

THE POST-CHAMPLAIN EVOLUTION OF THE
DRAINAGE PATTERN OF THE MONTREAL LOWLAND

by

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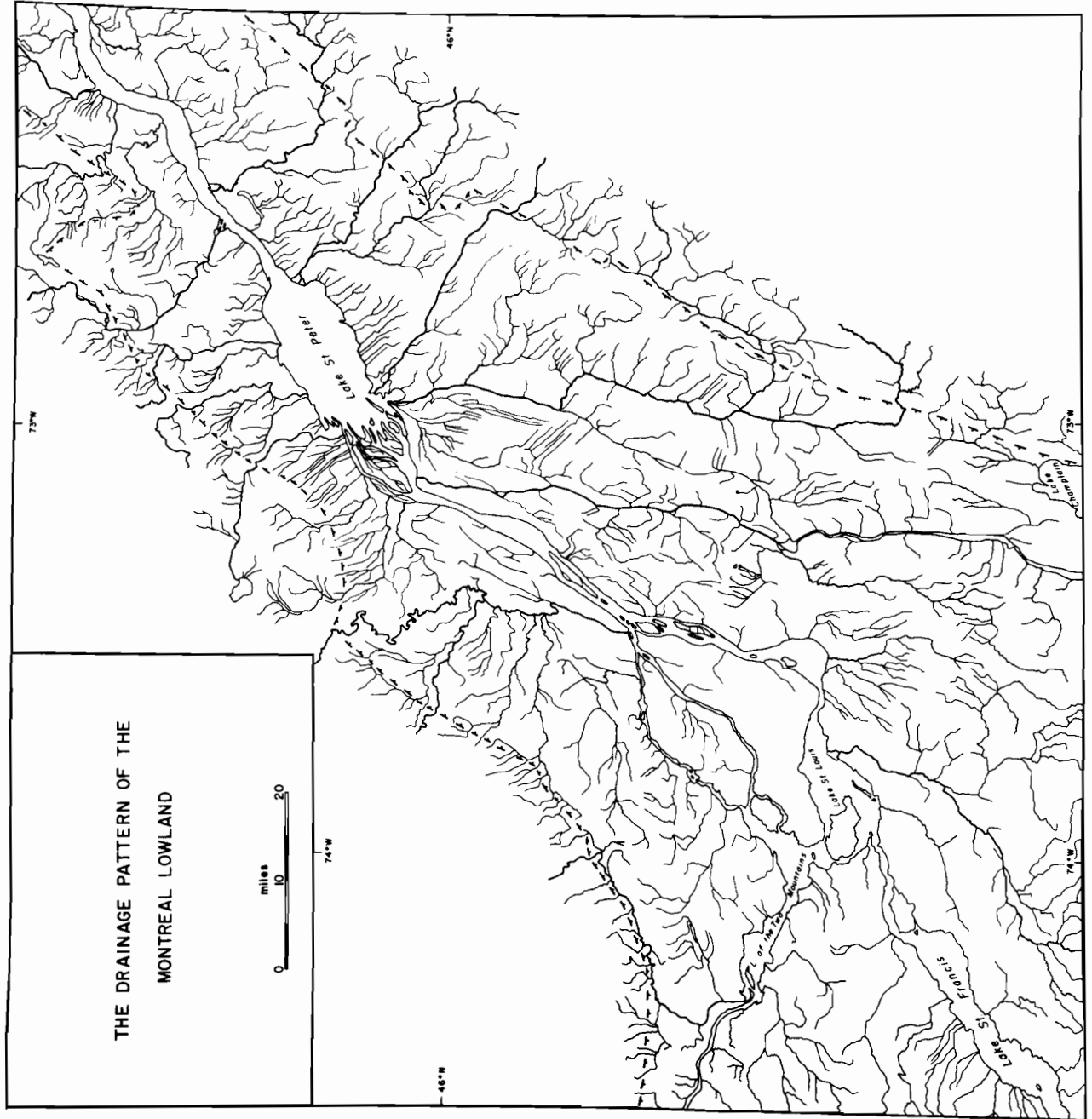
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CHAPTER I

Introduction

1. THE NATURE OF THE PROBLEM

The St. Lawrence River is one of the youngest of the world's great rivers. Much of its course below Lake Ontario traverses the floor of the Champlain Sea, a late-glacial marine embayment which flooded the lowland between the Canadian Shield and the Appalachian highland. The Champlain Sea stood at its maximum only about 11,400 years ago and the period of its regression has witnessed the development of a new drainage network upon the emerging sea floor.

It is the purpose of this study to examine the development of the drainage pattern in part of the St. Lawrence lowland, extending from the Quebec-Ontario border to below Trois Rivières; to correlate successive shorelines of the Champlain Sea in an attempt to identify particular stages in the evolution of the drainage, and to examine the influence of various factors upon the developing drainage network. The area of the study will be referred to as the Montreal lowland (Figure 1).

2. PREVIOUS WORK

The glacial and marine deposits of the St. Lawrence lowland have excited the attention of numerous geologists for over a century, and much of their published work includes brief references to physiographic features. However, despite the freshness of the morphological evidence there has been little work directed specifically to the solution of physiographic, even less of fluvial, problems.

