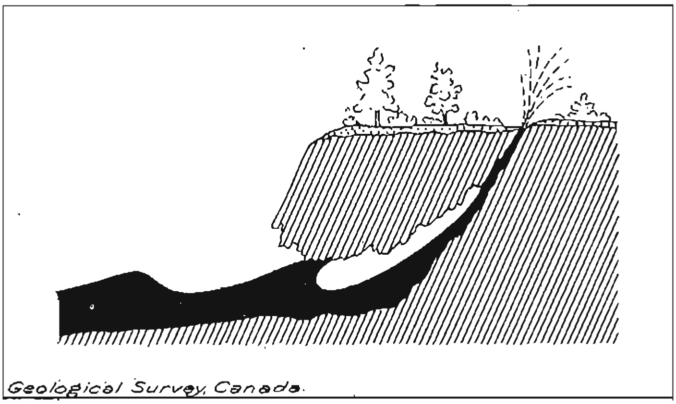


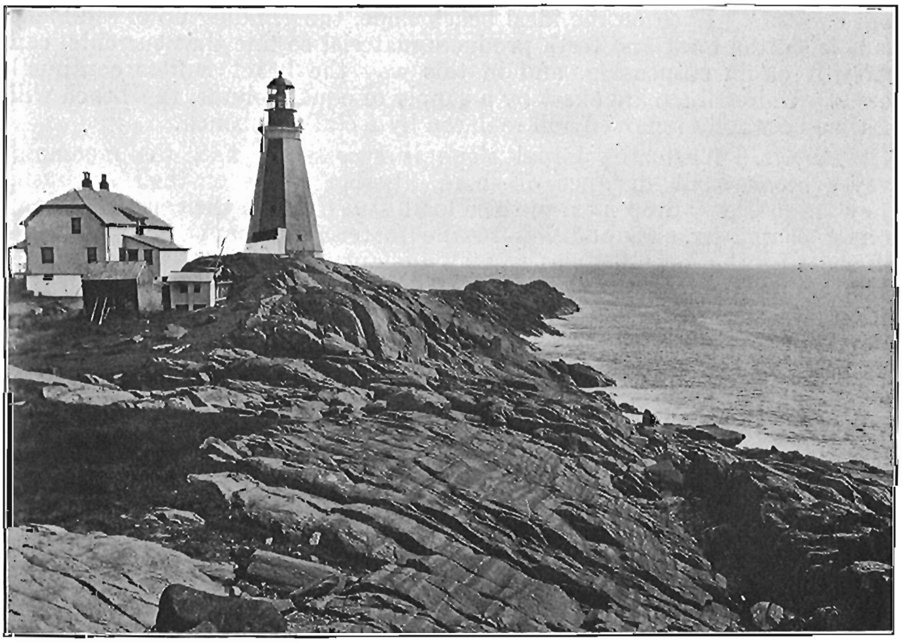
FIGURE 9. Cross-section of a cavern and spouting horn.

retire from it. The hydraulic pressure on the air in cracks and larger spaces is enormous; and it is both quickly applied and quickly taken away. By it, and by the direct quarrying action of the waves, a cave is in some places eaten far back into a cliff, and obliquely upward until a hole appears in the roof overhead—a condition seen in "spouting horns" and "blow-holes" (Figure 9).

Sea-cliffs of glacial drift in exposed positions commonly retreat several feet a year (Plate XVIII). At Louisburg (Figure 18) there has been a retreat of 7 inches, annually, since 1745, although the shore there is partly protected by ledges. The recession of cliffs in rock is seldom so rapid, but depends greatly on the resisting power of the rock. Chalk cliffs on the coast of Dover, England, have been retreating for centuries at the rate of 15 feet a year.

The height of a cliff depends upon the altitude of the ground which is being attacked by the sea. Changes in height of the cliff as it recedes cause changes in the rate of recession. So long as the sea is advancing into an upland which slopes toward it—the usual condition—the shore-cliffs will of necessity be increasing in height; accordingly, the cliff face, from which waste is being shed by landslides, creep, and rain wash, is constantly increasing in area, and the rate of supply of waste is increasing.

A. Wave-cut cliff, Pleasant bay.



B. Cape Fourchu lighthouse.

In time, the supply may threaten to exceed the capacity of the waves and currents to transport it. So it comes about that the most rapid retreat of the cliff is usually in the early stages of its life. The case of a drumlin island is peculiar; for it is obvious that when the cliff has been cut back beyond the top of the hill, it will begin to decrease in height again, and thus there will be an acceleration of the rate of recession; but the widening of the shore platform, meanwhile, will prevent this rate from becoming as rapid as it was at the beginning (Plates XIV B and XV).

Beach Ridges. Where the coastal slope is flatter than the slope of equilibrium, the on-shore movement of translatory waves encounters little opposition from gravity, and the off-shore movement of material by the undertow is weak; hence, material is shifted shoreward and is cast up at or near the water's edge. This process steepens the slope, and will continue until the slope of equilibrium is reached. The profile of a typical beach is a reverse curve: the upper part (landward part) of the ridge is short, steep, and convex upward, and the lower part (seaward part), below the convex summit of the ridge, is long, gentle, and concave. But the precise shape of the ridge is determined chiefly by the angle at which the beach material comes to rest when cast up out of the reach of the waves. The crest will stand distinctly above high-tide mark because both the tide and the waves are abnormally high at the time when beaches are mainly formed. Slope is not the only factor that determines whether waves and currents of a given strength will build a beach or cut a cliff and bench. Much more waste may be brought to a place by longshore drift than by the on-shore sweep of translatory waves. Some beach ridges accumulate, even on moderately steep slopes, where this supply from shore currents is greater than the undertow can sweep away.

Beaches are not permanent features, nor is the attainment of the profile of equilibrium a guarantee against ultimate destruction by waves and currents. Even on the ideal beach slope, the grinding up of sediment as it is shifted back and forth produces material so fine that currents can carry it off in suspension, and in this way the beach suffers continual losses. Unless these are offset by a supply of equal volume, the beach will in time be wholly removed and replaced by a cliff and bench.

Barrier. When the initial slope is excessively flat, the incoming waves break some distance off-shore. Losing much of their strength, they are forced to drop most of their load, and to begin the construction of a reef or barrier. In addition to the material which is brought from off-shore by the incoming surf a small amount is brought to the reef from the land by the outgoing undertow. The barrier, like the ordinary beach ridge, may be looked upon as a result of the effort of the dominant on-shore movement to replace the too-flat slope by a slope of equilibrium—it being necessary in this case that the beach ridge be built off-shore instead of at the water's edge, if a curve of sufficient steepness is to be constructed within the range of the waves. Again, however, the longshore movement of waste must not be ignored. Shore currents are often of great importance in the accumulation of barriers, for the breaker line is a line of peculiarly great agitation of the water. Sand and gravel are constantly being danced up and down in the breakers, and the shore currents, which would be powerless to move such coarse material if it were at rest on the sea-bottom, can shift it very considerably by repeated jerks while it is temporarily in suspension. In the protected bays and lagoons behind the barrier, sediment swept from the land by rivers or from the sea by tides may be deposited, and, aided by vegetation, may convert it into a tidal marsh. In case shore currents offer a constant supply of material to a beach or a barrier sufficient to offset the loss of material by attrition and off-shore transportation, the form and position of it will remain unchanged. The supply from shore drift may even exceed the loss, in which case the reef will increase in width by the additions to its seaward side. More frequently, however, the supply fails to keep pace with the loss, and the barrier is beaten ashore, becoming a beach ridge, and finally a sea-cliff.

The ultimate form of any shoreline, therefore, whatever its initial slope, is the cliff and terrace. If the water is deep, cliffs develop at once, and recede under the attack of the sea unless an abnormal supply of sediment be brought by shore currents. If the water be shoal, a beach or a barrier is first thrown up to establish the profile of equilibrium; but once this is done the grinding up and extraction of sediment causes the beach to vanish, and a sea-cliff to appear in its place.

FORMS CONSIDERED IN RELATION TO LONGSHORE MOVEMENTS

The changes brought about in the shoreline as seen on a map are particularly dependent upon the activity of the longshore currents; moreover, the exposure to wave-action is greater on the headlands; hence they will show the most rapid development of sea-cliffs, and the sheltered re-entrants the earliest development of beaches and barriers. The wasting headlands furnish beach material which shore currents and waves distribute in such a way as to fill up or shut off re-entrants. Some of the sediment is drifted along the beach by oblique waves and cast up in a pocket beach or bay head beach.

Spits, Bars, and Hooks. Where the coast is extremely irregular, it is obvious that a shore current cannot pass continuously around salients and in and out of re-entrants. Each strong salient splits the incoming waves so as to generate a pair of longshore currents, neither of which can hug the shore of the re-entrant into which it is passing. Beach material torn from the headlands will be carried obliquely out, along the line of breakers, on both sides, and dropped in deeper water, forming "spits." As the spits increase in length by additions at their free ends, they come in time to form a nearly continuous bridge or "bar." No hard-and-fast distinction can be made between a spit and a bar; they are merely different stages of growth of a single form. Nor should too sharp a distinction be drawn between a bar and a barrier beach, although it is convenient to think of a barrier as constructed chiefly by on-shore action and a bar chiefly by longshore drift. The upper half of Indian bay has been shut off by a bar; and the upper half of Wine cove is nearly closed by two spits. Where a bay like this one is nearly closed by a pair of spits, the direction of the dominant shore drift is plainly indicated by the overlapping of the ends of the spits, the one which lies to windward terminating in front of the other.

At the end of a spit, there is commonly a sharp turn, following the curve of the waves which run into the sheltered water of the bay. Deposits laid down on this curve during a single great storm may build a distinct hook, converting the straight spit into a "hooked spit" or "hook." After a period of comparative inactivity, during which the spit has grown out along its stem, another storm of the first magnitude may build a second hook beyond the first, and in like manner others may be constructed, forming a closely packed group of "re-curved hooks." A magnificent example at Englishtown, Cape Breton, is shown in Plate XIX. Owing to the ultimate destruction of beaches and barriers, it is not uncommon to find the stem of a re-curved hook partly cut away, exposing the curved ends in a truncated condition.

Triangular Bars. A miscellaneous group of beach deposits known as "cusps," "cuspate forelands," "looped bars," and "V-shaped embankments," are of special interest because of their peculiar and very graceful outlines and their high degree of individuality. Some triangular cusps are due primarily to shore currents set up by strong tides, which, because of periodic reversal twice each day, or because of interference of circular eddies, drop their load on the borders of a triangle of comparatively dead water. But many of these cusps and looped bars exist where tidal action is weak or totally absent, as in Bras d'Or lakes; and are known to be the product solely of oblique wave-action, working along lines oblique to the shore, as already described in considering shore currents. In some cases the loop or cusp has been built by wave-driven currents directed towards its point first from one side and then from the other; in other cases the loop originated as a hooked spit, whose point by continued growth has reached the shore. Looped bars also appear at the rear of islands where shore-drift from both sides trails backward along two converging lines until they meet.

Islands which are openly exposed to the sea, like the drumlins in Halifax harbour and Mahone bay, are, of course, open to more vigorous assault by waves than are the more protected parts of the coast; and their encircling shores, facing all points of the compass, naturally show all possible varieties of topographic form. Between the cliffed ends of neighbouring drumlin islands, curved spits or more continuous crescent beaches or bars mark the line along which storm waves break as their advance is held back at the headlands. "Spectacle island" is a name given at Chester and at other places to tied pairs of half drumlins; and it might well be used as a specific name for all of that class. Isolated islands like Big Fish island in Chester bay are so exposed that cliffs develop from the front around both sides, passing behind into a long, sinuous spit which has a distinctly tail-like appearance (Plate XX). By the construction of one or more bars between them and the mainland, cliffed drumlin islands become tied to it.

SEQUENTIAL FORMS DEVELOPED BY TIDES

On the coast of Nova Scotia no other agency attracts so much attention as the tides. The 45-foot tides of the bay of Fundy, the strong currents that race through the entrances to Annapolis and Minas basins, the vast red mud flats and marshes which occupy the heads of these basins and of smaller estuaries—all these serve to give the tides a very prominent place in the physiography of the coast (Plate XXI). Tides have been active

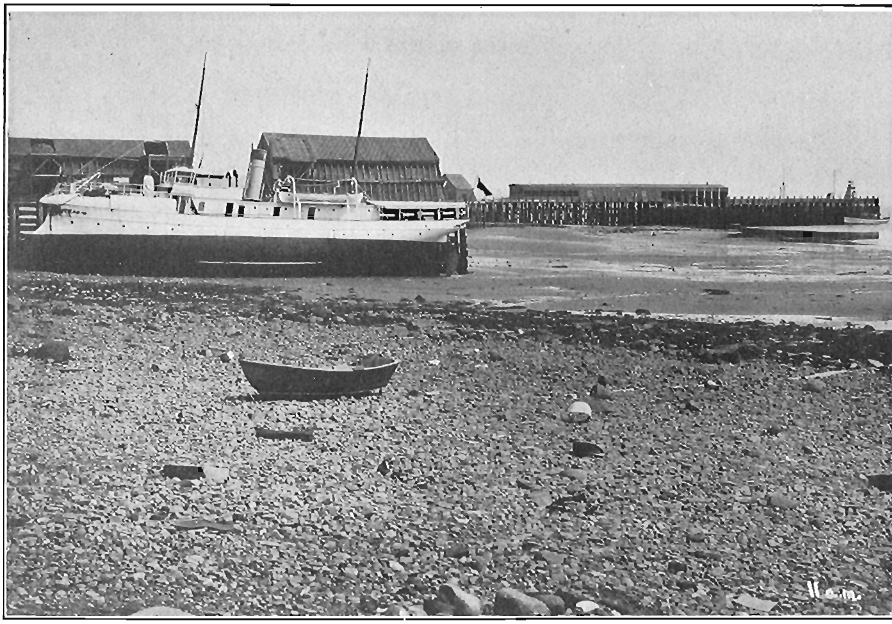
PLATE XIX

Recurved hook at Englishtown.

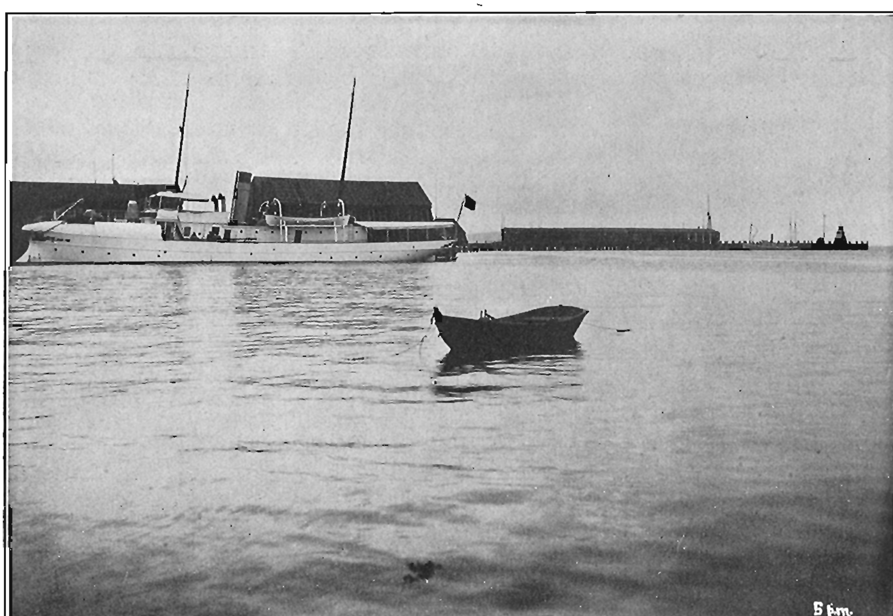
PLATE XX

Big Fish island, Chester.

PLATE XXI



A. Low tide at Digby.



B. High tide at Digby.

agencies ever since the departure of the ice-sheet, scouring, transporting, and depositing sediment on their own account, as well as co-operating with the waves and shore currents of the wind-driven kind.

NATURE AND CAUSE OF TIDES

The general nature and cause of tides, with their various fluctuations, are fairly well understood, but the complex tidal equation, whose factors, though variable, nevertheless have determinable values for any date or hour selected, is hopelessly complicated by the accidental and irregular influence of weather changes. During a storm, strong on-shore winds push the ocean bodily toward the shore, giving abnormally high tides. At Halifax, during an easterly storm, the additional rise from this cause is in many cases a foot; and in extreme cases it is much more than that. In the Saxby gale of October 5, 1869, the water reached a point 9·52 feet above low-water datum, or 3½ feet above the level of ordinary spring tides. During a gale in November, 1901, it fell short of the highwater mark of the Saxby gale by only 0·17 foot. The extreme difference of level at Halifax, as far as recorded by high and low tides, is 10·90 feet, as compared with the normal spring range of 6 feet. In Northumberland strait, the Saxby tide rose to a level 4 feet above ordinary high water of spring tides. At the head of the bay of Fundy the range of this famous tide was 70 feet; and it submerged 15,000 to 20,000 acres of salt marsh, most of which was under cultivation. One reason why storm tides rise so high is the low barometric pressure of the storm area, which tends to make the sea-level bulge up beneath it.

TIDES OF NOVA SCOTIA

In the open Atlantic the range of tide is small, probably only 2 or 3 feet. As the tide sweeps westward in a broad, low wave, passing across the edge of the continental shelf, and advancing over the banks, its height increases, just as that of a wind-driven wave increases on a shelving beach, because its energy is communicated to a smaller and smaller body of water. So at Sable island the spring tides have a range of 4 feet, and at Halifax, 6 feet. The advance of the wave across the banks is slower than at sea, yet rapid; for it moves at the rate of about 60 miles an hour, reaching Halifax 1 hour and 33 minutes later than at Sable island. The wave runs almost straight on-shore, reaching points between Halifax and Louisburg almost simultaneously. Differences in time of local high tide at ports within this long stretch of coast are not over 20 minutes and are due chiefly to purely local causes. As the wave advances its front slope becomes steeper than the rear slope, another point of resemblance to the wind-driven wave rolling in on a beach; in other words, the tide ordinarily comes in a little faster than it goes out. West of Halifax, the wave runs somewhat obliquely to the shore, so that its crest does not reach Shelburne until 35 minutes after high tide at Halifax, and cape Sable an hour after it.

Entering the gulf of St. Lawrence by an unobstructed flow through Cabot strait, the wave moves into the Acadian bay, swinging sharply around Magdalen islands and bathing the shores of Prince Edward Island and Northumberland strait with a current that flows from west to east until it is met near cape Tormentine by the slower but more direct tide that comes in around the Inverness shore of Cape Breton island. The range of tide in this Acadian bay is small, being 4½ feet at Port Hood, 2½ feet at cape George, 4½ feet at Pictou, and 4 feet at Pugwash. This is because the water that pours in through Cabot strait has ample room in which to spread out.