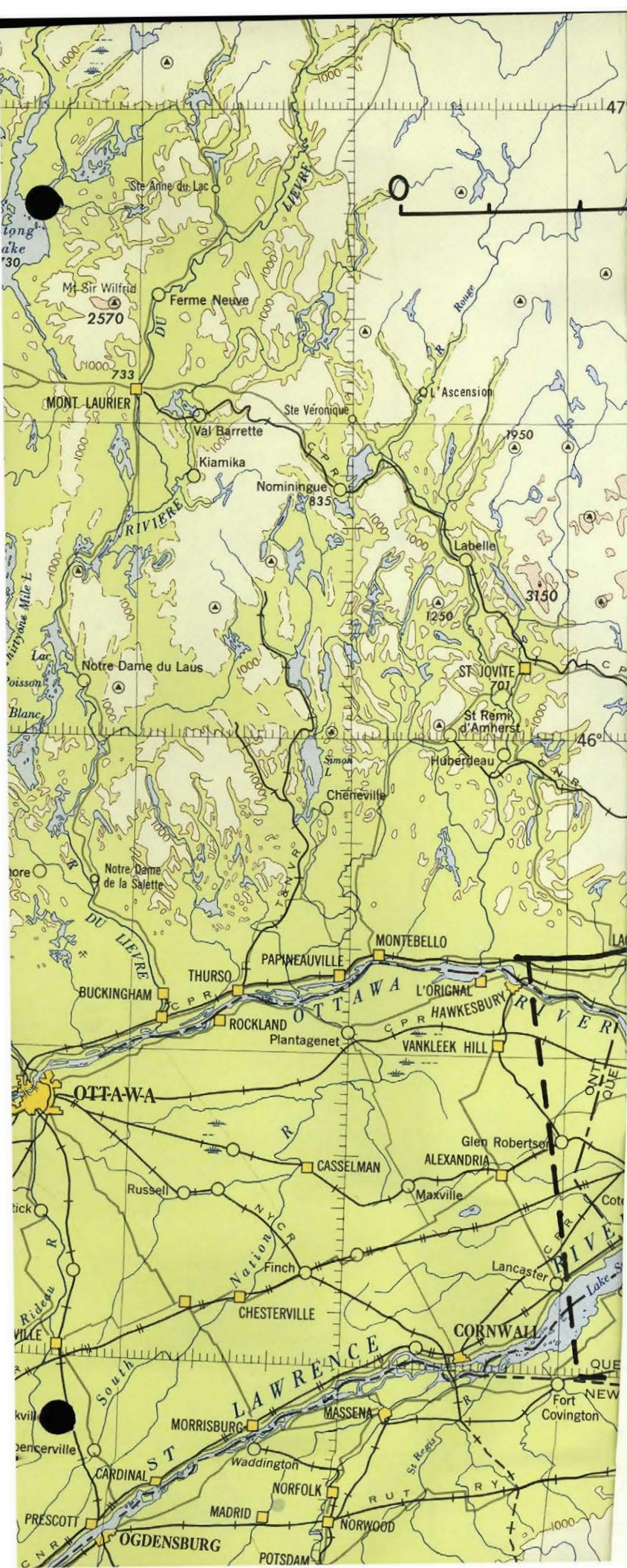
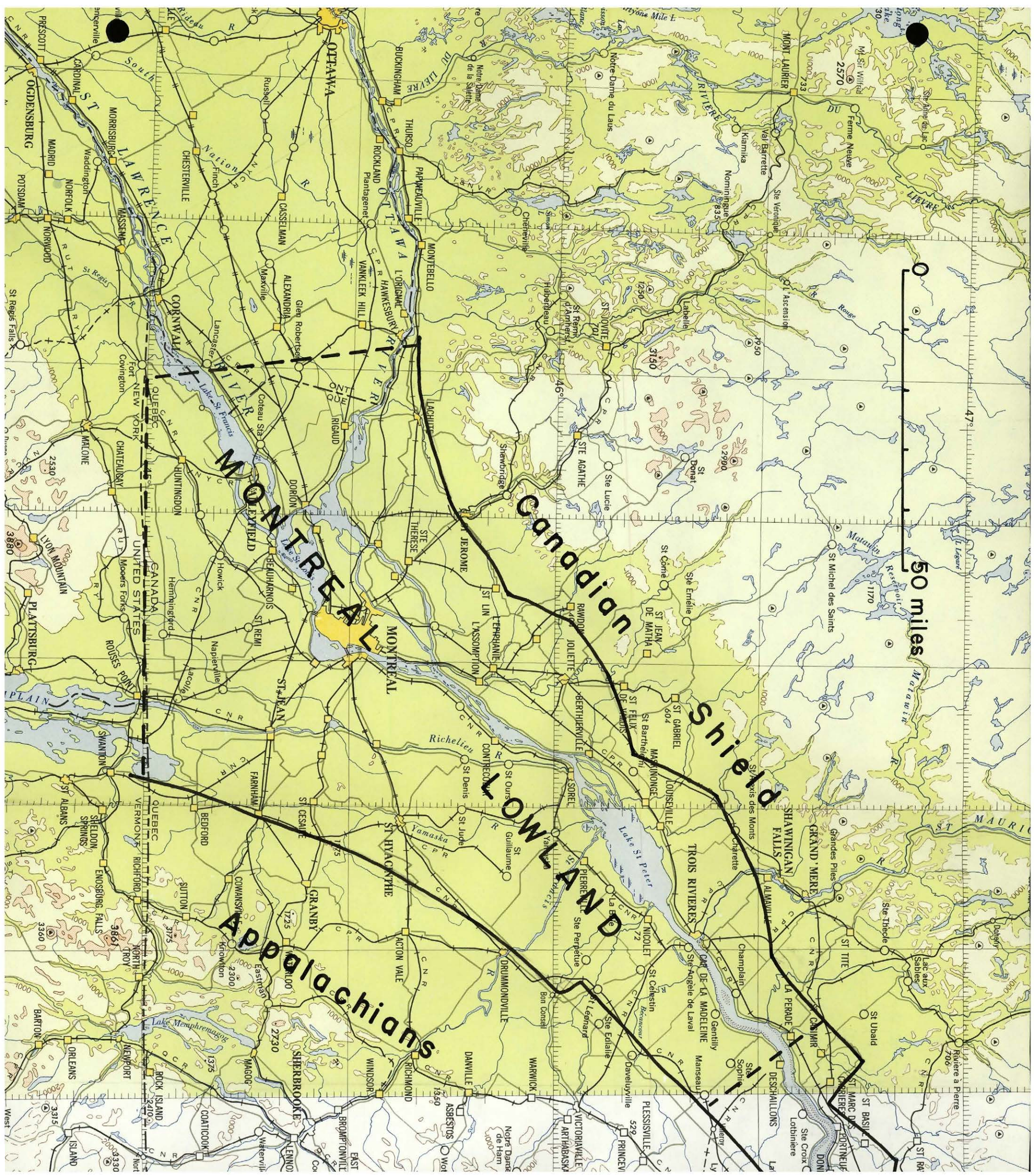


Figure 1.

The extent of the Montreal lowland

(from World Aeronautical Chart 2263,
1:1,000,000)

The structural limits of the lowland
are shown by solid lines; arbitrary
limits by broken lines.



Blanchard (1948, 1953) discussed certain aspects of the drainage pattern of the lowland in his geographical writings, paying special attention to the influence of the preglacial bedrock surface, the "Quebec platform". Discussion of the form and influence of this surface is carried further in the present study, and reference is made to other aspects of Blanchard's work.

Mackay (1949a, 1949b) made a regional geographical study of the lower Ottawa valley. His account of the physiography includes a detailed discussion of erosional bluffs of varied origin at different elevations, which provided a basis for the recognition and correlation of water marks by the present writer. He traced bluffs at 90-100 feet above sea level from the lower Ottawa valley eastward to Monts St. Bruno and St. Hilaire, referring them to a water body to which he assigned the name "Lake Montreal". This water body is shown in the present work to be a significant stage in the withdrawal of the Champlain Sea, and is renamed the "Montreal stage".

Mackay was not the first to recognize the significance of the Montreal bluffs, for Goldthwait (1933) described what he termed the 110-foot stage of the emergence of the lowland. Goldthwait also identified stages at 210 feet and 50 feet in the same work, which was the culmination of many years of study of the Champlain Sea, and which unfortunately remains unpublished. The present writer assigns the names "Rigaud stage" and "St. Barthélemy stage" to the 210-foot and 50-foot water bodies. Goldthwait was not concerned with the detail of the evolution of the drainage pattern, but gave a succinct description of the evolution of the St. Lawrence and Ottawa rivers.

Blanchard, Mackay and Goldthwait have been the only significant

contributors directly to the field of the present study. However, it would be wrong to limit the enumeration of previous workers to these three names, for the findings of numerous geologists, pedologists and paly-nologists have been incorporated.

The work of Clark (1952, 1955), Clark and Stearn (1962), Houde and Clark (1962) and Dresser and Denis (1944) has provided a basis for discussion of the influence of the bedrock geology upon the drainage pattern. Blanchard's work on the form of the bedrock surface, the "Quebec platform", has already been mentioned. Examination of the influence of this surface upon the present drainage pattern in parts of the lowland has been placed on a sounder footing with detailed mapping by Hobson (1962) and Freeze (1964). Other workers, for example Ells (1901) and Crosby (1932), have related the supposed preglacial courses of certain streams to the present courses and their conclusions are discussed.

The publication of maps of surficial geology has proceeded rapidly in recent years, by both the Geological Survey of Canada and the Government of the Province of Quebec. Reliable maps of soils have been published by the federal and provincial Departments of Agriculture, covering some parts of the lowland not mapped geologically; certain of the soils maps are accompanied by reports which include some discussion of physiography. Both surficial geological and soils maps have greatly facilitated examination of relationships between distribution of surficial deposits and the drainage pattern.

The geological field mapping of the lowland has been accompanied by a greatly increased understanding of the sequence of events during the Wisconsin. When the present work was begun, in 1958, little had been published since Antevs' major writings of 1925 and 1928. Renewed interest

in the glacial history of the region began with Osborne's papers of 1950 and 1951, and since then significant contributions have been made by Gadd, Karrow, Prest and Terasmae, under the auspices of the Geological Survey of Canada, by MacClintock, working for the State of New York, and by Parry of McGill University. Thus it is possible now not only to discuss the distribution of glacial deposits, but to understand, in some measure, the sequence of events leading up to the distribution; an understanding of the relationships between that distribution and the drainage network is thereby enhanced.

The lowland was inundated by the Champlain Sea after the withdrawal of the main mass of Wisconsin ice. Pioneer studies of the marine episode began more than a century ago and by now there is a general consensus on many aspects of the inundation: its extent, depth, age and deposits.

Many workers have contributed to knowledge of the extent and depth of the marine invasion, chief among them being Goldthwait, who summarized his findings in 1933. Several earlier writers had published elevations of the marine limit, but these tend to be inconsistent with figures derived from more accurate recent surveys, and have been disregarded. Radiocarbon dates of marine shells, made principally for or by the Geological Survey of Canada, have established the date of the marine maximum at about 11,400 B.P.. The surface distribution of marine sediments is known from geological and soils mapping, and knowledge of their depth is increasing.

However, divergent views are held on the nature of the marine transgression and regression. It is implicit in the writings of most recent workers that the sea entered the lowland at its maximum. Parry (1963), on the other hand, has found evidence to suggest that the sea rose

to its maximum from an earlier lower level. The nature of the marine transgression is of lesser importance in the present work, however, than that of the regression. Antevs, from his study of marine deposits, originally proposed a complicated sequence of oscillations of sea level in the Ottawa valley which he has recently abandoned (1962) in favour of a simple withdrawal from the maximum. Elson (1959), meanwhile, has suggested an oscillatory retreat on the basis of the evidence of littoral molluscs. Goldthwait based his discussion of stages in the regression on physiographic evidence, which led him to postulate a simple withdrawal with perhaps occasional halts.

Terasmae's palynological work (1960a) has indicated the feasibility of assigning relative dates to the emergence of the sites of bogs. In this way he has demonstrated that bogs of the same age lie at higher elevations at the northern than at the southern margin of the lowland. Previously it was possible to calculate differential uplift only of the plane of the marine maximum; Terasmae's work has provided a basis for examination of tilting at intermediate levels.

3. SUMMARY OF THE PRESENT WORK

a. The purpose of the study

It was the writer's intention when embarking on the present study to attempt an explanatory description of the development of the drainage pattern on the emerging floor of the Champlain Sea in the area around Montreal. It was an aspect of the physical geography which was worthy of attention, although little had been published about it.

In order to establish a coherent sequence of events it was necessary to recognize successive stages of the retreating Champlain Sea. The

determination of the present attitudes of successive water planes would also make it possible to consider the effects of tilting, due to differential isostatic uplift, upon the drainage pattern. It was also necessary to consider the changing volumes of water entering the area through the St. Lawrence and Ottawa rivers, and thus to link the recent physiographic history of the lowland with that of the Great Lakes and Lake Barlow-Ojibway.

It was essential to consider the nature of the surface upon which the drainage developed. This surface was the result of a combination of factors: the nature and form of the underlying bedrock surface, the nature, forms and distribution of glacial and marine deposits, and the nature of littoral processes immediately preceding the emergence. Finally, it was necessary to note any changes which had occurred in the drainage pattern since it was first established.

b. The nature of the evidence

Geological information was derived mainly from published maps and reports. It was hoped to supplement published material on the form of the bedrock surface by using a refraction seismograph to find the depth of surficial material. The results were not satisfactory as the available force produced an inadequate shock wave. River profiles surveyed by the Quebec Streams Commission provided additional evidence of the form of the bedrock floor. Maps of surficial geology and soils were supplemented by the interpretation of aerial photographs and by field observation to provide a basis for discussion of the nature and distribution of surficial deposits.

The major part of the field work, which was carried out during the

summers of 1958-1963, was concerned with the recognition and relative dating of stages of the Champlain Sea. The sea left evidence of its withdrawal in the form of shoreline bluffs, boulder concentrations and beach ridges, many of which are topographically conspicuous, or capable of recognition from aerial photographs. It was decided to regard the base of a bluff or boulder beach as marking the sea level of the time, an assumption which appears justified by a certain consistency of elevations measured along such a shoreline. Most of the measurements were made with a Paulin altimeter, reading to ± 2 feet. Readings from this instrument must be corrected for air temperature. The instrument itself is very sensitive to changes in temperature, and wherever possible measurements were made on more than one occasion. A Stewart mining altimeter, reading to ± 2 feet, was used in preference to a Paulin altimeter when possible. No temperature corrections need be applied to readings from this instrument, and it is less sensitive to temperature changes than the Paulin. It was decided that it would be unnecessary to repeat measurements taken with the Stewart altimeter, except to confirm the elevations of a few crucial points. It was fortunate that the surveyed elevations of many road intersections are shown on maps of the National Topographic Series, so that changes in air pressure could be calculated at frequent intervals. Published bench marks and railroad elevations were also used (Montgomery, 1935a, 1935b, 1940a, 1940b). In some cases elevations were obtained by levelling from established spot heights, but this method could not be practicably employed over the whole area. Reliable elevations of shorelines obtained by other workers were also incorporated.

Relative dates of emergence of certain sites were obtained by pollen analysis of bogs. Suitable sampling sites were selected with the

aid of aerial photographs. The surface elevation of the site was obtained by altimeter measurement, and the elevation of the base of the peat was then ascertained by probing. When the peat samples had been processed and analyzed for their pollen content it was possible to determine during which pollen zone the bog had begun to develop.

c. The treatment of the evidence and the results obtained

An introductory chapter is devoted to a discussion of the physiographic history of the Montreal lowland up to the Champlain Sea transgression. The matter of this chapter is derived largely from the work of others; however, a group of gravel ridges of fluvio-glacial origin is for the first time mapped and discussed as a whole.