The conditions in the bay of Fundy are quite different, and depend primarily upon the behaviour of the tidal wave as it passes the mouth of the gulf of Maine. One hardly realizes what this gulf is, when looking at an ordinary map; but on a chart where the depths of water arein dicated by submerged contours or by shading, it is a conspicuous feature. It is a broad gulf, nearly enclosed by banks between cape Cod and cape Sable, and has been aptly described as "a bowl with a break in its rim." The length of the curved rim or "sill" is about 300 statute miles, and the average depth of water on it is 258 feet. Within the threshold, the whole area of the gulf and its branches, of which the bay of Fundy is the largest, is 36,000 square miles. One-third of this area has a depth of more than 600 feet. The average depth is 450 feet, and the maximum depth 1,104 feet. The tides in this great gulf show the following strange characteristics:

Throughout the gulf, they exceed in height the tides of the rest of the Atlantic coast; and in the bay of Fundy they reach a height which is equalled in very few other parts of the world.

High tide occurs about 3½ hours later than it does elsewhere along the Atlantic coast, where it is nearly simultaneous.

High tide reaches all points on the inner margin of the gulf simultaneously, occurring at the head of the bay of Fundy at almost the same time as on the coast of Maine. It is evident, therefore, that this cannot be a progressive wave that rolls up the bay.

Currents which flow in and out over the sill, with great regularity, run uphill, against the slope of the deformed sea-level.

One explanation of these peculiarities, proposed by Mr. Henry Mitchell of the United States Coast and Geodetic Survey, is briefly as follows: As the incoming Atlantic tide reaches the margin of the continent, a strong flood current drifts southwestward along the coast from Nova Scotia to Florida. To this current, the gulf of Maine presents a dead angle; for it lies behind the southern peninsula of Nova Scotia. Just after high tide, which comes almost simultaneously along the coast, exclusive of the gulf of Maine, a general ebb current sets in, moving northeastward up the coast. To this current, the gulf of Maine acts as a pocket; for it lies almost directly on its path. Though the sea-level is falling, outside of the sill, the water, carried by its own momentum, pours across the sill and into the gulf, raising its level to a height in excess of that seen elsewhere along the coast. This strong inflow continues to run uphill for three hours, when high tide is at length established in the gulf. At the time of high tide, the average slope of the sea-level from the sill up to the head of the bay of Fundy is about 1 inch to the mile, giving a total rise of 20 feet. High water comes at nearly the same time throughout the gulf, but the range of tide varies greatly, as shown in Figure 10. As the tide commences to fall, the current reverses and flows out across the sill. Three

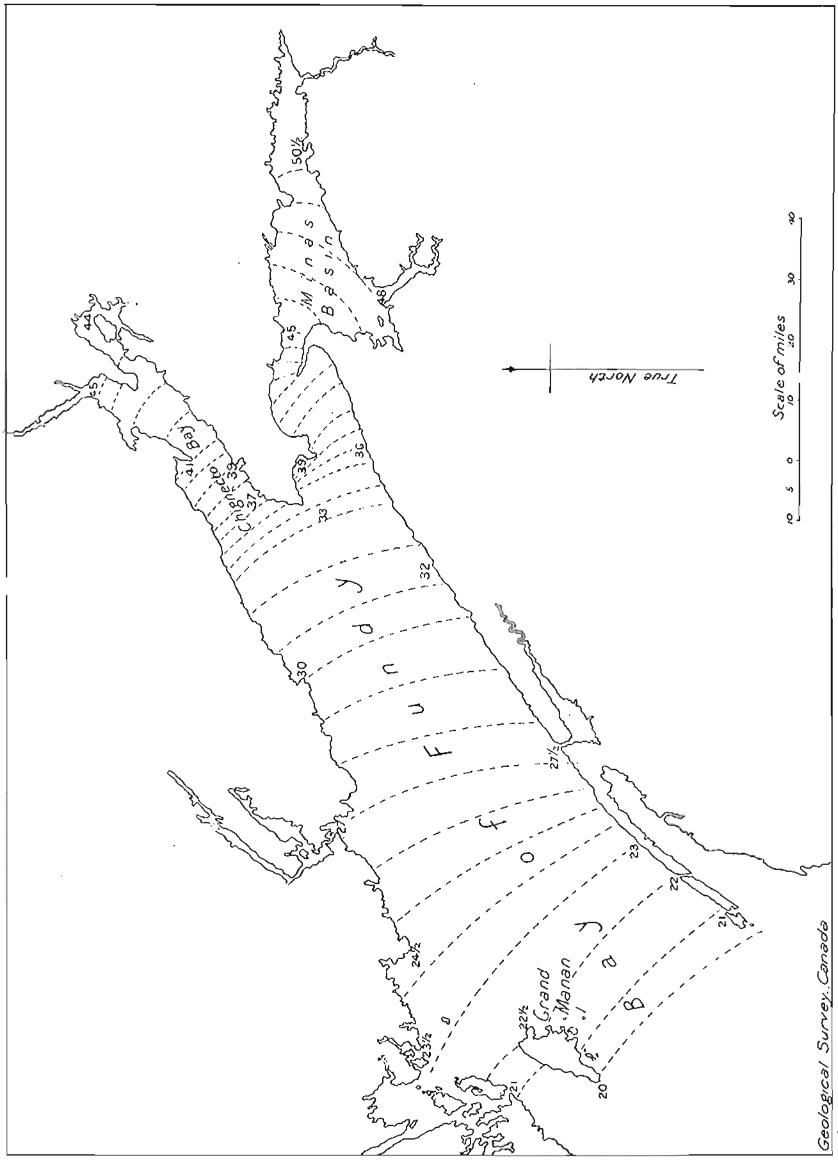


FIGURE 10. Range of tides in the bay of Fundy, figures represent heights in feet.

hours later this ebb current is running out with maximum velocity, the gulf is level, and low water is established outside the sill. Then, while the outer flood current brings rising water in the ocean, the ebb current from the gulf continues, though uphill, for three hours more, ceasing three hours before high tide outside, when the level of the gulf is at its lowest point.

Cape Sable island is of peculiar interest on account of the fact that it lies on the threshold of the gulf of Maine. Observations by Mitchell showed that the high tide comes 36 minutes earlier at Donald head, on the east side of the island, than at Clark Harbour on the west side, only 3½ miles around the shore. This is a shift of time greater than can be found in the 250 miles between Liverpool (N.S.) and Louisburg. The slope of the sea-level between the two stations on Cape Sable island, when steepest, is 5 inches to the mile, a slope steeper than that of the lower Mississippi river in time of flood; and yet the tidal current runs against it.

A more recent explanation of the great tides, suggested by Japanese investigators, is that the Atlantic tide augments a tidal undulation which originates in the bay itself, where they calculate the "proper period" is the same length—12 hours—as in the ocean. The impulse from the ocean, at 12-hour intervals, would thus become magnified, in the bay, until it reached a limit balanced by frictional resistance. The action is somewhat like that of a swinging pendulum which receives a series of impulses or "pushes" at intervals that are synchronous with its own period.

The increase in range of tide from Cape Sable island past Yarmouth and up the bay of Fundy is rapid, especially near the sill. The ranges on opposite sides of the bay, in Nova Scotia and New Brunswick, correspond closely, increasing from 5 feet at cape Sable to 45 feet at the head of the bay, and 50½ feet in Minas basin (Figure 10). Although the range of spring tides at Northumberland strait, opposite the head of the bay of Fundy, is only 10 feet, the mean sea-level in the two bodies of water is nearly if not quite the same, as shown by precise levels and observations by engineers engaged in the construction of the Chignecto Marine railway.

The currents that run in and out over the sill with every tide are not confined to the surface. Dr. W. Bell Dawson, Superintendent of Tidal Surveys, Department of the Naval Service, Canada, has ascertained by observations with a current meter that the velocity of the under-current is quite as strong as that at the surface. At five stations, the velocities of the current at a depth of 180 feet were found to be 95, 104, 93, 105, and 107 per cent respectively, of the velocities of the surface current. The whole body of water, down at least to 30 or 40 fathoms—the level of the sill—seems to move with equal speed. Mr. Mitchell has called attention to the occasional reports of sunken vessels which lay in 20 fathoms being broken up during violent storms, and quotes Captain Tower of the Boston Marine Society as authority for the statement that a diver of his, on the coast of Maine, having coiled a chain about his waist for extra weight, ventured down to the deck of a vessel 23 fathoms below the surface and there noticed that ropes were swaying to and fro and that the end of his chain was whipped about by the passing swell. It seems likely that in such a case as this, the depth reached by the current is due to a combination of the deep tidal flow and the storm-driven current, at a favourable stage of the tide. It is evident that scouring may go on, at irregular intervals, even as far down as 180 feet, and the banks may be swept smooth every year. Since the velocity of the incoming and the outgoing currents on the sill, as measured by Mitchell, are equal at all places, the effect of the scouring is probably to broaden the sill without changing its position.

On reaching the smaller indentations and projections of the shore, the behaviour of the tidal wave is altered in a variety of ways, by local conditions. If it runs up a funnel-shaped estuary, like a typical drowned valley, its speed is reduced, its height is increased, and its front is steepened. A river entering the head of such an estuary is dammed up at high tide so that the effect of the tide is felt far above the point reached by salt water. A tide of great range, like that at the head of the bay of Fundy, may rise so fast in the bay at the mouth of a narrow estuary that friction holds it back and it curls up into a tidal breaker or "bore." This happens regularly on the turn of the tide at the mouth of Petitcodiac river below Moncton, N.B., and under favourable conditions of tide on the Maccan, Kennetcook, St. Croix, and Avon rivers in Nova Scotia. The bore is a foaming wave, usually only a foot or two in height; but the noisy rush of water pouring in after it is impressive. It runs up the creeks at the rate of 6 or 7 miles an hour. The bore at Moncton in some places has a height of 6 feet. Strong bores are observed also on the Amazon, the Seine, and certain large rivers in China, where a height of 15 feet is attained.

A bay or a basin which has a very narrow mouth or entrance cannot be filled to normal high-tide level in 6 hours' time, nor emptied to normal low-water level in the next 6 hours; hence, its tide will have less range than the tide outside. Thus, in Bras d'Or lakes, the sea has to pass through such a long, narrow gateway that the range of tide is cut down from 5 or 6 feet (at Sydney and St. Ann) to about 1½ feet. This difference in height of the tides in Bras d'Or lake and on the Atlantic coast has necessitated the construction of a lock in the short tide-water canal at St. Peter.

In straits like the strait of Canso, Grand passage, and Petite passage, which connect bays or gulfs whose tides are more or less independent, vigorous currents or "races" develop, on account of differences of range of the tide at the two ends, or of differences in time of high tide. In the straits of Canso, currents run with so much variation in velocity and time that it was long supposed that they were due to the wind. According to Dr. Dawson, however, they are due to differences in character of the tides at the two ends of the strait. In Northumberland strait the tidal range is strongly affected by the moon's declination, which changes from month to month. In Chedabucto bay it is mainly affected by changes of the moon through the month. Inasmuch as the periods do not correspond, the differences of height of the sea-level at the two ends of the strait vary in a complex manner; and the current varies likewise. The winds may have a disturbing effect, but the currents are primarily tidal. They run about 5 miles an hour when strongest.

"Tide rips" are patches of choppy water, due to friction on the channel floor or on the more slowly-running lower water. On either side of a strait circular eddies may sweep the shore with considerable vigour. When there is a head wind, the rip is greatly augmented. On account of the interference of tides coming from opposite sides, many straits show such freaks as four tides a day, or no tide at all, or a tide of abnormal range. The straits of Nova Scotia, however, do not exhibit marked peculiarities of this sort.

EFFECTS OF TIDES ON SEA-CLIFFS AND SHORE PLATFORMS

The effect of the tides is to widen the field of action of the other shore agencies. Around the bay of Fundy, this is particularly evident, in the great breadth of the shore terrace, which in places extends several hundred yards from the foot of the sea-cliff (Plate XXII). Acting in conjunction with shore-ice and waves, the tides drag off blocks and smaller fragments which have fallen from the sea-cliffs and thus make the cliffs recede more rapidly than they otherwise would do. At some points on the coast, as at Partridge island, cape Blomidon, and cape Chignecto, the tidal currents are so swift that they act vigorously as transporting and eroding agencies, even when no waves or ice are present.

With a speed of from 5 to 8 miles an hour, they are able to sweep along coarse gravel and even cobblestones. The scouring effect of this constantly repeated movement on the rocky floor across which it takes place must be strong.

EFFECTS OF TIDAL CURRENTS IN GAPS

In the straits and gaps, particularly, the swift currents dig deep channels where they are confined, though smoothing the sea-floor outside and inside the gap. This is plainly shown in Digby gut. According to measurements based on the Admiralty chart, over 21,000,000,000 cubic feet of water run in and out of Annapolis basin through this gateway on each tide. To do so requires an average velocity in the gap of 2½ statute miles an hour. The rate actually attained at half tide, according to the Coast Pilot, is over 5 miles an hour. It is altogether probable that this current, like those of the more open bay of Fundy and the gulf of Maine, measured by Dr. Bell, is nearly as strong on the bottom as at the surface. Its velocity ought, therefore, to enable it to move stones several inches in diameter. That it does so is shown by the presence, as indicated, on the coast chart, of a deep hole, in the middle of the passage (Figure 11). If the gut were merely the drowned mouth of Annapolis valley, unmodified by tidal action, the line of deepest water would descend steadily from the upper part of the basin down through the gut, at a depth of about 90 feet to the bay outside. Instead of this, it drops abruptly as it reaches the gut into a hole which is over 180 feet deep; and steps up again at the farther end of the gut, where the water is only 96 feet deep. The amount of over-deepening by tidal scour thus appears to be over 84 feet.

Lest it be thought that this hollow in the bottom of Digby gap is merely the work of the ice-sheet, crowding through it during the southeastward advance, take a case where glacial erosion is ruled out by the character of the submarine topography. At the entrance to Guysborough harbour (Figure 12), the tides are restricted to a narrow passage by a long bar, known as Hadley beach. In the floor of the passage is a hollow

Plate XXII

Sea-cliff and tidal platform near cape Blomidon.

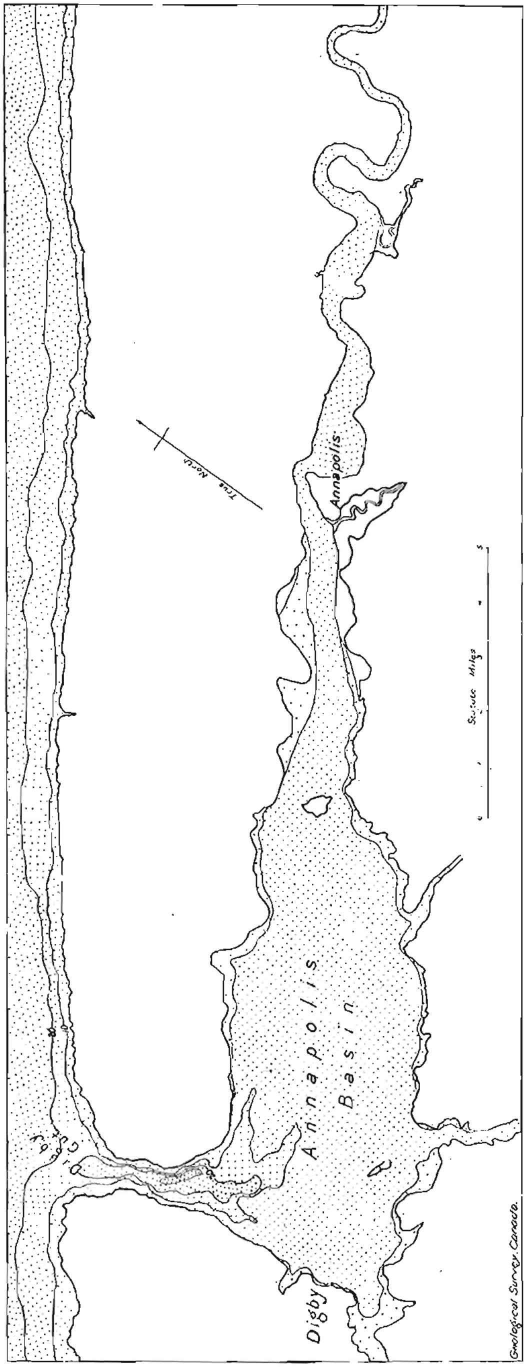


FIGURE 11. Digby gut and Annapolis basin, showing extent of scour by currents in Digby gut.

like the one in Digby gap, but more irregular in shape. The lines on the chart show the depth of this hole to be between 25 and 40 feet, whereas the depth just outside of it, at the two ends, is 13 and 16 feet respectively. In the bay behind the upper shoal, which extends between Hadley beach and Eliza point, there is a depth of 60 feet, which indicates the extent to which the bottom of the original unaltered valley of Guysborough river has been drowned. On the bay floor outside the lower shoal, off Hadley beach, the water deepens rather gradually to 40 feet. The 20, 30, and 40-foot lines show plainly that the submarine topography at the entrance consists of an immense, wave-built bar, heaped up to a height of 60 feet across the mouth of the estuary, and showing only its narrow crest in Hadley beach. The hollow lies on the summit of this great bar at the end farthest to leeward as regards shore drift. There can be no doubt in this case that the hollow is merely a subordinate detail of the bar, maintained by the strong scour of tidal currents, in spite of the constant drift of sediment along the front of the bar. The velocity of the currents here is only 2 knots, as compared with the velocity of 4 or 5 knots at Digby gap. If, therefore, the currents in Guysborough harbour can maintain a hole 40 feet deep, it seems probable that the much stronger current in Digby gap can scour to the depth of 84 feet unless the floor of the pass through North mountain is too rocky to allow it.

At the entrance to Minas basin is a line of three hollows similar to the one at Digby, but much larger and less regular in outline. The entrance, between cape Split and cape Sharp, is only 3 miles wide and about 2 cubic miles of water races back and forth through it every 6 hours, at a velocity of from 7 to 9 miles an hour. Off cape Split a long ridge or sill reaches across the entrance, evidently an extension of the trap ridge of North mountain, covered with 20 to 26 feet of water. Inside this ridge, between cape Split and cape Sharp, a long, straight trough reaches a depth of 57 feet. Just outside of the ridge, between cape Split and cape Spencer, a smaller hollow reaches down to 47 feet; and just beyond that, off cape d'Or, where a current flows at a rate of 7 miles an hour, there is a long trough which reaches 55 feet. These three holes, lying in the path of the strongest currents, must be kept open by tidal scour, for every incoming and outgoing tide sweeps vast quantities of mud and sand across them—sediment which would quickly fill them were it allowed to settle as it does all over the interior of Minas basin.

Scouring by tidal currents is seen also at the entrance of Bras d'Or, on Cape Breton island. The entrance, between Carey point and Noir point, is only a quarter of a mile wide and through it the tide rushes at the rate of 7 miles an hour. Although the broad, smooth floor of the bay just outside is only 30 feet deep, and the floor of the Bras d'Or 2 miles within it is only from 30 to 40 feet deep, the depth at the narrows is 76 feet.