A discussion of the palynological evidence follows. Ten new pollen profiles are added to those already published. The whole of the palynological data for the lowland is analyzed, and the present elevations of the boundary planes between bogs dating from pollen zones V, IV and III determined in four areas. The V-IV boundary surface lies at an elevation of about 200 feet above sea level, but has been isostatically deformed, while the IV-III boundary surface is horizontal at about 100 feet above sea level. Both surfaces lie at elevations and in attitudes comparable to those of well-defined shorelines, and are considered as equivalent to water planes. To the writer's knowledge this is the first time that palynological evidence has been used in this way. By combining the palynological evidence with radiocarbon dates of marine shells and peat an uplift curve is constructed for the Montreal area. In addition, erosional features in the lower Ottawa valley can be dated approximately by palynological methods and thus correlated with drainage from proglacial

Lake Barlow-Ojibway.

The evolution of the drainage pattern is then discussed region by region. In some cases significant stages in the development can be recognized, and emphasis is placed upon these in the discussion; in others it has been more appropriate to discuss the development in more general terms. The discussion includes an account of a series of diversions of drainage along the lowland section of the St. Narcisse moraine.

The final chapter first considers certain significant stages in the withdrawal of the Champlain Sea and in the evolution of the drainage, and concludes with a discussion of the relative importance of factors influencing the development of the drainage network. The stages which are recognized are the Rigaud or 200-foot stage, the Montreal or 100-foot stage and the St. Barthélemy or 50-foot stage. The Rigaud stage is marked by well-defined shoreline bluffs only in the lower Ottawa valley; it is associated with an increase in the volume of water passing down this section of the estuary. In this area the shoreline corresponds in elevation and slope with the V-IV pollen boundary surface and on this basis it is extrapolated throughout the lowland.

A far greater proportion of the Montreal shoreline is marked topographically. The shoreline may result from a minor relative oscillation of sea level when the eustatic rise temporarily exceeded the rate of isostatic uplift. The elevation of the shoreline is the same as that of the IV-III pollen boundary surface, and both are undeformed.

The Rigaud-Montreal interval, which lasted about 1,000 years, from 8,500 to 7,500 B.P., saw a great diminution in the extent of the Champlain Sea and the initial development of the drainage network over a considerable part of the lowland. By the St. Barthélemy stage the proportions of the

estuary were still further reduced and the drainage pattern had all but attained its present form. It is possible to suggest that the St. Barthélemy stage corresponds with a rapid eustatic rise of sea level at about 6,000 B.P..

In the discussion of factors influencing the development of the drainage network the form of the emerging sea floor is shown to have been paramount. Differential isostatic uplift, or tilting, is found to have been of relatively minor significance. Normal adjustments to structure hardly appear to have begun, a reflection of the extreme youth of the drainage system.

The present work is a contribution to knowledge in several ways. It provides an explanatory description of the evolving drainage pattern of the Montreal lowland. It re-examines and reinterprets Blanchard's "Quebec platform". It puts forward new evidence of the mode of glacial retreat. It demonstrates a method by which palynological data may be used to reinforce and extend the morphological evidence of shorelines, and in so doing it recognizes and provides approximate dates for significant stages in the withdrawal of the Champlain Sea. Finally, it links these stages with the evolution of the Great Lakes and Lake Barlow-Ojibway.

4. ACKNOWLEDGMENTS

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CHAPTER II

Physiographic background

1. BEDROCK GEOLOGY AND PRE-WISCONSIN PHYSIOGRAPHIC DEVELOPMENT

a. General geological description

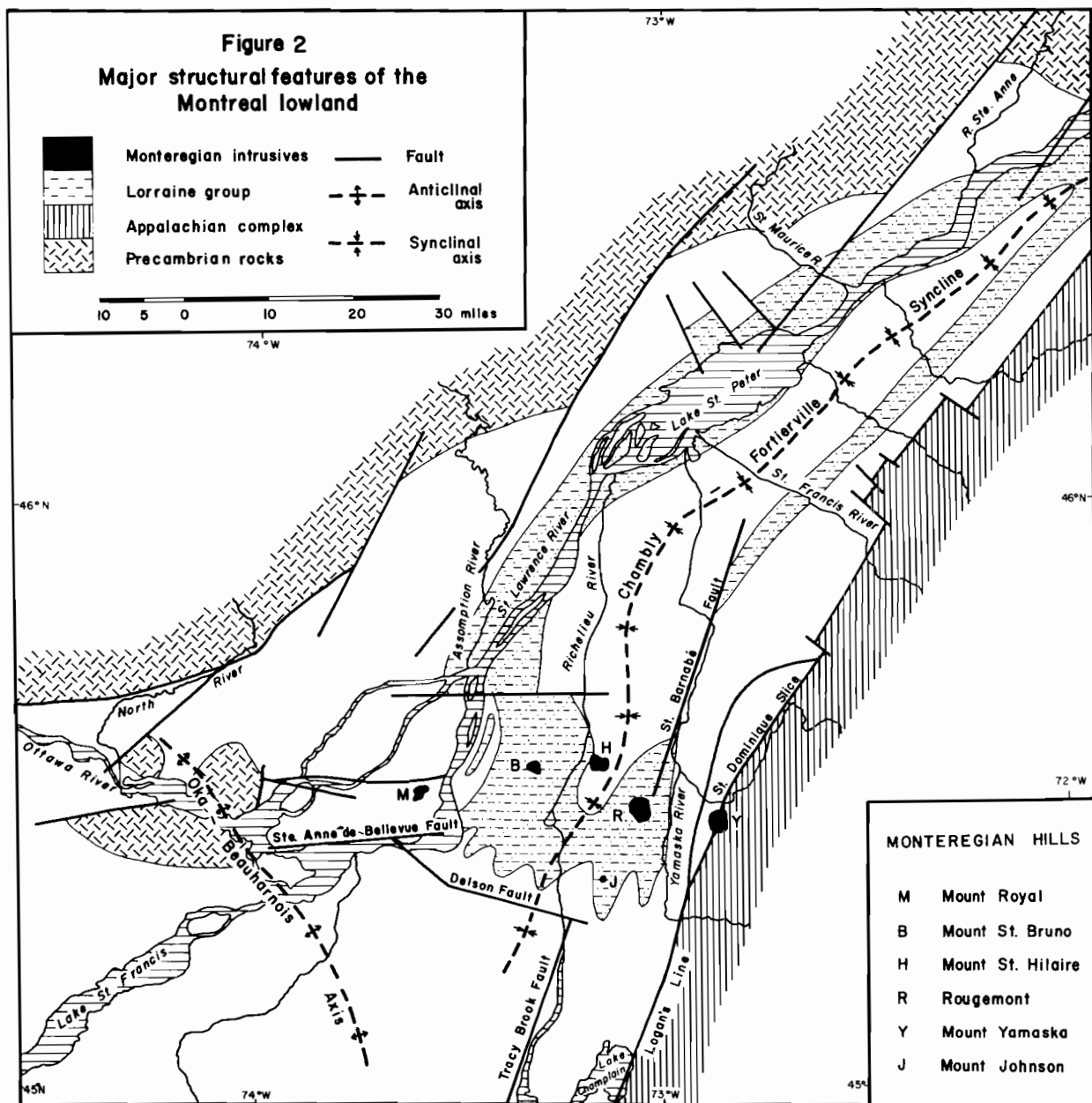
The bedrock of the St. Lawrence lowland is to a large extent obscured by surficial deposits. However, the lithology and structure of the bedrock base have indirectly influenced the present drainage pattern through their effect upon fluvial and glacial processes in pre-Wisconsin and Wisconsin time.

The most recent cartographic compilation of the geology is the Geological Map of the St. Lawrence Lowlands by Houde and Clark (1962). A summary table of the geological succession, adapted from Clark and Stearn (1962), is given as Table 1. It will be seen that the oldest sedimentary formation of the lowland is the Potsdam sandstone of probable Cambrian age, which rests upon the irregular surface of the Precambrian crystalline basement. The succeeding sedimentary strata are all of Ordovician age. The older Ordovician rocks are predominantly limestones, while the younger rocks consist largely of shales, with some limestone and sandstone. In general, therefore, the younger sedimentary rocks are less resistant than the older.

The outcrop pattern is determined by the two dominant structural features of the lowland, the northeast-trending Chambly-Fortierville syncline and the northwest-trending Oka-Beauharnois anticlinal axis (Figure 2). The arcuate synclinal axis may be traced from near the international border, west of the Richelieu valley, where it trends east of north, to Chambly,

Table 1. Geological Succession of the St. Lawrence Lowland

PERIOD	GROUP	LITHOLOGICAL CHARACTERISTICS	THICKNESS IN FEET
CRETACEOUS	Monteregian	Alkaline intrusives.	
ORDOVICIAN	Richmond	Red and green shale and sandstone. Some limestone.	2,200+
	Lorraine	Mainly shale.	2,500
	Utica	Shale .	300-1,000
	Trenton	Limestone with shale .	600-2,000
	Black River	Limestone .	60+
	Chazy	Limestone, sandstone, with shale .	0-410
	Beekmantown	Dolomite, with limestone and sandstone .	0-1,585
CAMBRIAN	Potsdam	Sandstone and conglomerate.	0-2,000+
PRECAMBRIAN	Grenville and Morin Series	Gneiss, quartzite, marble, anorthosite.	



where it is crossed by the Richelieu River. Northward the axis swings round to trend northeast, intersecting the course of the St. Lawrence River in Lotbinière county. Rocks of the Richmond group (shale and sandstone) are preserved at the centre of the canoe-shaped syncline. Southeasterly dips on the western limb of the syncline range from 1° to 6° , averaging 2° (Clark and Stearn, 1962). The outcrop of the Lorraine group (mainly shale) west of the synclinal axis is followed by the St. Lawrence River for almost 100 miles downstream of Montreal Island.

The regularity of the outcrops west of the axis of the syncline is interrupted by a series of northeast-trending faults, arranged en échelon. The downthrow is consistently to the southeast, and the faults may be traced from the sedimentary rocks of the lowland into the crystalline rocks of the Shield. Within the sedimentary area the faults have little topographic expression, but where sedimentary strata are thrown against the Shield rocks there is frequently a conspicuous east-facing scarp. Between the faults the sedimentary strata overlap the crystalline rocks, and the contact is frequently obscured by surficial deposits. Thus the northern margin of the lowland is a series of shallow embayments, each with a scarped western side, and less well-defined northern limits. Of the three embayments in the area under discussion the northernmost is drained by the Rivière Ste. Anne, the central embayment by the St. Maurice River and the Rivière du Loup, and the southernmost by the Rivière l'Assomption and its tributaries. Westward, adjoining the Oka-Beauharnois axis, the pattern of embayments is replaced by an arcuate south-facing scarp, probably formed along a number of separate fault lines which meet at low angles.

East of the axis of the Chambly-Fortierville syncline the

geological boundary between the lowland and the Appalachian system has been well described as a

complex of thrust faults, which, until it is possible to separate them into separate and recognizable units, may well be called "Logan's Line". At Philipsburg the contact is a clear-cut thrust dipping gently eastward. However, in general it is a zone of breccia a few hundred feet wide, well shown on the St. Lawrence, Becancour and Nicolet Rivers. For several miles west of "Logan's Line" the lowland rocks are tightly folded and overturned toward the west. (Clark and Stearn, 1962, p. 39)

This belt of complicated beds, known as the St. Germain Complex, also occurs east of Logan's Line, where it underlies the Appalachian piedmont, a belt of country at a higher elevation than the lowland west of the fault zone.

One of the faults associated with Logan's Line is mapped separately. It forms the western margin of the St. Dominique slice, where it gives rise to a well-marked west-facing scarp (Dufresne, 1947). The eastern limit of the slice is Logan's Line proper, where it appears to have determined the courses of the southward-flowing Black River and its tributary, the Rivière St. Nazaire. West of the St. Dominique slice is the St. Barnabé fault, which has no topographic expression, its existence being inferred from the evidence of well borings. The drift cover over the fault is thick, and it is mentioned only because of the remarkable parallelism of the fault and the Yamaska River for a distance of 16 miles.

The broad sweep of outcrops round the southern end of the Chambly-Fortierville syncline is interrupted by faults and distorted by a number of minor folds. The outcrops here may also be thought of as lying on the eastern flank of the anticlinal Oka-Beauharnois axis. In the south the Tracy Brook fault, which extends southward into New York State, defines the western limit of the Champlain lowland, and is closely paralleled by

the upper Richelieu River. The Delson fault, running from St. Jean to Lachine, has some influence upon the form of the present surface, and is the site of the St. Jean Rapids on the Richelieu River and of the Lachine Rapids on the St. Lawrence River. The easterly trending Ste. Anne de Bellevue and White Horse Rapids faults have possibly influenced the locations of the channels between Ile Perrot and Montreal Island, and between Bizard and Montreal islands and Ile Jésus (Clark, 1952, 1955).

On the Oka-Beauharnois axis two Precambrian inliers form St. Andrews Mountain, and the Oka-Rigaud massif which is transected by the Ottawa River. The inliers are in part bounded by faults, and rise above the general level of the lowland owing to the greater strength of the Precambrian crystalline rocks compared with the surrounding sedimentary strata. The sedimentary rocks exposed along the axis are themselves of greater resistance than the younger beds in the northeastern part of the lowland. Potsdam sandstone, for example, underlies the broad platform at elevations between 200 and 250 feet at the northern flank of the Adirondack upland.

The Cretaceous intrusive rocks of the Monteregian Hills have proved to be very resistant to erosion. The hills lying on a line across the lowland are, in order from west to east, Mount Royal (759 feet), St. Bruno (715 feet), St. Hilaire (1,363 feet), Rougemont (1,260 feet), and Yamaska (1,460 feet) which lies on Logan's Line. Mount Johnson (876 feet) lies south of the general line. It is believed that the intrusions were injected into sedimentary rocks the surface of which lay many hundreds of feet above the present bedrock surface. On St. Helen's Island, in the St. Lawrence River at Montreal, a brecchia contains blocks of Devonian limestone, indicating the former presence in the lowland of rocks of this age. Numerous smaller outcrops of intrusive rock, many of them dikes, are known

to occur, especially in the Montreal area, but few have any topographic expression, nor do they exert any influence upon the drainage pattern.

b. The Quebec platform

During the long post-Cretaceous period of denudation the area was reduced to a lowland. Blanchard (1948) made a study of the bedrock surface, which rises from a general level of about 100 feet above sea level at Montreal to 400 feet at Quebec City. He designated the surface the Quebec platform and ascribed its apparent slope to tilting.