Above water, the effect of these tidal races is seen in the construction of triangular cusps or forelands, which project into the straits, sometimes quite sharply. A fine example of these appears in Petite passage, near the ferry opposite Tiverton, where an angular projection, formed by the south ridge of trap, causes a strong tidal eddy to sweep the east shore. During the flood tide the current circles in one direction at the rate of 5 miles

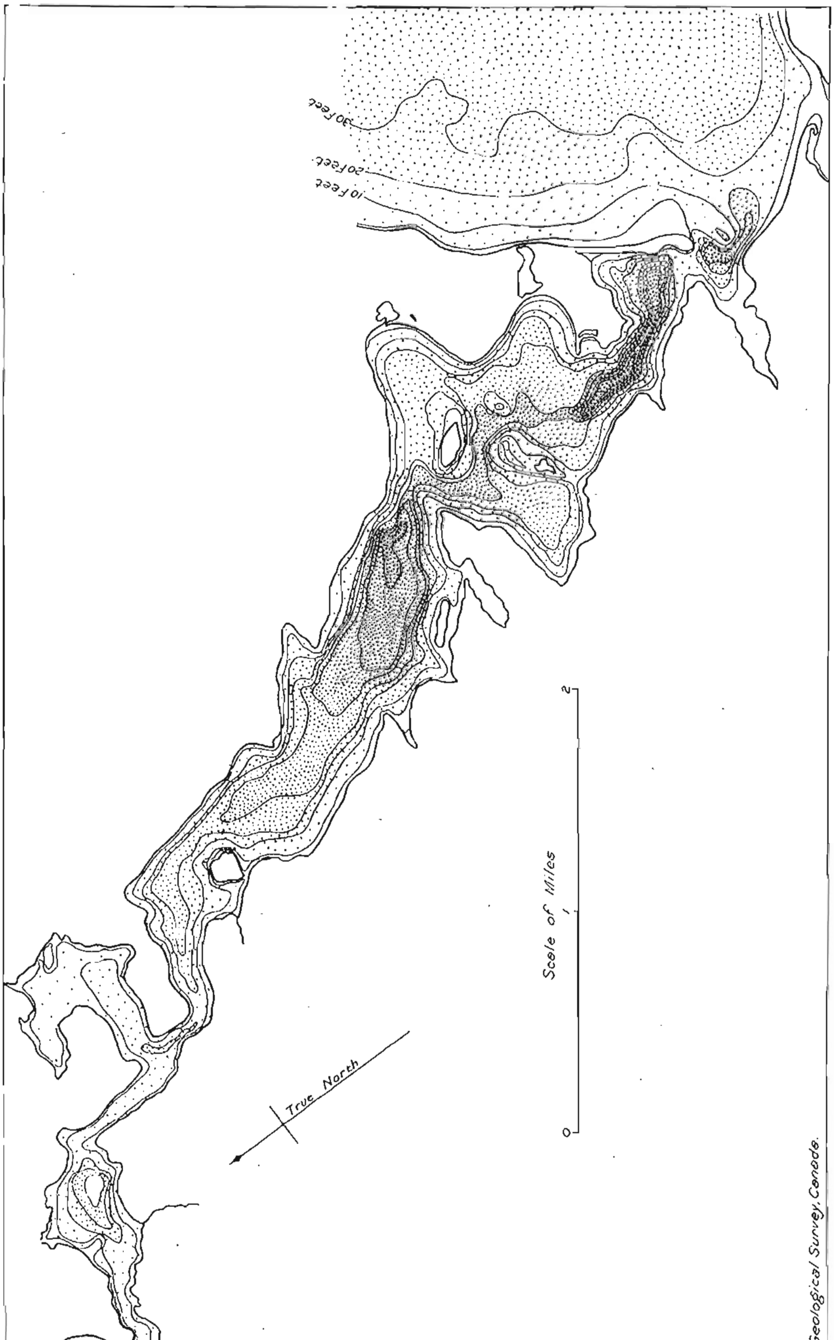


FIGURE 12. Contoured plan of lower part of Guysborough harbour.

an hour; during ebb tide it reverses and whirls in the opposite direction. The result is that a symmetrical triangular cusp has grown up. A similar cusp, but not so prominent, occurs in Digby gap near the life-saving station; and another, in the straits of Canso, at Eddy point, although the tidal current there has a velocity of only about 2 miles. Although these three triangular spits seem to owe their presence almost wholly to tidal currents, it is probable that wave-driven shore currents have aided in their construction; for, as we have already seen, spits that resemble them in form are common in Bras d'Or lakes, where tides are weak or wholly absent, and where wave-action alone can be appealed to.

SALT MARSHES AND TIDAL FLATS

The greatest gift of the tides to Nova Scotia, whether judged by size, or money value, or scenic beauty, is the salt marsh country of Acadia (Plate XXIII). Made famous by Longfellow in the sad, romantic poem of Evangeline, these seacoast prairies are vitally connected with the life of Nova Scotia. Because of their inexhaustible fertility and the ease with which they are cultivated, they will continue to be the most highly prized farming districts of the province for many centuries to come. A good description of the tide-washed shore of Minas basin as seen from the hills back of Wolfville is given by Frank Bolles in his essay "From Blomidon to Smoky."

"The tide was out, and miles of basin bottom lay red and shining in the sunlight. The dyke lands were intensely green, the sands, or mud, all shades of terra-cotta, the shallows strange tones of purple, and the deeper waters varying shades of blue. Colour ran riot in meadow, mud, and bay. Above and beyond all, directly in front of us, miles away, at the extremity of a grand sweep of shore which curved towards it from our left, was a dark red bluff crowned with evergreens. Its profile was commanding. From the edge of its forest it fell one-quarter of the way to the sea in a line perfectly perpendicular. Then, relenting a little, the line sloped to the waves at a gentler angle, but one still too steep for human foot to ascend. This was Blomidon, simple, majestic, inspiring.

"The distant northern shore of the basin was plainly indicated by a line of blue mountains, the Cobequid range, and we knew that between us and its rugged coast-line the mighty, pent-up tides of Fundy raced each day and night into the comparative calm of Minas and spread themselves there over the red sands and up to the dykes which the Acadian peasants had built round about Grand Pré. After receiving the image of Blomidon into the deepset corners of our memories, we looked next at Grand Pré, and, looking, gave up all previous impressions of it gained from Longfellow's poem. The Grand Pré which he imagined and painted without ever visiting the Gaspereau country is not the dyke land of reality. Both are charming, but around the vast level of green grass which lay below us there were no whispering pines or hemlocks, no suggestion of the primeval forest. To the low, undulating or level fields which bordered the Gaspereau, the Pereau, the Grand Habitant, and other rivers of this region, the Acadian farmers added by degrees marsh lands naturally swept by the tides, but from which they carefully and permanently excluded

PLATE XXIII

Grand Pré meadows from Hortonville.

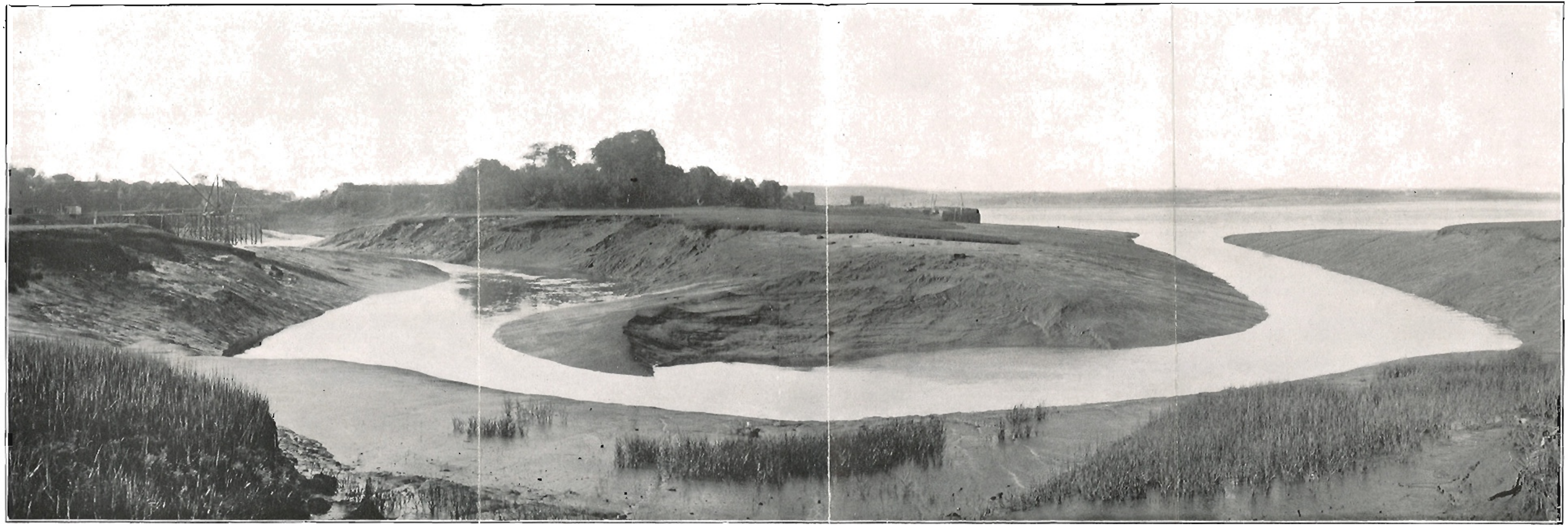
all salt water. Longfellow's picture is of salt meadows flooded annually by the sea, and surrounded by a forest country, romantic in character. We saw forests far away on Blomidon, and back of us in the upper reaches of the Gaspereau; but near the basin of Minas and the dyke country of Grand Pré the apple tree and the willow are, in this generation at least, kings among trees. To flood Grand Pré with salt water would be to carry ruin and desolation to its fertile acres, and sorrow to the hearts of its thrifty owners."

Looking down upon the basin from Blomidon, on the following day, Bolles wrote: "It was dreamlike to see the tide creeping in over the shining red sand and ooze, and changing their vivid tints by blending with them its own colours to make tones strange both to sea and sand. The wide expanses of mud left bare by the tide told in their own way the story of the Acadian dyke builder. No man of the soil could see the riches exposed daily to view without wishing to keep them for his own tillage."

If one wishes to learn more fully what these marshes are, and how their surfaces have been reclaimed and their creeks harnessed and controlled, let him read a paper by Prof. W. F. Ganong of Smith College.[1] Most of that which follows in the next few pages has been taken *verbatim* from his paper, though somewhat reduced and altered in detail.

Around the bay of Fundy and its branches, in New Brunswick and Nova Scotia, there are about 75,000 acres of salt marsh land and associated bogs. Of this large area, over one-half lies around Cumberland basin, extending up the Tantramar, Aulac, Missaguash, La Planche, Hebert, Maccan, and Nappan rivers, and spreading widely over the adjacent lowland surface. About three-eighths of this area, or 15,000 acres, lies in Nova Scotia, and the rest in New Brunswick. The country around Cumberland basin is rounded into low, smooth hills and ridges, separated by radiating river valleys. Among the ridges lie the marshes, seemingly level as the sea; and like it, they fill bays, surround islands, and are pierced by points. Seen from the neighbouring ridges, the marshes have an aspect characteristic and beautiful. They are treeless, but are clothed nearly everywhere with dense, rich grasses in many shades of green and brown, varying with the season, with the light, and even with the winds. For the most part, the merging of the colours is irregular, but in places, owing to the different treatment given by different owners to their land, or to the presence of fields of grain or pasture lots, there is something of the checkered appearance usual in highly cultivated land. The many ditches marked by denser growths, the rare fences, and the occasional roads or railways are other signs of the operations of man. Towards the sea are narrow fringes of unreclaimed marsh, poorer in vegetation and generally duller in colour, farther back the green of the marshes gives place to the brown and grey of the bogs, which are further distinguished by irregular shrubbery and trees, and many little lakes. Nobody lives upon the marshes, but scattered upon them are many great barns, all of one and the simplest pattern, unpainted and grey from the weather, standing at any and every angle. These barns are one of the distinguishing features of the marshes, and give to them a suggestion of plenty which is a true

[1] "The Vegetation of the Bay of Fundy Salt and Dyked Marshes." Bot. Gaz., vol. XXXVI, pp. 161-186, 280-302, 429-455.



Meander at mouth of Halfway river, Hantsport.

index of the economic condition of this region; for here are the most prosperous and progressive farmers, and the most thriving country towns in eastern Canada. Especially characteristic of the marshes are the tidal rivers which have helped to build them (Plate XXIV). As is well known the sea here shows a great range of tides, even to over 40 feet. The tidal rivers, winding in the most sinuous courses through the marshes, at times run full to their bordering dykes, loaded with brownish red mud; but the fall of the great tides sends their thick currents tumultuously out, to leave only tiny rills between deep, gaping gashes of slippery mud gleaming in the sunlight. Thus too are extensive flats laid bare about Cumberland basin. The suspended mud gives to the rivers and to the sea a dull red colour which is a striking and a characteristic feature of the scenery of the marsh country. Not all of the rivers, however, are red, for from some of them the sea has been shut out by ingeniously constructed dams, and in each of these the banks are clad with dense, green grass to near the bottom of the bed, along which winds a small, freshwater stream.

The "marshes," in contrast with the upland, appear to be misnamed, for instead of the soft bottom and the rank growth associated with the word marsh, the soil is everywhere as firm as the upland itself, and, on the reclaimed parts, are the finest grasses, luxuriant but not coarse. Indeed, a near view of the reclaimed marsh shows scarcely anything different from the best of fine-soiled, upland, grass land.

In structure, these marshes differ from those along the coast of Maine and Massachusetts. They are composed almost wholly of fine sand, silt, and clay, brought in by the tides and packed firmly into place, whereas in New England and other coast states, the structure is largely vegetable, consisting of interwoven fibres, rootstalks, and blades of salt grasses whose profuse growth has been from the beginning an important factor in catching and holding the muds. Nor was the sediment which has been heaped up to make the Bay of Fundy marshes and flats been brought by rivers from the surrounding land; it has been brought wholly by tides sweeping up from the gulf of Maine. The great bulk of this sediment is very fine, nearly all the particles having a diameter less than one-tenth of a millimetre, and most of them less than one-hundredth. It thus ranges from fine sand to silt and clay. Organic matter constitutes less than 10 per cent; and water from 2 to 4 per cent. The source of the sand is seen in the crumbling red sandstones outcropping in wave-eaten cliffs around the shores of Minas and Annapolis basins and elsewhere on the bay of Fundy, as well as in broad surfaces on the floor of the bay, which the swift, tidal currents sweep and scour, in the vigorous manner already described. Every twelve hours the incoming tide, clouded with this red mud, whirls, eddies, and rushes up the deep creeks, rising higher and higher and spreading out over the flats until at last it covers all but the grassy marsh itself. As the tide turns, some of the mud settles quietly to the bottom. To be sure, the greater part of it is carried back by the outflowing creeks; but on the whole it does not go as far as the point whence it came on the flood tide. That which is left, as a shiny, sticky layer, may be an inch or two in thickness, if the place is well sheltered from currents. In a hollow iron cylinder on the flats near Windsor, above low water, Mr. M. Murphy, provincial engineer in 1888, measured 30 inches of fine sand and mud deposited by the tides in one hundred and twenty-two days. Where the sea has been allowed to cover old dyked marshes or to invade ditches which it could not formerly enter, deposits 1 or 2 inches thick are known to have been made by a single tide. Professor Ganong, measuring the muddy water of tidal creeks, has found that sediment is commonly less than 2 per cent of the entire volume, although occasionally an outgoing current, just before low tide, may carry as much as 4 per cent. In this fashion a thickness of mud has accumulated which, near Aulac station at least, as shown by railway borings, is 80 feet.

As the tides move in and out of the creeks, between muddy banks, the currents are directed against one or the other, as in ordinary rivers, steepening them and undermining the salt marsh turf at the top, so that blocks are torn from it. Meanders or ox-bows thus develop, which resemble those of freshwater rivers, but are more symmetrical, because they are shaped by currents which run alternately up and down stream. Professor Ganong says that a comparison of modern charts with certain old French plans shows that the meanders have wandered considerably during the last century and a half. In some places, as near Aulac, there are concentric lines of dykes, 200 or 300 years old, far from any modern bends of the creek, showing where it formerly meandered. In the beds of creeks and of passages which serve as straits above half tide, like the "guzzle" between Boot island and the Evangeline shore, sands are thrown by the swift currents into ripples 2 or 3 feet high and several feet broad. Bars and shoals shift back and forth on the tide-swept floors of the basins, especially off the mouths of tributary rivers.

The surface of the marsh is completed by a firm growth of grasses, of which the fox grass (*Spartina juncea*) and the black grass (*Juncus Gerardii*) are the most abundant. It stands at mean high tide. Inasmuch as the range of tides rises, up the estuaries, the marsh level, likewise, rises inland. So, at the head of the marshes of the La Planche the surface is 5 feet higher than at the mouth of that river. A curious evidence of this slope is seen on a great "ox-bow" of the Tantramar, west of Amherst, where the incoming spring tide, rising as it circles the meander, overflows its banks, and lets the water drain back, downhill, across the neck of the meander, to the point which it passed a short time before.

The marshes, which are really the flood-plains of these tidal rivers, are higher along their banks than at points more remote from them; for when the waters spread over the marsh they naturally drop most of their sediment, particularly the coarse part, near the banks. It follows that whatever fresh water reaches the marshes by discharge from surrounding slopes, or by direct rainfall, accumulates in depressions around the margins of the marshes, or, if farther out, between the creeks. True freshwater bogs thus grow up, reaching their best development at the heads of the marsh, where they are commonly partly occupied by shallow lakes or ponds. Soundings show that the freshwater peat may reach a depth of 7 feet. Several explanations might be offered for the fact that the peat extends below high tide level; (*a*) it may have grown as a floating mat, and settled under the weight of constant additions, until it filled up the pond and rested on the bottom; (*b*) the area overflowed by the tide may have been so restricted by accumulations of sediment and by reclamation that it has caused the tides to increase in height, thereby raising the level of the salt marsh, and encouraging an equal upward growth of the peat bogs; (*c*) during the growth of the deposits, salt and fresh, the sea-level has risen; or (*d*) the coast has sunk, by an amount equal to the depth of the peat, below high water-mark. This explanation is put last intentionally, to show that though it is theoretically as acceptable as the other explanations, it is by no means obligatory.

To reclaim this marsh, three things are needed: (1) to shut out the sea, (2) to wash out most of the salt, (3) to provide for the removal of the fresh water falling as rain or draining from the upland. The sea is shut out by dykes of the usual sort. These are triangular in section, built of the marsh mud itself, many with a core of stakes and brush. Against the open sea they may be 6 feet high, and they are protected from the wash of the waves by lines of stakes or piling and loose stones; but along the rivers they are much lower, for up the rivers the marsh itself is progressively higher. The removal of the salt takes place naturally by action of the falling rain, which washes it through the drains into the sea. It requires three or four years in newly reclaimed marsh to do this sufficiently to allow the more useful grasses to grow. To allow the rain water to drain off is all important, not only for removal of the salt and for proper aeration of the soil, but also to prevent the ever-present tendency to formation of bog plants. This drainage is accomplished by a system of open ditches, which are only a foot or two deep away from the rivers, but are much larger and deeper near them, partly to give a fall and partly because of the greater height of the marsh there. At the outlets of these ditches on the rivers the fresh water is allowed to drain out by an arrangement which does not allow the tide to enter, namely, by placing under the dyke a wooden "sluice," in which hangs a "clapper," hinged at the top and inclining outward towards the river at the bottom. When the tide is out, the pressure of the fresh water opens this; when the tide rises, its weight tightly closes it. Of course, the fresh water then accumulates in the ditches, but never for long, for the sluice is not far below highwater-mark. These sluices and clappers last indefinitely, apparently preserved by some antiseptic action of the salt water. A sluice of this kind is used not only in the ditches but frequently in a dyke thrown across an entire river, as in the case of the Aulac. The entire structure, dyke and sluice, is then called an aboideau, and such a river is said to be aboideaued.