In detail the relief of the bedrock surface is considerable. Evidence of its form in one small part of the lowland is provided by Hobson's seismic study of the Vaudreuil map-area (1962). Figure 3 was based on Hobson's map and also incorporates borehole evidence from the margins of Oka Mountain (Maurice, 1957). The zero contour defines a system of buried valleys incised below the general level of the Quebec platform. The pattern of valleys suggests their original excavation by subaerial streams. Within the valleys enclosed basins occur, their floors as much as 160 feet below sea level. The basins are deepest where the valleys cross the Oka-Rigaud massif, and it is suggested that the concentration of glacial flow within the narrow, steep-sided valleys resulted in overdeepening. If this be so, it follows that a major valley crossed the Precambrian inlier in pre-Wisconsin time. It has long been accepted that it was the ancestral Ottawa, rather than the St. Lawrence, which was the major stream of the St. Lawrence lowland in preglacial time (Mackay, 1949a, 1949b). Ellis (1901) suggested that the preglacial Ottawa flowed across the lowland between Oka Mountain and the Shield. It is now suggested that the pre-Wisconsin Ottawa was already incised within the massif,

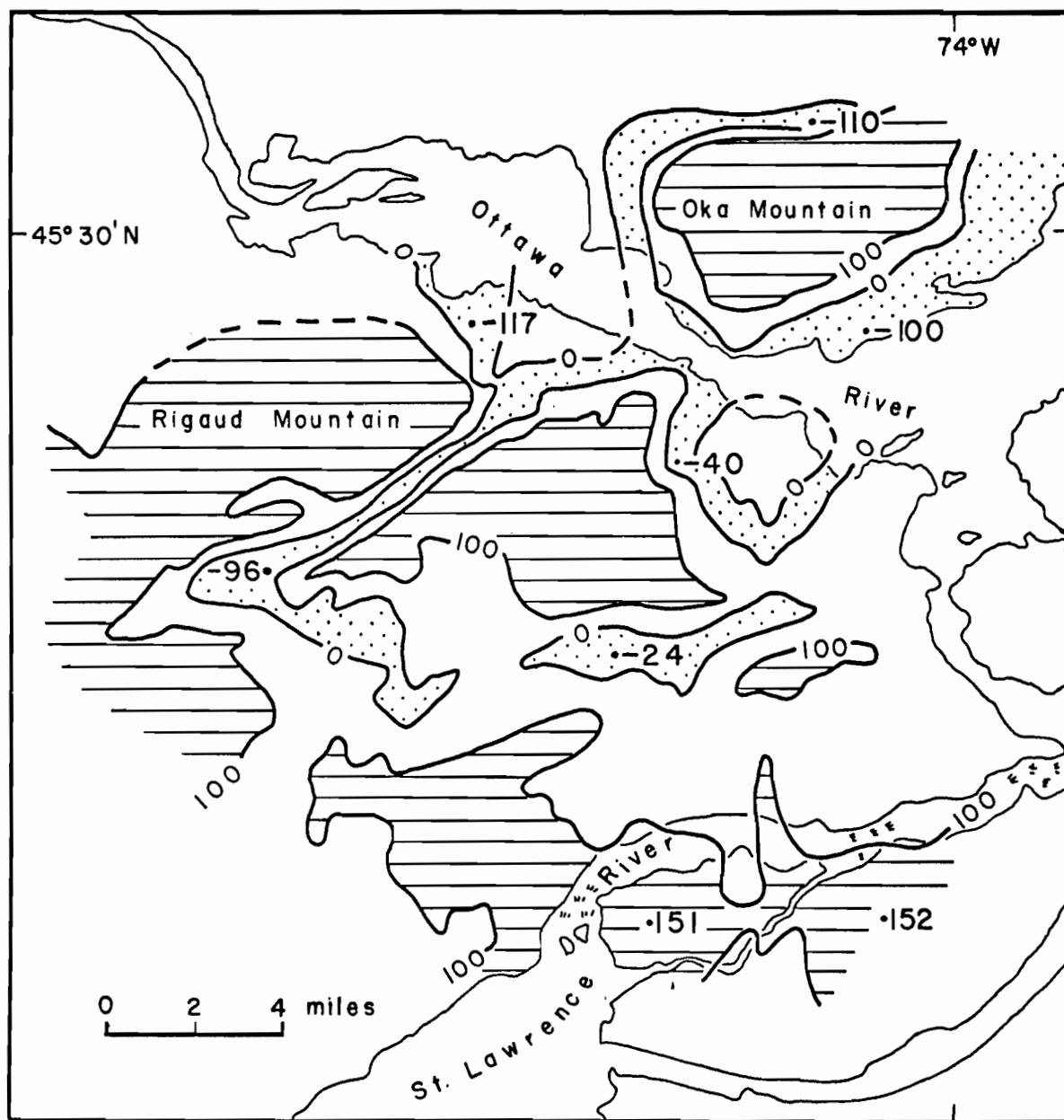


Figure 3. Bedrock contours on the Ottawa - St. Lawrence interfluvium
(after Hobson, 1962; Maurice, 1957)

and that the lowland north of Oka Mountain owes its form to general base levelling, rather than to its occupance by a major river. It is further suggested that the river was superimposed upon the rocks of the inlier from a sedimentary cover which was stripped away during the same denudational period which exposed the Monteregian intrusives. In the area south of the Oka-Rigaud massif the present drainage pattern bears no relation to the buried valleys. The St. Lawrence River, for example, where it flows from Lake St. Francis, crosses a bedrock high, the summit of which, at 150 feet above sea level, may be part of the Quebec platform.

The dissection of the Quebec platform in the Montreal area is indicated in Figure 4. The bedrock contours in the area south of the St. Lawrence River were drawn from a map by Freeze (1964), while those on part of Montreal Island were derived from the Drift-Thickness Contour map of Prest and Keyser (1961a). The bedrock surface rises to elevations of from 100 to 200 feet along the limestone spine of Montreal Island, and in an area of limestone and dolomite south of the St. Lawrence River. Freeze traced a depression from Beauharnois, where its floor descends to less than 40 feet above sea level, along part of the Châteauguay valley, through the Caughnawaga Indian Reserve and Laprairie to Chambly, where its floor is below sea level. A further depression, the floor of which descends to almost 50 feet below sea level, may be traced on Montreal Island along the line of the St. Pierre valley and parallel to the St. Lawrence River. The Rivière des Prairies also appears in part to follow a bedrock depression.

Further evidence of the dissection of the platform is provided by river profiles. The profiles of many of the rivers of the lowland may be divided into a steep upper section, where the river has cut down to

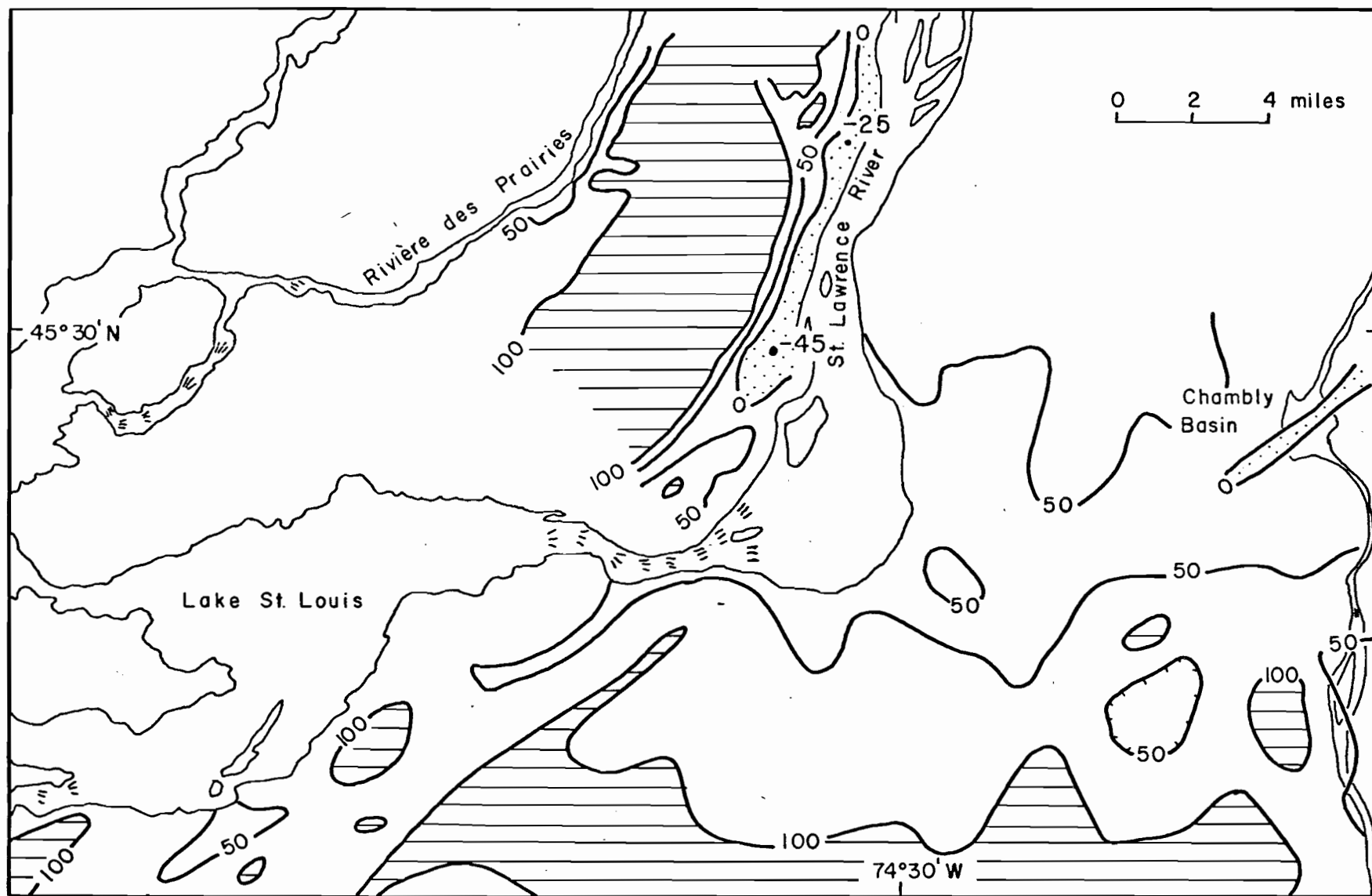


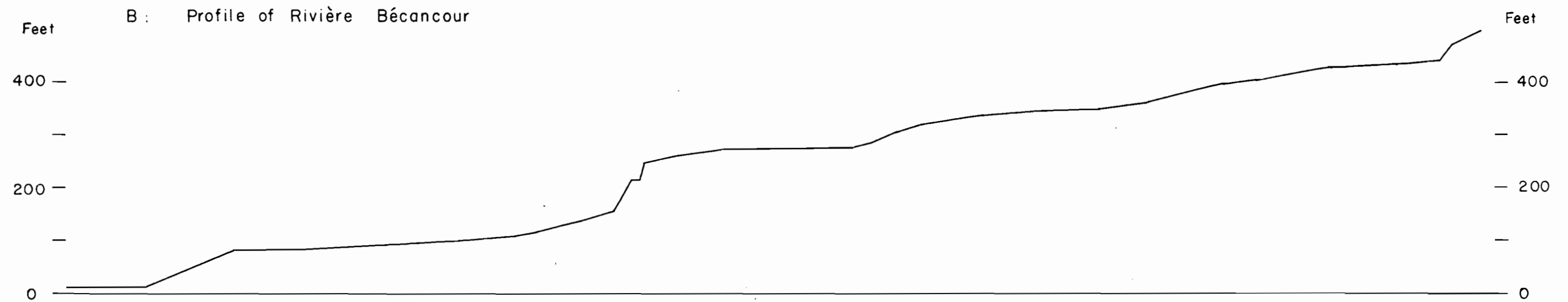
Figure 4. Bedrock contours in the vicinity of Montreal (after Freeze, 1964; Prest and Keyser, 1961a)

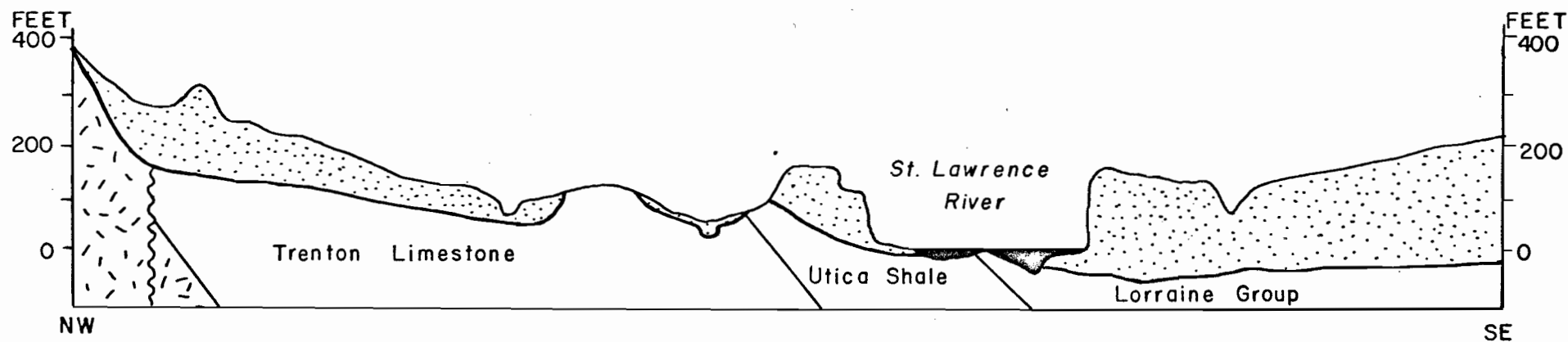
bedrock, and a graded or even horizontal lower section where the bed is in unconsolidated material. In areas of thick drift cover in the lowland the rivers are in process of being superimposed upon the bedrock base. The chances of such a stream being superimposed upon a pre-existing valley are small, and the form of the bedrock surface revealed in a stream bed is likely to give a good impression of the general form of the sub-drift surface in the area. The profiles of the Assomption, Ouareau and Achigan rivers provide an example (Figure 5a). Each river shows a marked flattening of gradient between 170 and 180 feet, and it is suggested that this represents the elevation of an undissected remnant of the Quebec platform.