The process of flooding a piece of land that has degenerated through cropping, or through bog growth, as a consequence of neglect of drainage, is simple. The dykes are broken down at convenient places, and the tide is allowed to flow at will over the old marsh. Bog vegetation is killed immediately by the salt water, and it, as well as the entire marsh surface, is soon covered with several inches to a foot, or even more, of new mud. This requires from one to three years, according to the situation of the marsh. The dykes are then rebuilt, ditches are opened, the vegetation goes through its usual cycle, and in from two to four years the land is again bearing rich English hay.

In addition there has grown up within a century a most important practice of reclaiming and converting into marsh both the lakes in the bogs and the bogs themselves. Its principle is simple, though the practice is by no means so. Canals are dug from the tidal rivers into the lakes, whereby the latter are drained and the tides are allowed to enter with the rich mud. In this way a lake may be entirely filled with mud and become the richest of marsh. After the lake has been thus reclaimed the surrounding bog is attacked. The salt water turned upon the bog kills at once all vegetation, which compacts, sinks, becomes covered with marsh mud, and gradually comes into rich marsh.

The marshes were first reclaimed by the Acadian French, who began the work in 1670 and continued it, raising much grain, until expelled by the English in 1755. They developed the methods of reclamation (of marsh but not of bog) still in use, and many of their old dykes are still to be seen. The extent of their operations is well shown upon several maps of the time, particularly on "A Large and Particular Plan of Chignecto Bay, 1755." The lands lay vacant from 1755 to 1760, after which they were granted to New Englanders and English, and their settlement and reclamation has continued steadily to this day.

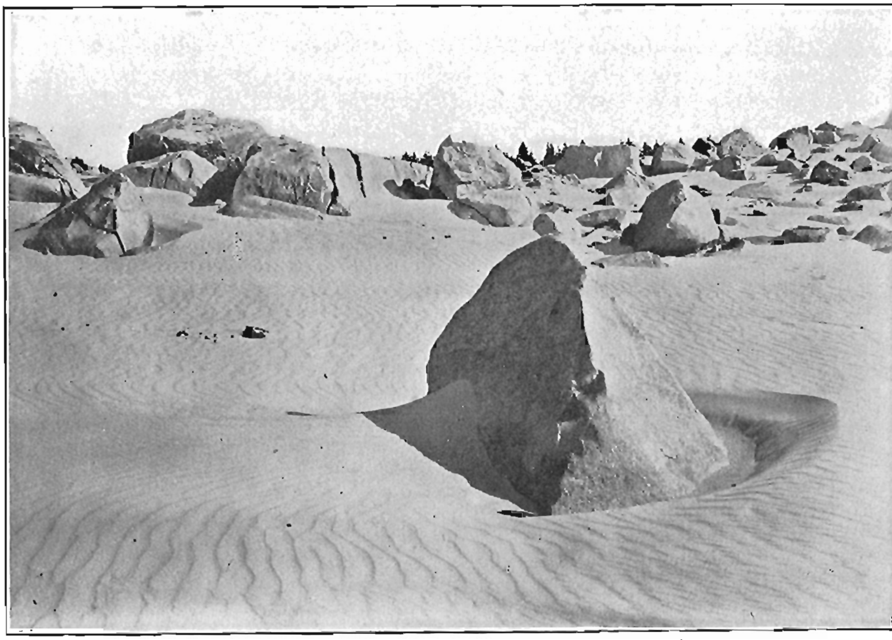
Professor Ganong is authority for the statement that some dyked marshes are positively known to have been cultivated for seventy-five years with no renovation whatever, and probably for one hundred or one hundred and fifty years before that. It is hardly surprising, then, that the surface of the dyked marsh is a foot or two lower than that of the wild marsh outside the dyke. Shrinkage would be expected, under the system of cultivation which has been described, because of loss of water involved in the lowering of the water-table, because of loss of material by solution and cropping, and because of settling of the uppermost layers as they are worked through by growing rootlets. There are no exact measurements to show how much shrinkage is to be expected from these causes; but with a tidal range of 30 to 40 feet, 2 feet does not seem too much to allow. It is possible, of course, that during the last three centuries the range of tide has increased, and the undyked marsh has been built up equally. The difference in height might be explained, also, by a sinking of the coast during this period, as some investigators have thought. This question will be discussed in the next chapter.

SEQUENTIAL FORMS DEVELOPED DIRECTLY BY THE WIND: DUNES

Dunes are sand-hills heaped up by the wind. Although commonly associated with desert conditions, they are likely to grow up wherever any considerable tract of sand is not held down by vegetation and is dry enough to be blown about by winds. In Nova Scotia there are small groups of dunes at many places; but good dune fields at only three places; southwest Port Mouton, cape Sable, and Sable island. In most cases the sand comes from beaches, having been previously transported by the waves and tides from the drift or from the disintegrated bedrock on the shore. A good idea can be obtained of the manner in which sand-hills originate by studying what takes place at the upper edge of a sandy beach like that at Lockeport.

As the wind sweeps across the smooth surface of the beach, fanning the sand along in a low cloud, it encounters weeds, tufts of grass, bushes, stones, and other small obstacles. At each point where the velocity of the small sand cloud is checked, sand grains are dropped, making a little drift behind the obstruction, perhaps only an inch or two high, yet easily distinguished when the wind has ceased and all sand is at rest. Its shape will depend primarily upon the character of the obstruction; but in any case its length runs in the direction of the wind that dropped it. In places where continuous surfaces of several square feet or more have been evenly swept by the sand, without drifting, distinct ripples may be seen—low, sharp-crested ridges, separated by shallow troughs of greater breadth, like lilliputian waves, made of sand. When the wind blows, these ripples creep forward, as sand grains are picked up and carried in, and others take their places—in so rapid and orderly a manner that one watching them forgets that the sand ripple is not moving bodily, but that the shape of it is creeping forward as individual grains hurry on their way. If the sand blast strikes a large rock, it divides against the front of the obstruction, swirls around and over it with accelerated speed, and heaps up a gracefully curved mound against its back (Plate XXVA). These sand-drifts are almost as white as snow-drifts, and possess the same variety and beauty of form.

Of the tens of thousands of embryonic dunes that spring up on a beach, few are destined to develop into mature sand-hills. Many are swept away by storm waves or scattered by the wind itself, owing to changes of direction. Those which are not utterly destroyed in this manner, but continue to grow, gradually overlap one another and are absorbed into hillocks and mounds several feet in diameter and perhaps a few feet high. These we may call "young" dunes. Their form varies greatly according to the behaviour of the winds and the character of the vegetation. If nothing but beach grass and very low weeds, like sandwort or wild pea, become established, as is frequently the case, the dune is low and flattish, expanding as fast as the grass extends its interlacing roots outward over a wider area, and sends up its long blades (Plate XXV B). Where shrubby forms of vegetation like alder and willow are growing in the sand, a more localized wind-break is afforded and one that increases in height faster than in area, because of the habits of growth of the bushes. Even those that are commonly to be seen in boggy places flourish as the dry sand piles up around them to a depth of 10 or 15 feet, allowing only their outer branches and leafy foliage to project. Thus the dune expands, under the guidance of vegetation, as time goes on, becoming more and more the cause of its own growth as it obstructs the wind more and more seriously. Its rate of growth may increase faster than the vegetation can follow; and the hill will then become master of the situation. No longer pinned down by buried roots, fibres, or foliage, the sand-hill will begin to move, under the influence of the wind which sweeps sand up its windward side and lets it fall on the leeward side. The transference of sand thus tends to give the migrating dune a steep front and a flatter back, and leads to a peculiar stratification called crossbedding. Individual sand grains, when examined with a lens, will be seen to be more thoroughly rounded than water-worn grains of beach sand; because dryness permits direct contact and rapid abrasion of their corners and edges, whereas wetness affords each grain a capillary film of water that serves as a cushion to protect it from impact of its neighbours. Beach sand endures for long



A. Sand drifted around boulder, Port Mouton.

B. Young dune in beach grass, Somerville.

periods of time, but wind-blown sand soon wears out, and fresh grains must be constantly supplied to a sand-dune if it is to continue to exist. As a dune marches inland it is liable to bury and kill forest trees, leaving only the bare, lifeless trunks and limbs, like grim skeletons, in its wake. In Nova Scotia, dunes are seldom more than 20 or 25 feet high; but some of those on Sable island are as high as 110 feet.

Dunes after all are fleeting forms. They vanish, one by one, as they move away from the beach; for though new dunes spring up behind them and cut off their supply, the sand in them is ground fine by constant friction, and is scattered more and more widely. The dune begins to spread and flatten. Beach grass and the other vegetation again get hold of it, and cover it little by little with turf. At last the dune has settled down to a period of quiet old age.

At any time in its life a dune on the shore is liable to suffer from inroads of the sea during great storms. Lines of dunes behind beaches very commonly have cliffed backs, in which rude stratification with layers of matted grass and other signs of periodic additions of material are freshly exposed by every storm. A beach pebble in a cliffed dune, several feet above high tide-level, may cause wonder as to how it got there, enclosed as it is by wind-blown sand. As a rule, if not always, the answer is that the stone was cast up by storm waves, which flung it out of reach of later waves, leaving it where it might later be buried by more dune sand. Sea-shells, fish bones, sticks, and other objects occur in dunes, also, where they have been dropped by winds or birds. All these are isolated, however, and only emphasize the prevailing uniformity of texture of the great bulk of the structure of the sand-hills.

SABLE ISLAND

Eighty-five miles off the coast of Nova Scotia is a slender, dune-capped reef of sand, known as Sable island. No other bit of land on the coast is so fully exposed to the fury of north Atlantic storms. It stands near the outer edge of the banks, with 100 fathoms of water close to its eastern end. Rich in romance as well as tragedy—for on its shores and hidden reefs countless vessels have been wrecked during the last three centuries—inhabited by a flora which curiously resembles that of New Jersey rather than Nova Scotia, and by birds which are not known to breed elsewhere; and seldom visited except by employees of the government, it is at once the loneliest and the strangest spot in the Maritime Provinces. Its origin is a mystery, for solving which there are several alluring clues.

Broadly speaking, Sable island includes not only the visible island, which is a long, narrow crescent of sand concave towards the north, but also its two bars, which extend to east and west from the horns of the crescent (Figure 16). Thus defined, it consists of the island proper, about 21 miles in length, the west bar, 17 miles long, and the east bar, 13 miles long. The island proper consists of two nearly parallel lines of sand-dunes, which meet at its extremities, but which are separated elsewhere by a shallow pond about one mile wide, so that the whole form is like a bow whose string is on the north side. The width is only 2 miles. It has been said that there is not a single pebble on the island, nothing but sand.

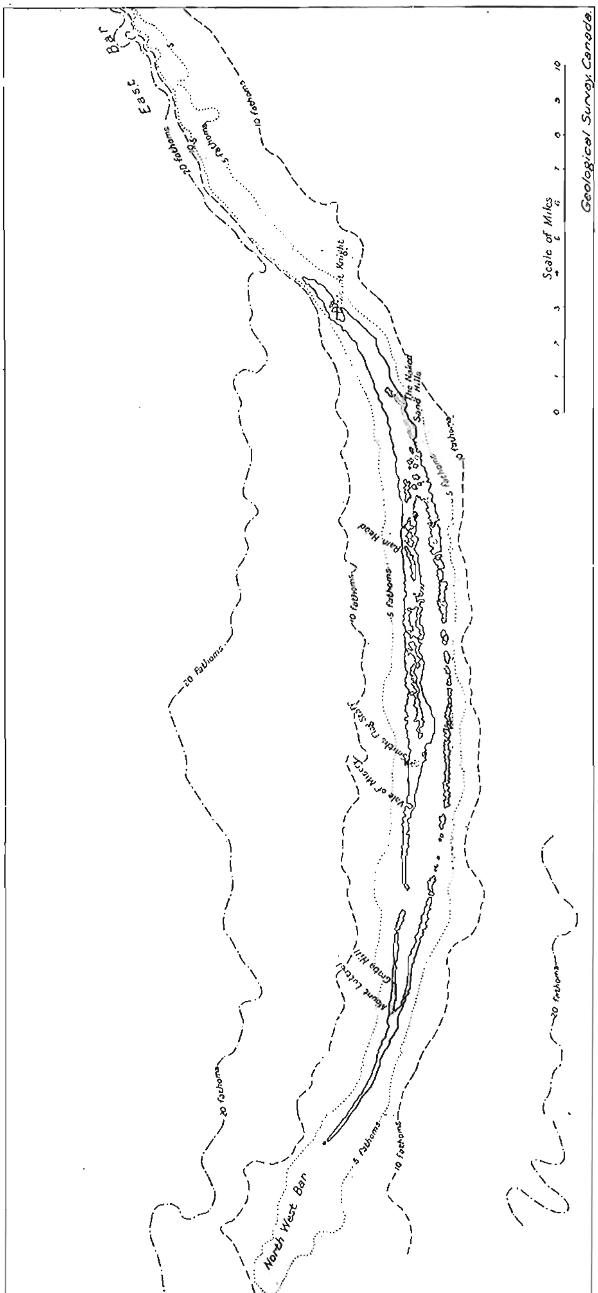


FIGURE 13. Sable island (by J. F. W. DesBarres, 1766 and 1767).

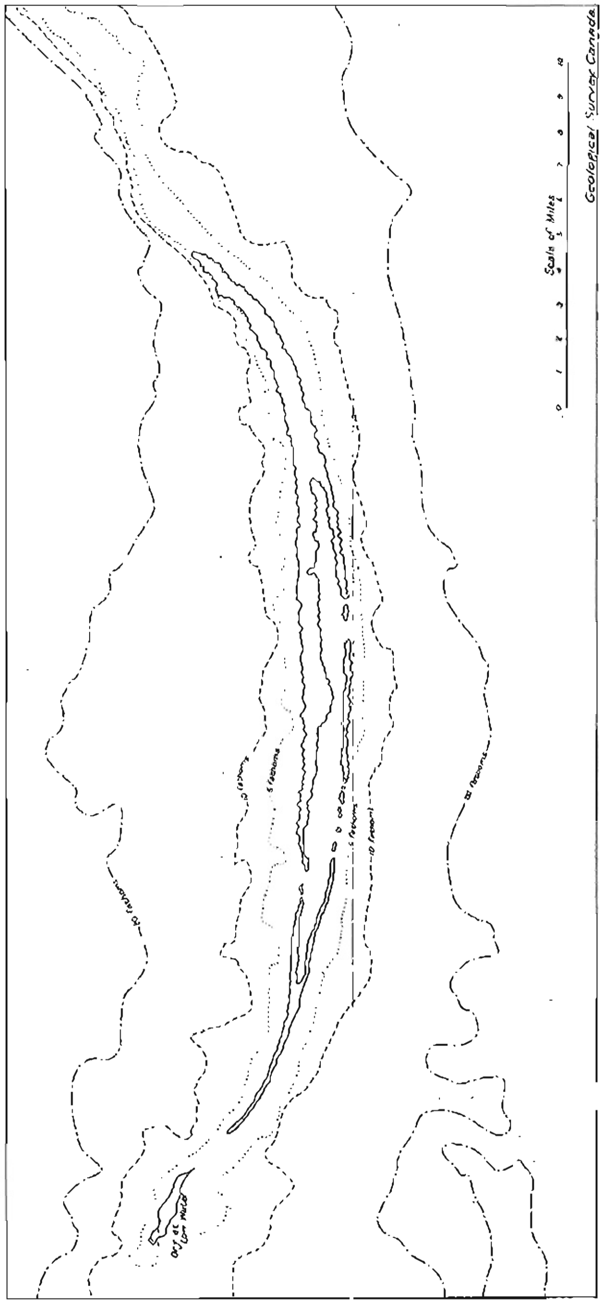


FIGURE 14. Sable island (by Jefferys, 1770).

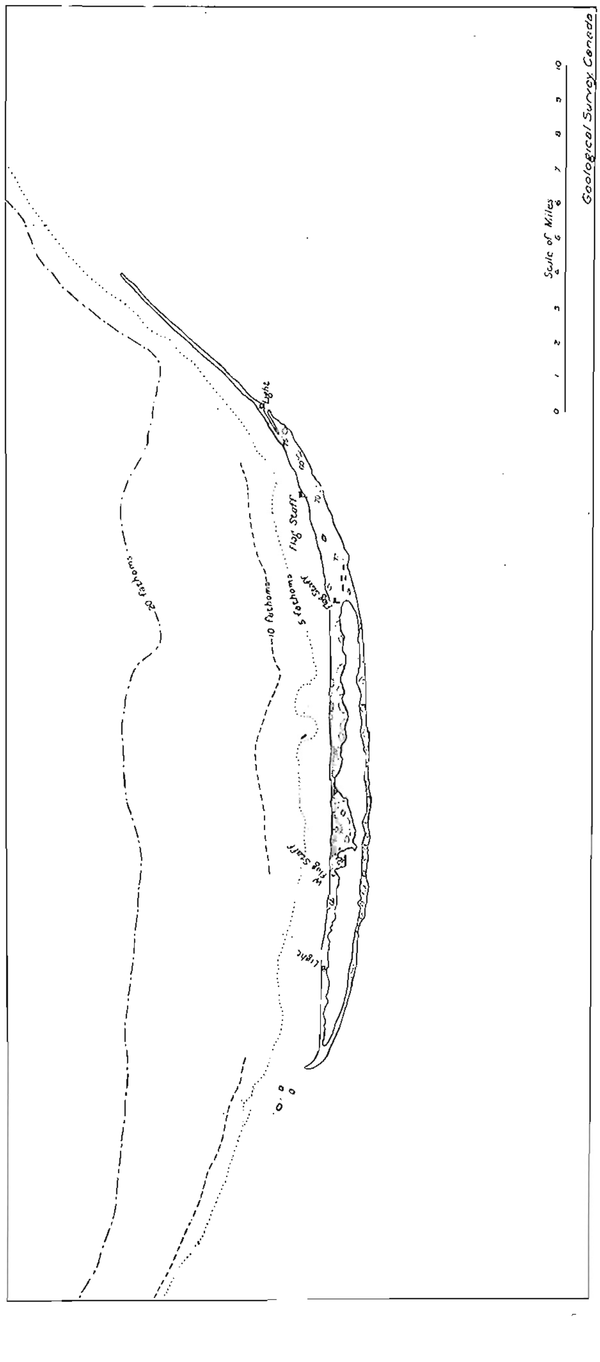


Figure 15. Sable island (from surveys by Bayfield and Shortland, 1851).

Mr. Boutillier, for twenty-eight years the superintendent of the Government station, says that "if there are small pebbles found on the shore they are probably ballast from wrecks." Some garnet sand and some magnetite sand occurs, but nearly all of it is quartz which has been handled repeatedly by wind and waves. The dunes commonly range from 40 to 75 feet in height; but at one place they reach 110 feet.

Although the tide never exceeds 4 or 5 feet, the shores of the island are swept by strong currents, which circle around it in a strange manner, under the influence of both tides and winds. Pieces of wreckage and bodies of those who have perished in the surf have often been swept half-way around the island before being cast up on the shore. This drift is highly efficient in removing sand from sea-cliffs where the waves are sawing into the shore, especially at the west end of the island, on the south shore. Landing can be effected only in small boats; it is always difficult, in many places dangerous, and in some quite impossible, on account of heavy breakers on the sand reefs which lie a few hundred yards offshore.

During the three centuries which have passed since the French navigators first visited and described Sable island, the sea has wrought extraordinary changes in its outline. The more important of these are shown by Figures 13 to 16. Earlier charts are not sufficiently accurate for close comparison, and later surveys have not been sufficiently detailed to bring out all the changes which observers on the island have recorded during the last half century. In 1767, when the Des Barres chart was made, the island was 26 miles long and $1\frac{3}{4}$ miles wide (except at its narrower ends). During the next eighty-four years, according to the chart of the Admiralty, by Bayfield and Shortland (Figure 15), it lost 6 miles from its western end (mainly by the destruction of the west bar), and gained 5 miles at its eastern end, through additions to the east bar, which appears as a long, narrow spit. The loss from the body of the island, disregarding the two bars, as measured from the east end of the central "pond" to the west end, during this period, was approximately 2 miles. The width of the island seems to have decreased, meanwhile, from $1\frac{1}{4}$ to $1\frac{1}{8}$ miles. The entrance to the pond, through its north bar, was closed by a storm in 1833, and never reopened. It is now known as lake Wallace. From reports of government officials since 1800, the following records are given of destruction by storms. During the four years between 1809 and 1813, 4 miles were removed from the western end, and the signal station had to be moved inland. In 1813, a single gale trimmed away an area approximately 40 feet wide and 3 miles long. In the thirty years prior to 1833, 11 miles of the western end disappeared, and the signal station there was moved three times. At least 5 miles of the 11 miles must have been from the outer part of the west bar, where waves formerly broke. In 1881, a gale removed a strip 70 feet wide and half a mile long; a month later a second storm trimmed away 33 feet from the whole length of the island; and soon after it, a third one removed an area 48 feet wide and a quarter of a mile long. A lighthouse which had been built near West point in 1873 was moved eastward a quarter of a mile in 1881, $1\frac{1}{2}$ miles farther in 1888, and is now (1915) again in danger of being washed away. The wasting of the western end of the island has not been equalled by the additions to the east bar. Evidently part of the sand cut away by the

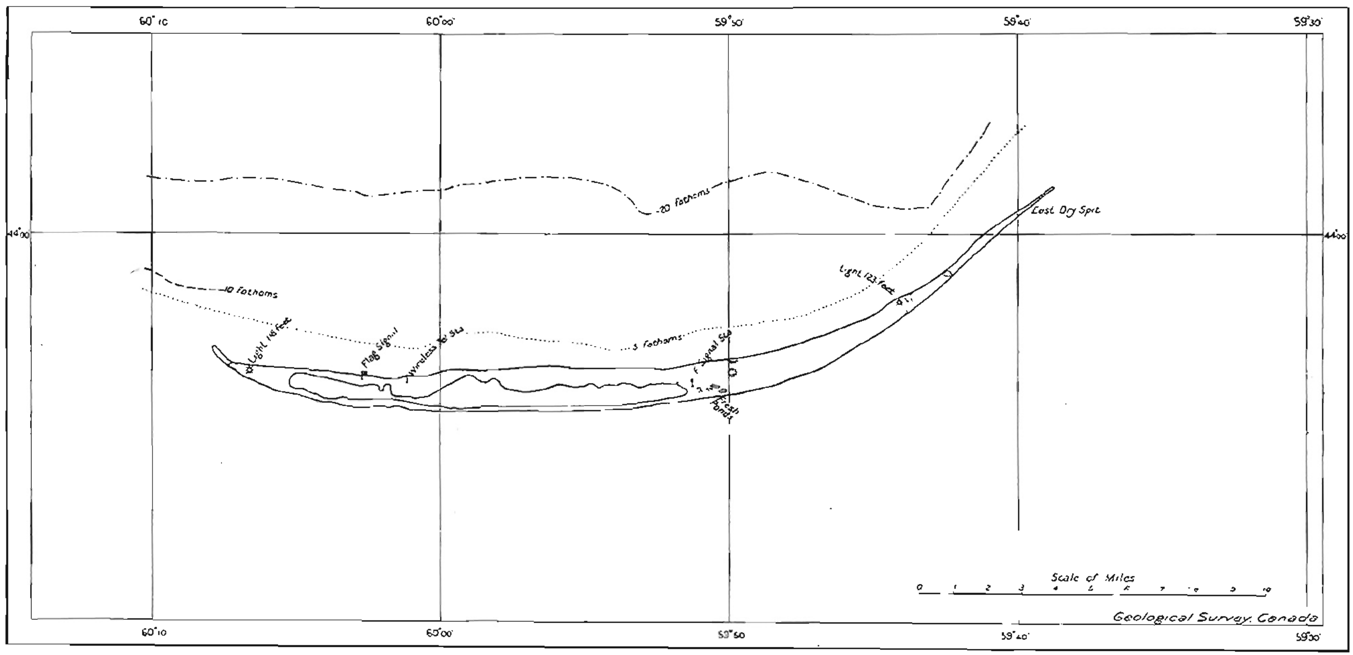


FIGURE 16. Sable island (from surveys by Bayfield and Shortland, 1851, and Canadian Government, 1899).

sea has been spread offshore, and the continuance of the process will eventually lead to the complete consumption of the island by the sea. It is also apparent that though alteration is always going on, slowly, the great changes are wrought by storms of unusual magnitude. Lashed by waves and swept by tides, reefs on the east bar which are commonly submerged are in some places heaped up into visible bars. This leads to sensational reports of newly created islands. Such a report was widely circulated in the daily papers in 1913. These temporary reefs are liable to disappear, later, as suddenly as they came, under the influence of wave attack from a different direction. At the rate at which the island (excluding the bars) lost in length in the period between 1767 and 1851, it would take about eight centuries more for the sea to consume it altogether. It is plain, however, from the records cited, that the rate of destruction has varied greatly, being very rapid between 1803 and 1833 and comparatively slow before and since that period.

In view of the gradual destruction of the island during the last two centuries, it is pertinent to ask how much larger it may have been ten, twenty, or fifty centuries ago, and how it came into existence. The pair of great sand-bars, with their high dunes, suggest a former condition like that on Magdalen islands, where at the present time several rocky islands with wave-eaten borders are tied together by double bars. In the course of time, as the cliffs recede farther and farther, the islands will be devoured, and the bars, released at both ends, may remain for a while, shifting across the wave-planed platform at the mercy of the sea while the winds maintain their sand-dunes, until at length they, too, are erased and submerged. If Magdalen islands stood far out in the Atlantic ocean instead of in the gulf of St. Lawrence, they might today be in the condition of decrescence which is seen in Sable island. The fact that the curvature of the sand-bars today is convex seaward may be accounted for by the more severe attack on the south side, bending the two ends of the bars back to form the "bow." It must be admitted, however, that the charts fail to show definite wave-planed platforms off the two ends of the island, where the hypothetical islands should have stood in the former stage.

Botanical evidence has been offered by Professor Fernald of Harvard University to show that Sable island is a small remnant of a sandy bridge which once stretched from New Jersey to Newfoundland. On the island is an assemblage of sand-loving plants which closely resemble the flora of Newfoundland and New Jersey, but not that of Nova Scotia and Cape Breton island. It is suggested that at the close of the glacial period plants had access to Newfoundland along a chain of sand-bars and islands, possibly in part terminal moraine deposits, and that this chain has been broken up and all but obliterated by the sea during the post-Glacial interval. At the rate of wasting of Sable island within historic time, such a chain as this might well have been destroyed in 5,000 or 10,000 years. Moreover, in addition to the direct, normal attack of the sea, there has been an increase in height of sea-level, within this period—or its equivalent, a sinking of the coast. Although the extent of this change of level is not known, as yet, it may have been an important factor both in causing the acceleration of the process of wave erosion, and in drowning the islands by direct submergence. It is indeed a strange fortune, that permits the witnessing today of the destruction of the last small link in so long a chain.

CHAPTER VI

CHANGES OF LEVEL

In the foregoing chapters, attention has been called to several changes in level of land and sea. The accumulation in early geological time of 5 miles of muds and sands of the Gold-bearing series, required a long-continued, slow subsidence of the sea-floor which must have been very uniform throughout Nova Scotia, and must have occupied many centuries. In the Devonian period came the conversion of the flat-lying sediments into folds, by a more violent internal movement of the kind that wrinkles the crust of the earth into mountain structures. After the reduction of these lofty mountains to the smooth plain of Cretaceous time, came the broad upwarping of the Maritime Provinces, by which the lowland became an upland. During the subsequent erosion of lowlands and valleys, there was at least one more upwarping, which caused rivers on the newly and unequally eroded lowlands to entrench themselves in the plains, after which a sinking of the whole region transformed its outer parts into banks, and the sea was able to encroach inland through drowned valleys. At the close of the last Glacial epoch, the land was more deeply submerged than now. The evidence of this is clear along the coast of Maine and New Brunswick, up the St. Lawrence valley, and around lake Champlain, where sands and clays containing marine fossils lie on top of the glacial drift, and distinct gravel beaches are found in places now from 100 to 600 feet above the sea. Apparently there has been an uplift of the region since the retreat of the ice; but as will presently be seen, it is perhaps possible that this change, as registered in the Maritime Provinces, consisted in part of a movement of the sea instead of a movement of the land. Following this change of level, by which the beaches came to occupy positions several hundred feet above the sea, there was a submergence of the coast in the same region, to an extent of at least 35 feet. This is registered by drowned forests around the head of the bay of Fundy. Finally, there are a number of features of various sorts which have led to a general belief that changes of level are still in progress. If that be the case, it is a question of practical importance; for it is obvious that a sinking of the coast, even at the rate of a few feet a century, if long maintained, involves serious loss of property, and necessitates protective measures of great expense for future generations, if not for the present generation. It is well, therefore, to examine the evidence and consider whether it be valid.

RAISED BEACHES FORMED DURING THE RECESSION OF THE ICE-SHEET

Evidence of post-Glacial emergence in Nova Scotia is found chiefly along the Bay of Fundy shore. It consists of shell-bearing clays on the floor of Annapolis valley and Minas basin, raised beaches on Brier island and near Digby, and raised deltas and estuarine flats near Parrsboro, Truro, Bear river, Sissiboo river, and elsewhere. Terraces on the shore of Arisaig have induced the belief that they, too, are elevated strands; but the correctness of this interpretation may be questioned. On the south coast, from Yarmouth around to Canso, and on the entire shore of Cape Breton raised beaches or other signs of post-Glacial emergence are absent—a fair indication that that part of the region did not participate in those uplifts which are so distinctly registered in Maine, New Brunswick, the Champlain valley, Quebec, and Brier island.

Brier island is the most exposed place on the Bay of Fundy side of the province. Here the double trap ridge of North mountain dips into the sea. The two rocky crests of the island are covered with stony drift and disintegrated soil. While it was submerged, the waves beating on the side of the north ridge, behind what is now Westport, gathered stones from the drift and ledges and made beaches of them in pockets and coves near the hilltop. There they remain today, about 115 feet above mean sea-level. The absence of beaches or of any rolled gravels above that level, in contrast with the abundant signs of wave-action below it, suggests that the 115-foot beach registers the upper limit of post-Glacial submergence, but the area above that height is small, and the negative evidence alone is not wholly to be trusted. The larger stones collected from the ledges on this north ridge were packed into coarse pocket beaches, and the smaller stones were swept southwestward across a gap in the ridge and spread out in a broad beach, on which the Westport cemetery now stands. In a pasture between this cemetery and the hill, faint beach crests can be distinguished on the surface, and on the road to the cemetery from the village several good beach ridges are crossed, the most distinct one being at the church, about 30 feet above mean sea-level. In the cemetery the structure varies from coarse gravel to fine sand. It is noticeable that the stones in the beach deposits become increasingly round and small down the slope, because, while the coast was emerging from the sea, waves and undertow were constantly dragging stones offshore and working them over into newer, lower beaches. The exposed situation of the island, and the southwestward movement of its latest glaciation make it appear certain that the submergence was by the sea, and not by any temporary ice-girdled lake. All that is needed to establish fully the marine origin of the beaches is the discovery of marine shells in them, similar to the shells in the beaches of New Brunswick and Quebec. If the 115-foot beach mark the full measure of submergence on Brier island, the change of level on this side of the bay of Fundy is only about half as great as on the New Brunswick side; for beaches associated with shell-bearing clays and sands near St. John testify to an emergence of 200 feet. If this difference be due to a broad upwarping of the region, tilting it in a southeasterly direction, as suggested by the lines shown on Figure 17, signs of very little uplift may be looked for east of Yarmouth, and probably none at all along the south coast, between cape Sable and cape Canso. At Freeport, on the north side of Grand passage, opposite Westport, rolled gravels lie on the trap ridge behind the village, but they seem to have no definite wave mark at the upper limit. What little ground there is above 115 feet is occupied by decayed ledges of trap on which the opportunity for distinct marks of wave-action is less favourable than on Brier island.

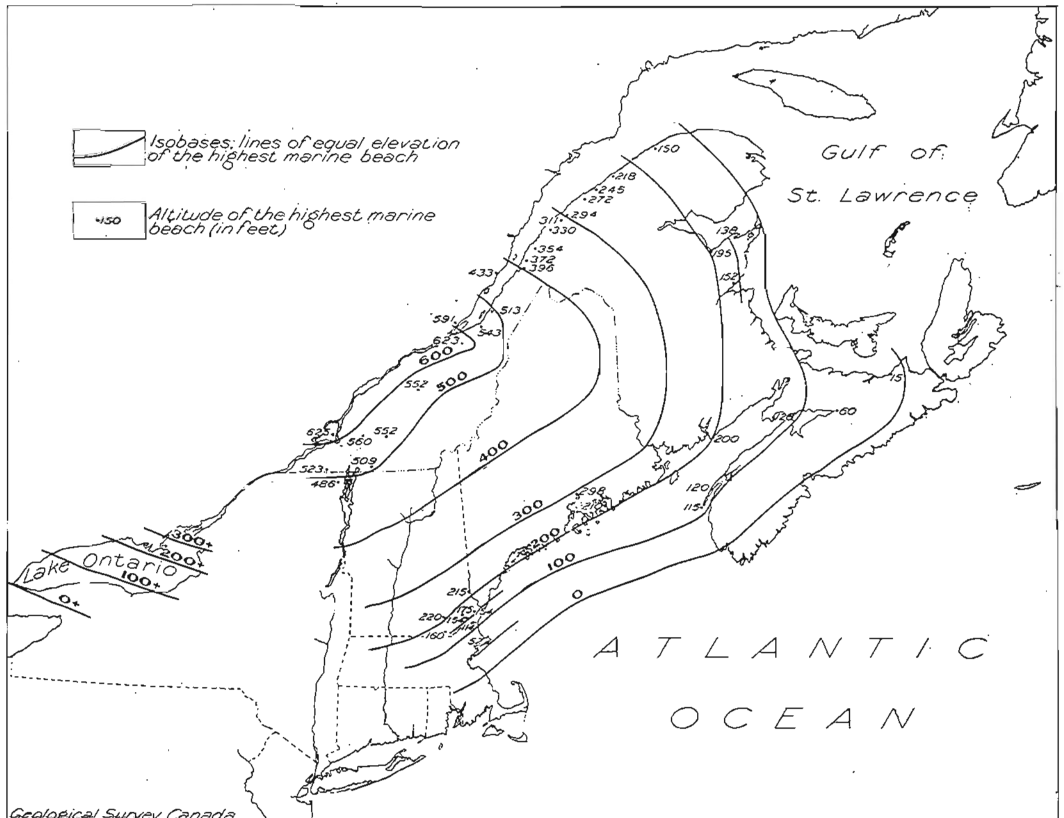


FIGURE 17. Post-Glacial upwarping (shown by isobases).

At Sandy cove, 20 miles northeast of Brier island, is the great gravel plateau described on page 100, with its extraordinary kettle-hole and kames. The altitude of the plain, 120 feet above the mean sea-level, corresponds so closely with that of the beaches on Brier island that it seems probable that, like them, it marks the level of the sea at the time the ice withdrew. The reported occurrence of shells in the deposit, although this was not confirmed by the writer, is strongly suggestive of a marine origin for the gravels, since shells are common in the post-Glacial sea deposits, but they are quite unknown in the stratified drift deposits which accumulated in front of the retiring ice in bodies of fresh water. The presence of the steep-sided kettle-hole and kames seems to require that the plain emerged from the sea to its present height before the enclosed ice block had entirely melted away. Although it is not easy to tell how long an ice mass might linger, thus surrounded by gravel and sand, it is hardly likely that it could remain more than a century or two. The emergence appears, therefore, to have progressed rapidly after the withdrawal of the ice-sheet. This corresponds perfectly with evidence gathered from the upwarped marine beaches of Sweden, by Ragnar Liden, who has been able to compute accurately the rate of emergence as 5 to 6 inches a year for several centuries during the ice recession.

Around Digby, gravels cover the lower ground; and near the Pines hotel they reach up to 123 feet, although the beach-like slope seems to end at 85 feet. Near point Prim an old cobblestone beach is exposed in cross-section in a sea-cliff facing the bay of Fundy, and reaches inland to the foot of a low, rocky cliff about 80 feet above high tide. It is difficult to decide whether this is an old sea-cliff; for it lies in the woods, and the ground at its foot is covered with fallen slabs of bedrock that show no signs of being waterworn. Farther east, near where the road to the lighthouse reaches the government property, three low ridges with even crests and smooth, front slopes resembling beaches run through a field, at altitudes of 88, 73, and 43 feet. They are loose and stony in composition, but the stones are rough and angular instead of waterworn. This might be due to the presence nearby of ledges of amygdaloidal trap which does not quickly become worn into round pebbles.

On the gentle, drift-covered slopes around the head of St. Mary bay, and at the lower end of Annapolis basin, in situations where the slope and exposure would seem to be ideal for beach building, and where plenty of stony material lies embedded in the till, ready to be gathered by the waves, there are no distinct signs of a former submergence by the sea. It is hard to account for the general absence of old strand lines in districts like this which must have been submerged. Possibly shore ice during the departure of the glacier protected the shores from wave-action, and the exceptional range of tide may have prevented distinct marks at any one level afterwards. At the mouths of rivers, however, like the Sissiboo and Bear, are high gravel terraces which are fragments of old flood-plains, showing to what height these valleys were filled with river gravels at the close of the Ice age; and it is not unlikely that the uppermost terrace, in each case, marks the old sea-level. The lower river terraces have no great significance; for they have resulted from the dissection of the valley filling by the river since the uplift of the region, and are probably determined by local conditions. On Bear river, a quarter of a mile above the railway bridge, the topmost terrace is 88 feet above mean tide; on the Sissiboo, near Weymouth, the highest one is 85 feet.

The Parrsboro delta—disregarding the lower river terraces which have been excavated through it—has an altitude near its outer edge of from 60 to 80 feet above mean tide; but as its original margin has been carved away by the river and the sea since the period of emergence, the figure given is not a good measure of the upper marine limit. At several points farther west, on the shore of Minas basin and Minas channel, similar terraces or deltas of gravel and sand have been observed by Dr. Chalmers and others, at similar altitudes, as follows: Parrsboro shore, between Black rock and Diligence river, 110 feet; Spencer Island village, 128 feet, West Advocate, 130 feet. The gravels and sands that cover the floor of the Annapolis-Cornwallis valley are in part, at least, marine; for starfish and shells have been collected from brick clays near Middleton; but since these deposits are scarcely 30 feet above sea-level it is hardly likely that they mark the upper marine limit. They seem instead to be tidal flats which formed on the lowland while it was emerging from the sea. The extensive delta plain on which Truro stands, at an altitude of approximately 60 feet, possibly represents the limit of post-Glacial marine submergence at the head of Minas basin. There are miscellaneous river terraces and irregular gravelly deltas on the shore of Minas basin between Kentville and Windsor, as, for instance, at Hantsport, where a good cross-section can be seen in a railway cut beside Halfway river; but all these deposits lie well below the limits set by the Parrsboro delta and the Truro plain.

In several places on the Arisaig shore overlooking Northumberland strait, are benches and bluffs which have been regarded as elevated strand lines. Although they occur immediately behind a sharply-cut, modern sea-cliff, in a situation which would be openly exposed to wave-action, the terraces lack some of the fundamental characteristics of wave-carved features. A real shore cliff should have an horizontal base, except where landslips or gullies have made it and the bench irregular, or where later attack by the sea has removed part of the bench. The terrace should have at least a veneer of stratified, wave-rolled gravels or sand, gathered from the cliffs and dropped at no great distance offshore. Following the shore-line, there should be found distinct beaches or spits or bars at the ends of the cliffs, where they were interrupted by a valley or where the seaward slope changed to one that was too gentle for cliff cutting, but was favourable for beach building. In short, a shore which has been strongly cliffed should be distinctly and continuously registered. The Arisaig terraces satisfy none of these conditions. The benches, although uniform in level for short distances, rise and fall in an unnatural manner. The lowest and most distinct ranges from 10 to 25 feet above mean sea-level; a second one varies from 60 to 85 feet, and a third from 125 to 145 feet. On the whole, the terraces seem to decline towards the east. The highest one, in particular, is obscure and irregular, and does not have a well-defined cliff behind it. Although the lowest bench, at two places where it makes its appearance, is covered with rolled gravels, and although the second bench at one point where it is cut into by the receding cliff of the modern beach has a distinctly stratified structure, this material does not look like beach gravel, but like glacial outwash; for it consists of coarse boulder beds alternating with fine sand beds. The terraces are discontinuous. There are stretches of coast 2 or 3 miles in length where there is no sign of terracing on the slopes within the range of the supposed submergence. Gently undulating swell and sag topography, common in a ground moraine country, extends from high levels down to the brink of the modern sea-cliff, from 20 to 40 feet above mean tide. In some of the re-entrants, where gentle slopes offer ideal conditions for the construction of long sand-bars, as at Malignant cove, where a strongly built bar appears on the modern shore, there is no higher water-mark whatever. The gentle slopes below 150 feet are as a rule covered by typical boulder clay, containing glaciated stones. Now, it is hardly likely that the sea would carve distinct terraces like those under consideration where the slope is rather steep, and fail at the same time to leave a record of wave-work in the coves and on the more gentle slopes between the cliffed places. The terraces must have some other origin. Although in one place there is a section showing stratified gravels of beach-like habit overlain by boulder clay, it does not appear that the cliffs and terraces are ancient sea-cliffs which were overrun and locally obscured by a sheet of glacial drift during the last ice advance; for in that case none of the terraces would be covered with washed gravel and there are places where there is a considerable thickness of gravels on their surfaces. It is possible that the terraces are connected with the flow of ponded waters along the hillsides during the retirement of the ice front. But it is more probable that they mark the boundaries between belts of hard and soft rock, which run nearly parallel to the coast at Arisaig, and which have yielded differentially to weathering. There is known to be block faulting, also, in the rock structure, which may have influenced the outcrops of hard and soft belts. Of the three terraces only the lowest one shows any of the characteristics of a marine terrace; for it is distinct, is covered with rolled gravels, and extends up certain small stream valleys in old flood-plains. Its discontinuity and lack of horizontality, however, are causes for doubt as to its origin.

There are two different conceptions of the nature of the change of level which is recorded by the raised beaches. It may be assumed that the sea-level has been constant, and that the change consisted in the bulging up of this part of the continent, which raised the shore-lines out of the sea; or it may be assumed that the land has been stationary, and the sea-level fell as the ice withdrew, leaving the beaches high and dry.

The conception of a bulging up of the earth's surface is illustrated by Figure 17 on which the observed upper marine limit at many places is connected by lines of equal elevation, or "isobases." The raised beaches in Nova Scotia seem to harmonize well with those of eastern New Brunswick, Maine, and southeastern Quebec. It is evident that the uplift was not connected in the least with the extent of the ice-sheet, for northeastern Nova Scotia and the island of Cape Breton, which were glaciated by the Acadian Bay lobe during the last great ice advance, appear to have suffered no change of level.

The theory that it is the sea-level which has changed, while the land has stood still, is based upon two facts. It has been shown by Dr. R. S.

Woodward that while the ice-sheet remained the gravitative pull of its mass must have distorted the sea-level, lifting it to a considerable height near the perimeter of the ice-sheet, from which it sloped outward at a rapidly decreasing rate to an essentially uniform level within a few hundred miles. Dr. Woodward estimated that an ice-sheet of the size of the extinct North American glacier, with a thickness at the centre of 10,000 feet, and with a slope which was almost imperceptible near the centre but increased near the margin to about 25 feet per mile, like that of Greenland, would have caused the sea-level to stand fully 300 feet higher than normal at its perimeter. From the ice-front outward, the sea would have descended in the first 69 miles at an average rate of about four-tenths of a foot per mile. The thickness and the area of the sheet which Doctor Woodward assumed are excessive for the stage when Nova Scotia was glaciated; so the amount of distortion of sea-level there could hardly be as much as 300 feet. Nevertheless, it would appear that a lowering of the sea-level from its temporary distorted form to its present, normal form, as the ice-sheet withdrew, is a possible cause for all the apparent elevation which has been noted in the 115-foot beach on Brier island, the 120-foot outwash plateau at Sandy cove, and the 130-foot plains of the Parrsboro shore. The extraordinary rapidity of the emergence which seems to be required by the kettle-hole and kames in the middle of the Sandy Cove plateau is easier to understand if the emergence was caused by the lowering of the sea-level as the ice retired; for the retreat of the glacier may have been rapid. It would not be so easy to believe in the rapidity of the change of level if it consisted in an upwarping of the land; for it is generally supposed that all such changes are slow and long continued. Although the absence of similar raised beaches in other parts of the coast of Nova Scotia and Cape Breton island might be offered as an objection to the idea that the change was one which affected the sea over the whole glaciated region, it must be admitted that there is a puzzling absence of distinct records even in that part of the coast where the change of level is locally recorded by raised beaches and fossils so distinctly as to be unmistakable. Perhaps the most cogent reason for preferring the theory that the movement was a positive upward movement of the land is the fact that where the old water-planes have been carefully measured and plotted in profile, as in the St. Lawrence valley and the Great Lakes region, they show a much steeper slope than those which Doctor Woodward estimated to be possible as a result of gravitative attraction by the ice. On the whole, therefore, the emergence seems to have been due to an upwarping of the land.

LEDGES FAULTED SINCE THE ICE AGE

There are evidences in some places of small dislocations in the bedrock since the Glacial period. The best observed example of this post-Glacial faulting is seen on a ledge beside the Annapolis post road about 2 miles northwest of Caledonia Corner. This ledge is on the southwest side of the road, about 100 yards beyond a blacksmith shop. Though small, it attracts attention because it looks like a flight of steps. Its odd form is due to the fact that the smooth top has been broken in two places about a foot apart, and displaced vertically along the planes of cleavage. The uplift is on the northwest side of each fault crack. That the faulting took place after the surface of the ledge had been glaciated is shown by the fact that the edges of the steps are not in the least rounded, and that where the grooves run out to the edge of each step, they match grooves on the step below, which begin at the base of the little fault scarp. This indicates, of course, that the displacement was a vertical one, with no horizontal component. Some of the grooves can be traced 3 or 4 feet. They run south 33 degrees east, or roughly perpendicular to the fault scarps, which are north 51 degrees east. A less distinct case of post-Glacial faulting is to be seen about 200 yards farther northwest, on the other side of the road, where another glaciated slate ledge is broken along the cleavage in three places about 2 feet apart, by amounts respectively of 5, 8, and 7 inches. Here, also, the northwest side is the uplifted one, at each fault. The ledge is too much weathered to show distinct striæ; but there is little doubt that the displacement occurred after the glaciation. Step faults of 1 or 2 inches displacement occur in other parts of Nova Scotia. One or two obscure cases are to be seen on the deeply grooved ledges of slate beside the Prince of Wales tower in Point Pleasant park. Another has been observed on the Fairy rocks at lake Kejimkujik. At St. John, N.B., on the corner of Delhi street and City road, is a slate ledge whose heavily glaciated surface is broken by a great many displacements of an inch or so. In this case, unlike the others, the north side is the downthrown one.

Wherever post-Glacial faults have been observed, in Nova Scotia, New Brunswick, southern Quebec, New Hampshire, New York, and Michigan, they occur in highly cleaved slate; and the slipping has occurred on the cleavage planes. The displacements are as a rule only an inch or two, although the accumulated displacement of several faults in a single ledge often amounts to more than a foot. In rare instances, displacements of as much as 3 to 5 feet have been found in a single fault. It is possible, of course, that these faults are purely superficial. It is, however, natural to connect them with the earthquakes which have occurred from time to time in the province -as, for instance, the shock of March 21, 1904, which jarred the greater part of Nova Scotia. Shocks as widespread as this one seem to demand a deep source. A slip of only a few inches, if very sudden, would be easily sufficient to produce a shock like that of 1904.

FORESTS DROWNED BY THE SEA

At several places around the head of the bay of Fundy there are forests which have been deeply drowned by the sea and buried by mud flats and marshes. The tree stumps stand firmly rooted in hard ground, composed of decayed ledges and glacial boulder clay, yet covered at high tide by 30 or 35 feet of salt water, and even at half tide by 10 feet or more, and it is obvious that since they grew there has been either a sinking of the coast or a rise of mean sea-level. The well-preserved condition of the wood shows that the stumps belong to the later part of post-Glacial time. The most widely known submerged forest in Canada, and in many respects the most remarkable, is at old Fort Lawrence, 3 miles west of Amherst, on the boundary line between Nova Scotia and New Brunswick (Plate XXVI). The description written by Sir William Dawson in 1854 gives a correct picture of the forest as it appears at the present time.

PLATE XXVI

The drowned forest at Fort Lawrence.

"It occurs on the edge of the marsh near the mouth of the La Planche river . . . . at the extremity of the Fort Lawrence ridge, which separates the La Planche from the Missaquash. The upland of Fort Lawrence slopes gently down toward the dyked marsh [near the brick power-house of the Chignecto Marine railway] on crossing which we find outside the dyke a narrow space of salt marsh thinly covered with coarse grass and samphire (*Salicornia*) and at the outer edge cut away by the neap tides so as to present a perpendicular step about 5 feet in height. Below this is seen, at low tide, a sloping expanse of red mud, in places cut into furrows by the tides, and in other places covered with patches of soft, recently deposited mud . . . . At the distance of 326 paces from the abrupt edge of the marsh and about 25 feet below the level of the highest tides, which here rise in all about 40 feet, I saw the first of the rooted stumps, which appear in a belt of sand, gravel, and stones mixed with mud, which intervenes between the slope of mud already mentioned and the level of low tide. [This is glacial boulder clay, stripped of its former covering of tidal deposits] . . . Beyond the stump first seen and extending to a depth of at least 30 to 35 feet below the level of high tides other stumps were irregularly scattered as in an open wood. The lowest stump seen was 135 paces beyond the first; and between it and the water-level there was a space of 170 paces without stumps, but with scattered fragments of roots and trunks, which may have belonged to rooted trees broken up and swept away by the ice. On digging under and around some of the stumps, they were found to be rooted in a soil having all the characters of forest soil. In one place it was a reddish, sandy loam, like the ordinary upland of Fort Lawrence; in another place it was a black vegetable soil resting on a white, sandy subsoil. Immediately over the soil were the remains of a layer of tough bluish clay, with a few vegetable fibres, apparently rootlets of grasses, which seemed to have been the first layer of marsh mud deposited over the upland soil. All the rootlets of the stumps were entire, and covered with their bark, and the appearances were perfectly conclusive as to their being in the place of growth. Of thirty or forty stumps which I examined, the greater number were pine (*Pinus strobus*), but a few were beach (*Fagus ferruginea*); and it is worthy of note that these are trees characteristic rather of dry upland than of low or swampy ground. The pine stumps were quite sound, though somewhat softened and discoloured at the surface. The beech, on the other hand, though retaining much of the appearance of sound wood in the interior, was quite charred at the surface, and was throughout so soft and brittle that large trunks and roots could be cut through with a spade or broken with a slight blow. Owing to their softness, the beech stumps were worn down almost to the level of the mud, while some of the pines projected more than a foot; even these last were, however, much crushed by the pressure of the ice, which, with the tides, must eventually remove them. The largest stump observed was a pine 2 feet 6 inches in diameter; and showing more than 200 annual rings of growth."

A visit to this drowned forest when the tide is out is an experience well worth having. The deep, sticky mud makes walking uncomfortable, unless the observer is provided with rubber boots; but thus equipped, or even barefooted, he will find the sensation of strolling through a forest, 30 feet below high tide-mark, both novel and impressive.

The same forest bed was observed by Chalmers of the Geological Survey at the western end of the excavation of the dock of the Chignecto Marine railway, at a level 30 feet below the surface of the marsh, or 8 feet below mean tide. This is only a few hundred feet away from the stumps described by Dawson. In the section, which was 300 feet long, Dr. Chalmers reported that the forest bed sloped seaward about 20 feet. The trees appeared to be rooted in 2 feet of partly stratified gravel and sand, underlain by boulder clay. These stratified deposits are believed to be the post-Glacial marine deposits of the Champlain stage. Tamarack, black spruce, birch, alder, poplar, hemlock, elm, and ash were recognized. Another forest of the same date occurs just across the provincial boundary line, west of Missaguash river, extending to 32 feet below high tide. Spruce, beech, pine, and tamarack are there rooted in vegetable mould with a sandy subsoil. Chalmers reported that borings through the marsh at Aulac station, by the engineers of the Intercolonial railway, struck fresh-water peat at a depth of 80 feet -59 feet below mean tide. If this be, as he believed, a continuation of the same forest bed, it shows that the depth to which the coast has been drowned is much greater than that recorded at Fort Lawrence. He observed stumps also at Edgett Landing, near Hillsborough, N.B., 15 feet below mean tide.

The famous marshes of Grand Pré, in the land of Evangeline, cover another "forest primeval," which reaches a depth of at least 33 feet below high tide. A good exposure of it may be seen on the flats behind Boot island, on both sides of the "guzzle," about a mile east of Evangeline beach. In a sharply undercut bank at the edge of the salt marsh, near William Reed's house, a large pine stump is enclosed in black soil and covered by 6 feet of red mud and marsh turf. The stumps are upright, and their roots penetrate an underlying bed of boulder clay containing many glaciated stones. Rootlets, also, run down into this clay. The soil bed contains birch bark, twigs, leaves, and other debris common in the woods. The upper 6 to 12 inches of the boulder clay is bluish grey, whereas that below is red. This is probably the old bleached subsoil, on top of which the humus accumulated. On the rather steep bank of the "guzzle," where the stony surface of the upland is broadly exposed, larger stumps stand in positions of growth, singly and in small groups. Evidently most of them, and all except the largest and most firmly rooted, have been torn out and carried off by the tides and shore ice. The lowest stump observed is 33 feet below high tide. Out on the flats, beside the "guzzle," the same old stony upland is widely exposed at low tide; and several stumps that appear to be those of giant pine trees stand in an upright position. The trunks measure from 20 to 26 inches in diameter. In the layers of blue clay which lie immediately above the tree roots, tough, hollow stalks that look like water-lily stems are abundant. These are probably rootstalks of *Spartina stricta*, a grass common on the borders of salt marshes. The general absence there of smaller stumps, logs, or other debris suggests that the large stumps stand just where they grew and are not, as some believe, modern tree stumps undermined by cliff recession at the high tide-mark, dragged out by shore ice, and dropped on the flats. If that were their origin, debris would be found scattered all over the flats; many stumps would be in overturned positions, and there would be only small growth instead of huge trunks, for no trees so large have grown on this shore in recent times. Moreover, the stumps are all on one continuous upland surface, easily recognized by its stony character and its firmness under foot; and the surface extends without interruption up to the edge of the salt marsh, where, as already described, the forest bed is evidently buried by the marsh.

On the shore about a half mile west of Evangeline beach is a large stump similar to those at the "guzzle," from which the salt marsh deposits have recently been stripped. The stony soil in which the tree grew appears farther out on the flats, between half tide and low tide; but only broken wood and sticks are to be seen here. For many years past, other stumps have been seen along this part of the beach, and it is clear that the forest is an extension of the one behind Boot island. No doubt it underlies the whole area of the Grand Pré marshes, though it is seen only at the shore.

Two miles southeast of Boot island, on the flats at Avonport, fifteen or twenty big stumps occur on stony ground several hundred yards from shore, near low tide-mark. The lowest one observed is 32 feet below high tide. The stumps here are more broken by ice than at Boot island and Fort Lawrence, and the old forest soil has been almost obliterated. Similar stumps are said to occur on the flats off Hantsport; 3 miles farther up Avon river; and at the mouth of Folly river, 12 miles west of Truro. Careful search would probably locate such stumps at many other places around the bay of Fundy shore.

One is inclined at first to associate the submergence of these old forests with the extraordinary tides, which have a range of from 35 to 45 feet at the localities mentioned. The drowning of the trees cannot have been caused, however, by an increase in the range of tide, such as might have been produced by the removal of a barrier which formerly shut out the sea. Not only is there no trace of such a barrier, in the bay of Fundy, but had one ever existed sufficient to shut out the tide entirely from the upper end of the bay, the water-level there, whether fresh or salt, could hardly have been lower than *mean sea-level*, and trees would not have grown below that level. But the stumps now reach 10 or 15 feet below mean sea-level; and if the record at Aulac be correct, to 59 feet below it. It must be concluded, therefore, that either the land around the bay of Fundy has sunk, or the Atlantic ocean has risen in level at least 15 feet, and probably over 35 feet and so recently that the wood is still very well preserved.

On the south coast, drowned stumps or forest beds are to be seen at Yarmouth, Cape Sable island, Lunenburg, and Halifax. They have been noted near Guysborough, also, and doubtless occur at many other places. In some of these places the stumps lie below mean tide-level; but in others they appear only a few feet below high tide, where a local increase in the tidal range would be a sufficient cause for the drowning. Nevertheless it is fair to assume that they all have been drowned by the widespread submergence which is so plainly registered at Fort Lawrence and Boot island.

At Yarmouth, stumps occur beneath salt marsh deposits on both sides of the harbour. On the west side they are exposed in a drainage ditch where the road to Markland crosses a broad dyked marsh about a half mile north of Yarmouth bar. A continuous mass of interwoven roots and stumps lies from 1 to 4 feet below the top of the marsh, in upright positions, with logs, sticks, and other forest debris matted down into a black bed of peat (Plate XXVIII B). This is a relatively young forest growth; for most of the stumps are less than 6 inches in diameter. Several large stumps occur on the seaward side of the beach that encloses False bay, just south of the Markland hotel. Though they stand between mean and low tides, it is possible that their low position is in part due to their having grown on soft ground and been pressed down by the weight of the beach as it was beaten back over them. That process is going on at a short beach at "the point" of West cape, south of the Markland.

Similar conditions are seen on the east side of Yarmouth harbour near Thrumcap beach. This place is interesting because it illustrates the manner in which the salt marsh may be pressed down by an advancing beach which buries it, and by continued movement inland allows the buried and compacted marsh turf to appear on the seaward side of the beach, where it might be mistaken for evidence of coastal subsidence. A number of stumps stand on the beach behind Mr. Purney's house, with their roots partly embedded in sand. A spongy peat found with them outcrops more extensively on the beach farther north, between tides, and has the appearance of being old salt marsh turf hardened by burial. More stumps, covered by only a few inches of salt marsh deposit, stand erect in a black peat bed near the little group of fish houses, at the edge of a small marsh that lies behind Thrumcap beach. The black peat cracks easily in an horizontal plane, after the manner of freshwater peat and upland humus, and the numerous stumps are firmly rooted in the ground below. The forest bed does not appear more than 2 feet below high tide at this place; but it is not improbable that its absence from the flats farther down is due to scouring by ice. A few stumps appear at about the same level near Thrumcap rock. On the outer side of Thrumcap beach, near its connexion with the land, there are many stumps and a compressed bed of peat. It is evident that the advance of the heavy cobblestone beach over the salt marsh, here, has greatly compressed the deposit. Five or 6 feet of cobblestones have packed down the marsh turf to about half its original thickness, so that it outcrops on the seaward side of the beach 6 feet below the normal level. The advance of this beach has buried the head of a tidal creek and partly concealed fences and stone walls. The surface of the marsh sags very perceptibly near the beach, so that the water stands in little pools in the spaces between piles of cobblestones which make scallops along the back of the beach. The tendency of the buried peat beds to pack down as the beach advances over them is increased by the loss of ground-water through the bevelled edge of the bed, where it outcrops on the front of the beach. In the peat bed, where it protrudes through the beach, are sticks, logs, and several stumps in erect attitudes. Near the foot of the beach, protected by ledges, and partly buried by boulders, are a number of stumps, of which the lowest is $8\frac{1}{2}$ feet below high-tide level of the marsh. This stump stands only 3 or 4 feet away from the exposed ledge, on ground apparently solid, and it is not probable that it and the others owe their low position to the compression that has so greatly reduced the thickness of the overlying marsh deposit. The tidal range here is from 14 to 16 feet; the lowest stumps are, therefore, below mean tide;

and register a real change of level of land and sea, although other factors may have co-operated to drown them.

On Cape Sable island, a marsh-covered forest occurs on the road from Clark harbour to Hawk point. Stumps half buried by the marsh can be seen sticking up through the salt grass and mud. It is not known to what depth the forest bed extends offshore.

At Lunenburg a submerged forest may be seen at Stump cove, on the sheltered side of East Point island. Most of the trees in this forest are small. They extend down to low tide-mark, and so are covered by about 8 feet of water at high tide.

On McNab island in Halifax harbour, stumps are exposed on a sandy beach at McNab cove, near the mouth of a small creek. There are thirty or forty of them, one being over 8 inches in diameter, but most of them smaller than that. A few rods behind them the modern gravel beach is being beaten inland over wooded ground, killing spruce trees and threatening to bury their stumps. The springy character of the beach where the drowned stumps stand suggests that in this case compression of the ground, favoured by quicksands or an old peat bog, has been a contributing factor if not the chief cause of the drowning of the stumps. The lowest of them lies only 2 feet below high tide.

This second post-Glacial change of level, by which the forests were drowned, may be accounted for as either a negative movement of the land or a positive movement of the sea, as Professor R. A. Daly of Harvard University has recently urged. The data are insufficient for determining the correct conception. If the sea-level has risen it is probably because the sea received the large volume of water that had been locked up in the ice-sheets, during the Glacial period. It is estimated that the ice-sheets of North America and Europe covered not less than 6,000,000 square miles. This is about one-twenty-fourth of the area now occupied by the sea. Assuming that the ice had an average thickness of 3,000 feet— which is conservative—its melting would have raised the sea-level (according to Daly), about 125 feet; with an average thickness of 3,600 feet, the rise would have been 150 feet; of 4,000 feet, 167 feet; of 5,000 feet, 208 feet. Although recent submergence is registered in so many other parts of the world as to lend favour to the view that there has been a positive movement of the sea instead of a negative movement of the land, drowned forests in the British isles and Scandinavia appear from recent detailed studies to register more than one oscillation of level of the land during the retirement of the ice border. In southern Sweden, especially, it is believed that the coast sank while the interior was rising. The history of late glacial warpings in Canada and New England will perhaps prove to be as complex as that worked out in Scandinavia.

SIGNS OF PRESENT STABILITY OR INSTABILITY OF THE COAST

In view of the foregoing evidences of changes in the relative position of land and sea since the Ice age, it may well be asked is the coast stationary at the present time, or is it rising, or falling? There is a prevalent opinion among those who know the shore that it is undergoing slow subsidence.

This view is so well expressed in the following letter, written by Dr. Charles A. Hamilton, of Mahone Bay, that with his permission it will be used to introduce the evidence and arguments concerning subsidence.

The letter bears the date of January 16, 1915. Dr. Hamilton refers to a locality where he spent his boyhood, on the estuary of Guysborough river (Figure 12).

"Projecting from its north shore you will see, in the neighbourhood of Boylston, three prominent points. It is of the shores of the expansion between the two most westerly of these points that I shall more particularly speak; but my remarks apply to the whole estuary as well. Beyond that my memory is not sufficiently clear to make a trustworthy statement.

"The land around this inlet is fairly high, rising at a distance of one-fourth to three-fourths of a mile to a height of perhaps 250 to 400 feet. The immediate banks of the river were for the most part fairly low—from a few inches to a few feet in height. In my younger days most of the points and many strips along the water were wooded with small hardwood and softwood trees. In other places, pastures and grass fields ran to the water's edge.

"My reasons for believing that this district is subsiding are as follows:

"(1) A rate of recession of the river banks, even where these are covered with grass or bushes, much greater, apparently, than can be explained by simple erosion.

"(2) Along the wooded portions, a fringe of trees, dead or dying in a sense hereafter to be explained.

"(3) The heads of some (perhaps many) little coves had beds of peat over which the tide rose.

"(4) (and most important). A pine stump on the beach, rooted in a peaty material which was covered by a thin layer of gravel. *The salt water flowed around and over this stump soon after half tide.*

"I will take up (1) and (2) together, beginning with an example concerning which my memory serves me well. On the north shore of the expansion, between the most northwesterly points, there grew at my earliest memory (1865–66) a sapling maple. It sprang from the side of the bank (here about 3 feet high, and grass-covered to the bottom), about $1\frac{1}{2}$ feet from the upper limit of the gravel. By the late seventies the trunk was over the gravel, the roots being all on the shoreward side. About 1890, the trunk was at least 2 feet over the beach, connected with the bank by an isthmus of strong roots covered with a little ground. It was still alive, but stunted. By 1904 it had disappeared. This state of affairs was common round that shore. I remember many large trees with their trunks several feet over the beach, where they could not possibly have grown. Many times I picked my way at high water along the wooded portions of the shore through a tangle of bushes or small trees, some dead but still connected with the bank by their roots, others projecting a greater or less distance over the beach, eking out a precarious existence, or more or less vigorous in proportion as their roots had hold on the banks.

"Was this due to simple erosion? I think not. The shores of this small and irregular sheet of water are well sheltered, and the bit of beach of which I have been more particularly speaking is singularly well protected. Moreover, I am referring to grass- or wood-covered banks. The process, I think, was this. As the salt water rose, the lower line of vegetation was killed; the soil of the banks when wet would then ooze out, especially in spring and fall, and be washed away by the higher tides. The mat of vegetation would then settle down, preserving more or less perfectly the contour of the banks.

"The condition of the trees is, I think, just what one might expect in the case of secular subsidence. As the waters rose, the outer roots would slowly die and decay, and the inner ones strengthen. The other phenomena described would follow until at last the tree would be overturned by the wind.

"(3) With one exception I will say nothing about the peaty material, at the head of the coves, since I neither observed them critically nor is my memory clear enough to be trusted. The exception was a small, narrow inlet, filled (as I first remember it) for about three-fourths of its length with peat. This terminated on its outer edge in an abrupt face, the greatest height of which was 2 feet or more. The salt water lapped the base of this bed at about half tide; the highest tides rose over it. The peat which was slowly washing out was light brown and fairly tough; but I do not know of what it was composed.

"(4) The pine stump mentioned seems to me conclusive evidence of subsidence; at any rate, think as hard as I may, I can explain its position in no other way. As I first remember it, my impression is that it was about one-fourth way down the beach; as I last saw it, one-third or more. About it I saw occasionally exposed peaty material out of which I have pulled branches of trees and pieces of root. It was a large stump, consisting of a number of spreading roots, connected together in the centre so as still to show faintly the outline of the trunk. Unfortunately, in the late eighties, the coincidence of a big thaw and a very high tide brought the ice out of the cove, carrying the stump with it.

"*That tree grew there. Of that I have not the slightest doubt.* The water off the stump was shoal, the beach almost on a level with the field beyond, which itself rose very gently for some distance back, so that there can be no question of a slow creeping downward of the land, and no other explanation seems possible except subsidence . . . . .

"Curiously enough, since writing the above, I have had, very unexpectedly, to revisit the locality. I had time only for a hurried glance; but I saw enough to show that the process is still going on, as rapidly as ever. I noted particularly a spruce, the trunk of which stood about 6 feet over the beach, connected with the bank by a strong mass of bare roots. About 1890, that tree, if growing then, was situated on the bank. In 1904 it was not far enough over the beach to attract my attention. The peat in the cove has mostly been washed out. Just how much was left I could hardly determine, on account of the snow and ice."

These four lines of evidence deserve careful consideration first, as proof of a vertical change in relation of land and water, without taking into account the fact that such changes of level may be either negative movements of the land or positive movements of the sea.

(1) The low bank has been steadily receding, since 1865, at an average rate (judging from the trees described) of several inches each year. The

rate may have been very variable; but it is not known to have reached one foot per year. Is this unnatural, even on a bit of shore as well sheltered as this one? The waves are small, no doubt, but they must play a part in the transportation of fine sediment, once it has been loosened from the bank; and where there is transportation from a shore without compensating additions of material from elsewhere, it means erosion. According to the Admiralty charts, a current of two knots an hour passes through the estuary off the two points. During spring freshets it is probably stronger. Granting that this would not be felt at the shore, under ordinary conditions, it is nevertheless evident that when acting in connexion with broken ice the tides would remove not only large pine stumps which had formerly been embedded in peaty ground, in shallow water (as Dr. Hamilton testifies), but stones, sand, and clay from the beach and the foot of the bluff. Occasional planing down of the gently-inclined shore terrace, by these agencies, every year or two, would require a proportionate recession of the bank at its upper margin. Where the rate of recession is so slow, the bank might well remain covered with sod most of the time, as the unconsolidated material, loosened by frosts, weighted by ground-water, and washed by rains, caused it to work slowly downhill to the beach. Only an unusually severe attack, like that which Dr. Hamilton describes as having come in the late eighties, would be likely to leave a bare scar at the foot of the bluff; and this would soon be covered again with vegetation. There are so many factors to consider, in estimating the probable rate of recession of a sea-cliff under different conditions, that it is not possible profitably to offer statistics to fit a case like the one in question. It is hardly too much to say, however, that conditions similar and equal to those described by Dr. Hamilton can be duplicated on the shores of lakes which are known not to have changed in level.

(2) Trees die as the bank recedes. This is, of course, inevitable, whatever the cause of the recession. The removal of soil from their roots will sooner or later overcome their tenacious hold on life. Salt water rising around their roots would hasten their death, to be sure; but it is not necessary. Whether the land slowly sinks or the sea slowly advances on the land while it stands unchanged in level, the roots on the seaward side will in time lose their function and begin to decay, allowing the tree to continue to grow for a while in a leaning position, until even the innermost roots succumb to the attack of the sea, and the tree falls. This process, like the preceding one, may be observed on the shores of lakes where wave-action is slight and where no change of level and no salt water enter into the question at all.

(3) Peat beds (doubtless of freshwater origin) in the coves, with their exposed sides cliffed by the "river," have bottoms near or at half tide-mark, and tops covered by the "highest" tides. The greatest height of the peat bank is "2 feet or more." The range of tide at Guysborough is 4½ feet at neap tides and 6½ feet at spring tides. If it is supposed that this peat bog developed in a landlocked depression, occupied at first by fresh water—a common condition in the drift-covered region—and that it began as a floating mat which gradually packed down under its own weight until it rested on the floor of the depression, there will be a deposit whose base is at least as deep as mean sea-level. Now, suppose that the

recession of the bank removes the outer rim of this peat bog, and exposes the peat itself to the trimming agency. The ground-water, with which the peat is saturated, drains away through the new sea-cliff, and the peat squashes down, probably to one-half its original thickness, judging from measurements in similar bogs in eastern New Brunswick. The shrinkage thus induced carries the surface of the bog below the level of spring high tides, and the conditions of the present day are all fulfilled, without appealing to any change of level of land and sea.

(4) The pine stump, rooted in tough peat, on the flats below high tide, has been *submerged* by the sea. To that extent the evidence is incontrovertible. But there is nothing to show *when* the submergence took place. So far as Dr. Hamilton's careful testimony goes, the pine stump may be the last survivor of an old fossil forest like those at Fort Lawrence and Boot island, described on pages 157 and 159. When first seen by him, the stump was already below sea-level, part way down the beach; and the only change recorded since that time has been the eating back of the edge of the land at the upper margin of the beach and the tearing away of the stump by outgoing ice and tide in the late eighties. Thus interpreted, the stump ceases to be an evidence of *modern* submergence, and becomes instead evidence of submergence *of unknown date*. It is not improbable that the submergence concerned is the one described in foregoing pages, and attributed to either a downward warping of the coast or an increase in the depth of the ocean. At the same time, it is possible that the submergence has been caused by an increase in the range of tide, due to scouring at the tidal entrance of the estuary.

It is concluded, therefore, that *though, there has been submergence, it is not necessarily still in progress;* and, further, that even if it is now in progress, it may be due not to coastal subsidence, but to a local change in high tide-level, in the manner described by Johnson as common to irregular shores which change in outline under wave attack.[1]

Depth of Water on Reefs. Statements have occasionally been made that certain ledges which were formerly bare at low tide are now covered, or vice versa. Discussing this subject in 1877, in a report of the United States Coast Survey, Dr. Henry Mitchell referred to a number of ledges on the coast of Nova Scotia, and showed that in every one the supposed change was fictitious, since the latest descriptions agreed closely with those of the seventeenth and eighteenth century navigators and cartographers. A few of these cases may be quoted, to support the idea of a modern coastal stability.

The "Coast Pilot" of the British Admiralty, corrected to 1911, says: "Trinity ledge off cape St. Mary consists of three small heads close together, all of which uncover at low water spring tides, the highest being then $3\frac{1}{2}$ feet above the water . . . . The others are just awash." DesBarres, in his "Sailing Directions" in 1776, says of this rock: "When the tide is out, three stones appear above water." According to Mitchell, who had studied DesBarres' old charts in detail, in connexion with his own surveys, the datum always used by DesBarres is not ordinary low tide but the low spring tide. The description written one hundred and

[1]Johnson, Douglas W., "Botanical Phenomena and the Problem of Recent Coastal Subsidence", Bot. Gaz. LVI, 1913, pp. 449-468.

thirty-nine years ago, therefore, accords with the facts as stated in the modern "Coast Pilot." Captain Shortland's chart of 1862 gives the ledge the phrase "dry at low water of spring tide," as does the more recent chart of 1891. It is certain that there can have been no emergence, therefore, since 1776; and it is almost as certain that there has been no submergence during the same period.

Jig rock, at the entrance to Shelburne harbour, offers similar testimony. In the "Coast Pilot" for 1911 it is said to be covered (at mean low water) by $1\frac{1}{4}$ fathoms. According to DesBarres, in 1776 it had 6 feet. If DesBarres' datum was low water of spring tides, as Mitchell believed, the two measurements, of 1776 and 1911, agree within a few inches.

Brazil rock, 8 miles southeast of cape Sable, is described in 1911 as "a dangerous, rocky shoal, having 2 fathoms water, over which the sea breaks in bad weather." DesBarres, in his large map of cape Sable, as well as in his smaller charts, gives Brazil rock 10 feet of water. His sailing directions of 1775 also give 10 feet; but in his sailing directions of 1776 he says: "The Brazil is a small, flat rock with 12 feet of water and within a cable distance all around you have 6 to 8 fathoms." "The fact that DesBarres finally decided upon 12 feet, after stating a less depth," says Mitchell, "indicates that he referred to spring tides in one case and mean tides in the other. Since the tides are at this point only of 6-foot range, the plane of reference, whether from a long series of observations or not, can differ but little from the truth." Mitchell was puzzled by the fact that de Chaubert, in 1750, reported that this rock "breaks and uncovers at low water." He explains the statement, however, by supposing that this observer mistook the heavy summer growth of kelp for bare rock; and points out that Champlain did not see and note Brazil rock, although he cruised around cape Sable for several days. Furthermore, if de Chaubert's statement had been true, it would require a sinking of the coast, here, of at least 12 feet in the twenty-six years between 1750 and 1776, although, in the one hundred and thirty-five years between that date and 1911 there has been no change of level. The statement is in all probability a mistake, as Mitchell decided, and the stability of the sea-level on Brazil rock, so well recorded during the last hundred and thirty-five years, undoubtedly prevailed for a long time previous to the record.

Green ledge, in Green bay, east of Port Medway, "a quarter of a mile in extent, has a small portion which uncovers at the least quarter ebb," according to the "Coast Pilot" for 1911. Since the range here is 7 feet, the summit of the ledge, at ordinary low tide, must stand about $1\frac{1}{2}$ feet above the sea. Champlain shows the ledge on a map of Port de la Haie (1604) by the same conventional sign which, in his map of Port Royal, he explains as indicating flats left bare at low tide. The inference is obvious—that there has been no perceptible change of level, here, in the last three centuries.

Old Beaches. A belief in subsidence of the coast within modern time has been based, in some instances, upon differences of altitude of old and new beach ridges at a given locality. Thus, where an older beach "A" stands behind a modern beach "B," and the crest of "A" is 4 feet lower than "B," it is inferred that the coast has sunk 4 feet since "A" was built. In some cases this inference is correct, namely, where the beaches to be compared have perfectly uniform crest-lines and there is no indication that there has been any considerable shifting of the course of shore currents. That there is chance for error, however, is shown by the conditions at Cow bay, near Halifax.

A great curved bar of gravel stretches across the middle of Cow bay, shutting off a salt pond. The gravel has been collected not only from cliffs of glacial drift at both sides of the bay, but from shoals near the middle, where presumably there were islands during the earlier stages of construction of the Cow Bay bar. Two or three sandy gaps in the gravelly beach indicate plainly that the bar has not been developed simply by supplies of shore drift coming from its two ends, but in a more complex fashion. Old beach ridges which lie behind the modern beach confirm this view, and by their curvature suggest where small islands formerly lay, in the bay off the present bar. From the picnic grove near the east end of the bar, a very conspicuous ridge of coarse gravel and cobblestones can be traced through the grove for 200 yards through the woods, a few rods behind the modern beach, and nearly parallel to it. It is as perfect in form as if it had been built during the last great storm; but the spruce trees which grow on it show that it is at least 40 or 50 years old. Its crest, by careful measurement, is noticeably higher than the crest of the present beach, 4 feet higher in one place. Shall it be concluded from this fact that the coast has risen 4 feet since the earlier beach was built, possibly within the last forty or fifty years? Surely it would not be safe to do so; for the possibility must be admitted of occasional great storms, like the Saxby gale of 1869, which, by the way, occurred just about the time when the spruce trees seem to have started to grow. Levels run along the crest of this beach give reason to believe that its extra height is a storm effect; for it varies as much as 2 feet in a distance of only 250 feet, where it is best developed, and falls off in height towards the west, coming to an end before it has reached halfway across the pond.

The unreliability of beaches as an index to coastal stability or instability is further shown by a group of still older gravel beaches several hundred yards west of the picnic grounds, just beyond the first sandy gap. The modern beach there is 4 or 5 feet higher than at the east end, perhaps because it gets a local supply of gravel from a shoal or lost drumlin. Behind it are two distinct groups of beaches: a pair which run parallel to the modern beach and seem to belong to the same stage as the beach in the picnic grounds; and several short, curved beaches whose trend shows plainly that they were built when there was a small island off the middle of the bar. These are shown in Plate XXVII. The crests of these oldest beaches stand 9 or 10 feet below the crest of the modern beach. Taken alone, this might lead to the conclusion that there had been a subsidence of the coast at Cow bay during the interval between the construction of the oldest and the newest beaches—exactly the opposite conclusion to that which would have been drawn from the beaches at the east end of the Cow Bay bar. The lesson is clear: in a situation as exposed as this is, the crest of a beach is sure to vary several feet in height from time to time, under the influence of storms and on account of alterations in the outline of the shore, by which old sources of supply are cut off and new ones make their appearance. In one place the modern beach will be built up far

PLATE XXVII

Old beaches at Cow bay.

above earlier beaches; in another the reverse will be true. The crest of the modern storm beach at Cow bay ranges from 6 to 12 feet above normal high water-mark.

A condition of things somewhat like this is found at Yarmouth bar; but the beaches form a more complex group, and the old headlands between which they grew cannot be so definitely located. The bar is a broad, crooked barrier, separating Yarmouth harbour from the open sea on its west side. Though narrow at the southern end, where it is protected by a wooden breakwater and causeway, it broadens at the northern end and is occupied by a busy little fishing village which gives the beach a quaint picturesqueness that would delight an artist. Here, in a triangular area of several acres, are three groups of concentric beaches, intersecting one another in such a way as to show that they were built by shore drift coming first from one side and then from the other. The beaches nearest the upland were, of course, the first to be built; and the others followed in order. The modern storm beach rises high above the old beaches. Where it cuts across them, its crest stands 5 or 6 feet above theirs, and 10 or 11 feet above the ordinary high water-mark. Now, it would be folly to assume that because the modern beach has a crest 6 feet higher than the next preceding group, and 7 or 8 feet higher than the oldest ones, the coast must have sunk, or the sea-level risen during the construction of the bar. The crests of all stand above the present high tide-level, by amounts which beaches might be expected to stand under various conditions of exposure. In the early history of this district islands of glacial drift off the present shore afforded shelter as well as material for the construction of the innermost beaches. As these islands were worn away, the lines of shore drift changed and the exposure increased, allowing higher beaches to be cast up on new curves; until, today, the breakers roll in heavily on the western side of the bar, piling up cobblestones to a height much greater than they could have reached under the old conditions. Such false evidences of modern coastal subsidence as these will not be misleading if it is borne in mind how the continued advance of the sea on an irregular coast of glacial drift may bring about a more and more vigorous attack.

Level of Tidal Marshes. It has long been a matter of curiosity that the surface of the old dyked marshes of Acadia are lower than the uncultivated marshes just outside. Sir William Dawson called attention to this fact many years ago. "In some localities, portions of marsh formerly reclaimed have been abandoned, and it is said that it is now more difficult to maintain the dykes than formerly." But continuing, he says: "We may, however, readily account for all this by supposing that the mud has settled or that the tides have increased in height or have changed in their direction, in consequence of the contraction of the channels by the dyking of new portions of marsh land. We are not, therefore, under the necessity of arriving at the unpleasant conclusion that our fertile marshes are again settling down beneath the level of the sea, or that the waters of the bay of Fundy are likely to overflow the upland farms." Thus did this careful observer of Acadian geology show the fallacy of an argument which has naturally been popular with those who are acquainted with the dyked marshes. How far two centuries of cultivation would affect the level of a tract of salt marsh is a question for the solution of which there is no quantitative observations; but in the Bay of Fundy district, where the range of tide is 30 to 45 feet and the ground water-level is dependent upon artificial drainage at mean tide-level, there must be a considerable shrinkage —enough, it would seem, to account for a lowering of 2 or 3 feet. Meanwhile the coast may have remained quite stationary.

As Mitchell pointed out in the paper already referred to, there is good evidence in the writings of old historians of Acadia that the undyked salt marshes of Annapolis basin have not been elevated in the last three hundred years; for three centuries ago, as now, they were overflowed by the spring tides. Champlain's map of 1604 shows marshes near Port Royal (Annapolis) as "prairies which are inundated by the great tides," and the text of his book makes the same statement. Lescarbot's map of Port Royal (1609) is accompanied by the statement that the marshes lacked trees because "the high tides, principally those of March and September, overflow the banks." In his farewell song, he says:

> "Adieu vallons herbus que le flot de Neptune
> Va baignant largement deux fois a chaque lune."
> ("Adieu, fertile valleys, that twice in each moon
> Receive far and wide the waves of Neptune".)

It is thus certain that the surface of the marshes at Annapolis three hundred years ago stood at or above the height of ordinary high tides and below the two spring tides of each moon, just as they do at the present day. It is very unlikely, therefore, that in the last three centuries there has been any elevation whatever; for if there had been, the marshes would now stand out of reach of the spring tides, unless, indeed, the tide has increased in range meanwhile, as fast as the marshes have been elevated. On the other hand, the facts do not preclude the possibility that the coast has been sinking; for in that case the surface of the marshes would have been maintained at mean high tide-level by constant additions of sediment upon their surfaces. The evidence against coastal subsidence must be sought elsewhere.

Invasion of Louisburg by the Sea. Addressing the Geological Society of London in 1861 on recent elevations and depressions of the coast of North America, Dr. Abraham Gesner said: "In the island of Cape Breton . . . several upheavals and depressions of the land were observed . . . Among the latter is that of the ancient city of Louisburg, which forms an interesting feature in Colonial history. This place was once the stronghold of France in America, and had one of the finest harbours in the world. It was well fortified, and a population of 20,000 souls was contained within its walls. It was taken from the French by 4,000 Provincial troops under Colonel Pepperell, in 1745. Afterwards Great Britain restored it to France. In 1758 it was again captured by General Amherst.... The inhabitants of the city were dispersed and the British government expended £30,000 in blowing up the fortifications....Had Louisburg continued to exist up to the present time, its abandonment would not have been the less certain; for the sea now flows within its walls and overflows sites that were formerly inhabited. Its submersion is plain and distinct. The rock upon which General Wolfe landed has nearly disappeared. The waves break against the south wall, which they have undermined and thrown down. The higher parts of the fortress afford shelter for sheep;

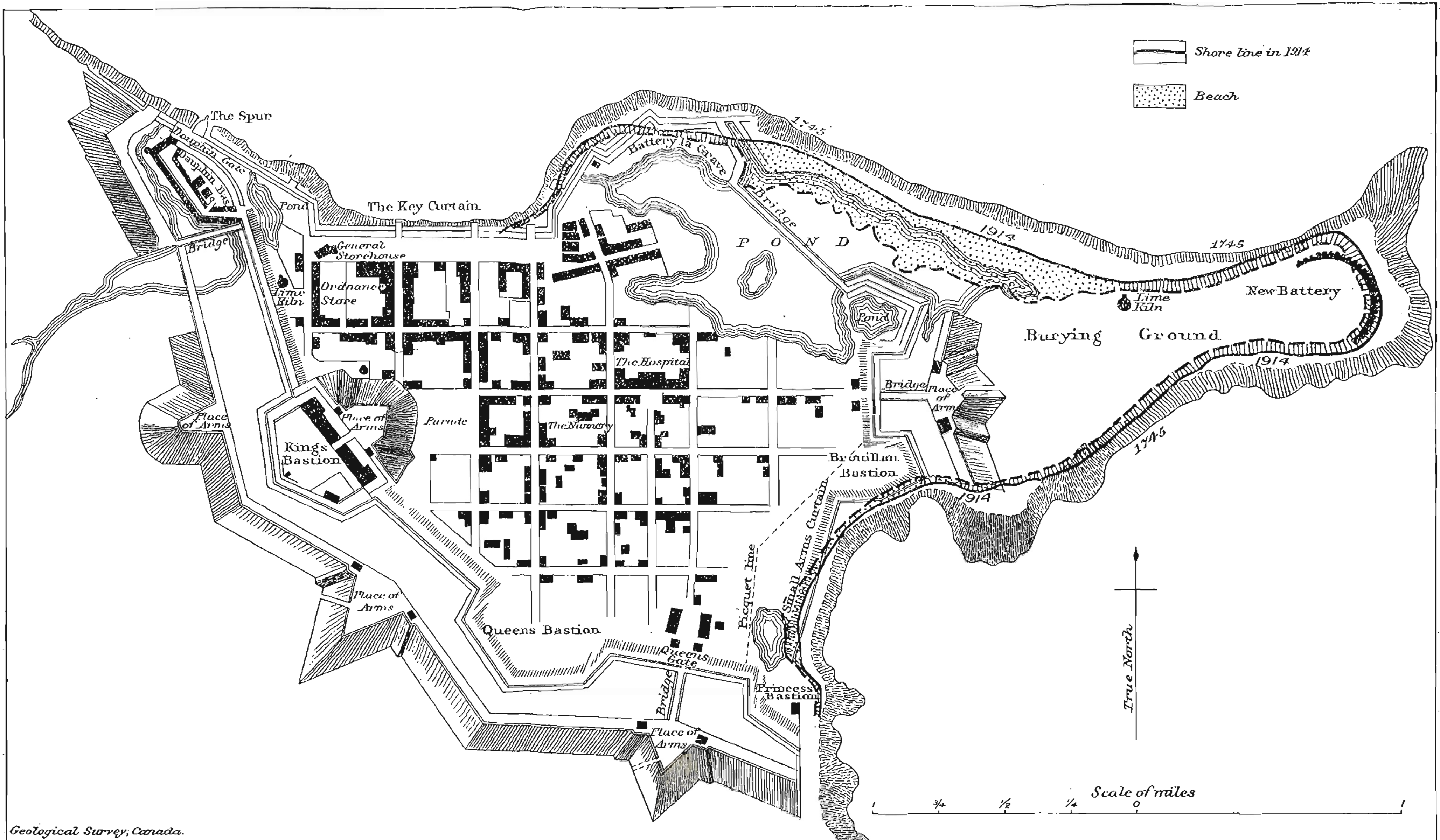
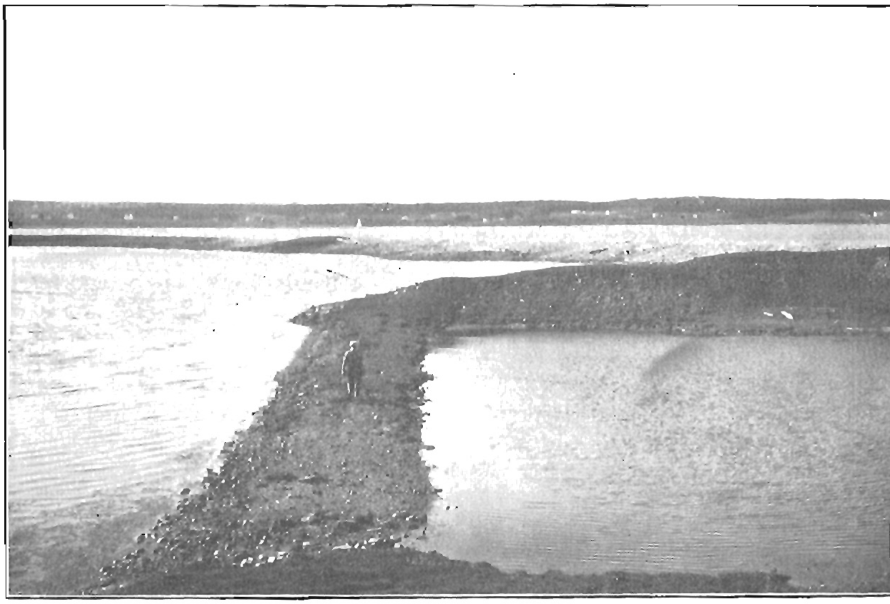


FIGURE 18. Plan of old Louisburg, showing changes in the shore-line between 1745 and 1914 (Based upon plan by Lieut. Col. Gridley.)

but each succeeding tide flows freely into the north side of the deserted city."

The facts as they appear at the present time are shown on Figure 18, which is based upon the well-known map made by Lieut.-Colonel Richard Gridley, in 1745. A photographic copy of Gridley's map was taken into the field, mounted on a plane-table, and the shore-line of 1914 was plotted directly upon it, by measurements and triangulation from easily determined points, such as angles in the parapets. The changes wrought by the sea in the interval of one hundred and sixty-nine years are considerable; but it will be seen that they are changes accomplished by the direct horizontal attack of the waves, alone, without any change of level. The low drift bank on the protecting headland has been cut back nearly 150 feet, in spite of ledges that rise nearly to high water-mark, leaving only the rear part of the "new battery, 1748." All along the shore the cliff has been trimmed back, and the sea has broken in through the fortifications at Brouillon and Princess bastions. On the north side, the barrier enclosing the large pond has been beaten inland 75 or 100 feet, greatly reducing the area of the pond, but *not altering its level.* This is shown by the fact that the outline of the pond, except where the bar forms its shore-line, is just the same today as when it was mapped, although its shores are flat and a rise or fall of the water-level by only 1 or 2 feet would cause conspicuous changes. Inside of the Maurepas bastion is a little pond which is separated from the larger one only by a low roadway about a foot high. Its outline is precisely the same as when Gridley mapped it (Plate XXVIII A). The shallow arms of the pond, also, correspond to those mapped in 1745. The island in the middle appears to be only a shoal from which salt grasses grow up through the water. The wooden piles that supported the narrow plank bridge rise a foot or two above the level of the pond, as they probably did in 1745. The "north side of the city" which Dr. Gesner referred to as being regularly overflowed by high tide, is presumably the part bordering the pond, near where the hospital stood. At present this is wet and marshy; for it stands only a few feet above the surface of the pond, and is saturated with ground-water; but it is not overflowed by high tides as Dr. Gesner says it was regularly overflowed in 1861. It is possible, of course, that at the time of Dr. Gesner's visit there was a temporary break in the beach which admitted the tides to the pond without restraint, allowing them to submerge its shores to a greater height than they do now. Certainly the outline of the pond today differs in no marked degree from that of 1745; and it is thus compulsory to adopt the view that the coast has neither risen nor fallen in the last one hundred and sixty-nine years. Dr. Gesner's visit was made about one hundred and fifteen years after Gridley's map was compiled and fifty-four years before the visit of the writer; so that such a marked sinking of the coast as Gesner supposed to be in progress would have been still more plainly evident in 1914, unless there had been a reversal of the movement in the intervening fifty-four years. It is clear that all the apparent effects of coastal subsidence which he describes may be atributed to the normal, natural advance of the sea against the old walls and across the beach. If the storm waves occasionally invade the fortifications, it is simply because they have eaten through the ramparts by many repeated assaults.



A. Maurepas bastion and tidal pond at Louisburg.

B. Old forest under salt marsh, Yarmouth.

CONCLUSIONS

Summing up these lines of evidence we find:

(1) Records of soundings on ledges off the coast of Nova Scotia during the last quarter of the eighteenth century show approximate equality with the depths now recorded, and limit the change of level, if any has occurred within the last one hundred and fifty years, to a foot or less. The old charts and descriptions furnish no ground for supposing that any change whatever has occurred.

(2) Beach ridges, which at Yarmouth bar and Cow bay would appear to record recent coastal subsidence, show a great variation in crest altitude, which is due to changes in exposure to surf during the destruction of old islands and reefs, rather than to any lowering of the land. They, therefore, are of no value as evidence of modern submergence.

(3) The salt marshes are overflowed by spring tides, but not by ordinary high tides, just as they were in 1609. It is very unlikely, therefore, that there has been any *emergence* for three hundred years. Although there may have been a slight *submergence*, as suggested by the slight inferiority of altitude of old dyked marshes, this inferiority is satisfactorily accounted for by shrinkage under prolonged cultivation and by increase in range of tide.

(4) The recession of the shore-line—prevalent, characteristic, and perfectly normal, under the ceaseless attack of the sea—explains the killing of the trees at the water's edge, the cliffing and drowning of fresh-water peat, and the invasion of the old fortress of Louisburg by storm waves. No submergence is required: merely erosion.

(5) Though other evidences of modern conditions are either non-commital or inconclusive, because they depend upon measurements not of sufficient accuracy, and so do not show positively that land and sea are now in equilibrium, the enclosed pond at Louisburg, acting as a natural tide gauge for mapping in 1755 and 1914, appears to prove complete coastal stability for that period.

These conclusions are in agreement with those reached by Johnson, to the effect that the Acadian shore-line, like that of the eastern United States, has enjoyed a period of approximate stability for several thousand years, and that the supposed evidences of modern subsidence are deceptive, being due to a variety of causes unrelated to any progressive change of level, prominent among which are local variations in the level of the high tide surface due to variations in the form of the shore-line.[1]

[1] Johnson, Douglas W., "Fixité de la Côte Atlantique de l'Amérique du Nord," Annales de Géographie, XXI, 193-212, 1912; "The Shoreline of Cascumpeque Harbour, Prince Edward Island," Geog. Jour. (London), XLII, 152-164, 1913. *See also* the same author's "The Atlantic Coast and the Problem of Coastal Subsidence" (John Wiley and Sons, New York City) in which the Acadian shore-line and the question of modern subsidence are fully treated.

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