A section across the lowland in the Grondines map-area (Karrow, 1959) shows the bedrock surface north of the St. Lawrence River at elevations between 100 and 150 feet. The river bed itself is cut in Utica shale at about 25 feet below sea level, while the lowest elevations on the bedrock surface occur south of the river, where Lorraine shale has been eroded down to 50 feet below sea level (Figure 6).

The correspondence of the elevation of the bedrock floor north of the river in the Grondines area with that in the Assomption valley and the Montreal and Vaudreuil areas is significant. The Quebec platform thus defined is untilted. Blanchard, however, postulated uniform tilting to account for its elevation of 400 feet at Quebec City. Examination of the profiles of the Bécancour and Southwest Nicolet rivers (Figures 5b and c) suggests an explanation of this apparent anomaly. The rivers show a succession of partially graded reaches in their upper, bedrock-controlled sections. Both rivers display such a reach above 280 feet, and it is significant that there is a suggestion of partial grading at the same elevation in the profile of the Rivière Maskinongé, which drains from the

Figure 5. Profiles of Rivières l'Assomption,
Bécancour and Nicolet Sud-Ouest
(vertical exaggeration 132)





Stippling indicates surficial deposits

Vertical exaggeration ca.30

Figure 6. Section across the St. Lawrence valley, Grondines map-area (after Karrow, 1959)

Shield (Profile of Rivière Maskinongé, 1934). The river profiles provide evidence, therefore, of a surface intermediate in elevation between the widespread 150-200 foot platform and the 400-foot surface at Quebec City. It seems probable that the dissection of the lowland in preglacial time proceeded by a sequence of partial erosion cycles, and that the 400-foot surface at Quebec City is older than the lower platform. Thus it may be unnecessary to invoke tilting to explain the apparent rise in elevation downstream. The absence of broad lower platforms in the area of Quebec City may be due to the restricted width there of the belt of weak lowland rocks.

c. The preglacial drainage pattern

The available evidence suggests that in pre-Wisconsin time the drainage of the lowland was carried northeastward by a major stream. Goldthwait (1933) recorded a deep channel 100-150 feet below sea level at Quebec City, and suggested that it was excavated by the preglacial river. The incision of the main stream, and of its tributaries in the Vaudreuil and Montreal areas, was probably in response to an early glacial low sea level.

The evidence at present available does not permit the pattern of buried valleys in the lower Ottawa valley to be linked with those in the Montreal area. It can be stated with some certainty that a buried valley underlies none of the exits from the Lake of the Two Mountains, for Ottawa water is retained in the lake at an elevation of 73 feet by bedrock sills. It may be that the drift-filled valley of the ancestral Ottawa lies across the mainland north of Ile Jésus, for some of the lowest points on the bedrock surface occur north of the Lake of the Two Mountains (Figure 3).

The pattern of depressions in the Montreal area poses a problem of its own. Freeze (1964) suggested that the Beauharnois-Chambly depression is of fluvial origin. His map indicates a depression along the Richelieu valley and a Beauharnois-Chambly river would have been tributary to the ancestral Richelieu. On the other hand, the evidence from Montreal Island indicates that the Beauharnois-Chambly depression is intersected by the drift-filled St. Pierre-St. Lawrence valley (Figure 4). If both these depressions are of fluvial origin, they were formed at different times by different drainage systems. However, an alternative explanation is possible. The eastern section of the Beauharnois-Chambly depression, between Laprairie and Chambly, is less well-defined than the section west of Caughnawaga; it is, moreover, cut in soft shale. It may be that a col between the preglacial St. Lawrence and Richelieu valleys was deepened here by glacial erosion, and it is significant in this respect that only a few feet of drift overlies the bedrock floor of the depression. If this eastern part of the depression is of glacial origin, then the Beauharnois-Caughnawaga section falls into place as being tributary to the preglacial St. Lawrence valley.

The course of the main stream below Montreal Island appears to have been little different from that of the present St. Lawrence River. Karrow's section across the Grondines map-area (1959) indicates that the preglacial stream may have followed a course a little to the south of the present river (Figure 6). The correspondence of this buried valley with the outcrop of the Lorraine shale is of interest, for it is in this area that the St. Lawrence River diverges from the Lorraine outcrop which it follows for many miles. While it is probable that the preglacial river had already etched out this weak outcrop, deep glacial gouging later

confirmed its influence upon the course of the present river.

2. WISCONSIN GLACIATION

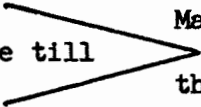
a. The lower St. Lawrence valley

It is probable that the St. Lawrence lowland was occupied by ice during all the major Pleistocene glaciations, although no evidence has been found of any glaciation earlier than the last, or Wisconsin. Even Wisconsin events are not fully understood, although recent work has added much to our knowledge. One area which has been studied in detail lies across the St. Lawrence valley in the vicinity of Trois Rivières; the Geological Survey of Canada has published six one-inch maps of surficial geology for an area which extends from the margin of the Shield to the Appalachian piedmont (Gadd, 1959, 1960a, 1960b, 1960c; Gadd and Karrow, 1960; Karrow, 1959).

The earliest glacial deposits recognized in this area are red varved silts (Table 2), which were deposited in a lake or lakes dammed by ice advancing up the valley toward the south or southwest (Gadd, 1955, 1960a). The ice contorted the lacustrine sediments and deposited upon them the red Bécancour till; both silt and till derive their colour from the shale and sandstone of the Bécancour River formation which lies at the axis of the Chambly-Fortierville syncline. The Bécancour ice appears to have been insufficiently thick to have depressed the crust, for no marine deposits overlie the Bécancour till. It is, however, overlain by non-glacial deposits of the St. Pierre interval. These consist of sand and peat, of freshwater origin, and represent a period the length of which Terasmae (1958) estimates as 6,000-7,000 years. The age of the peat has been given most recently as approximately 65,000 years (Dreimanis, 1960). Neither the length of the interval nor its age makes it possible to equate

Table 2

Wisconsin succession in the Montreal lowlandA. The lower St. Lawrence valley

St. Narcisse till  Marine deposits of
the Champlain Sea

Lacustrine deposits

Gentilly till

Varved deposits of Lake Deschaillons

Non-glacial deposits of the St. Pierre interval

Bécancour till

Red varved silts

B. The upper St. Lawrence valley and adjacent areas

Marine deposits of the Champlain Sea

— Unconformity —

Lacustrine deposits

Fort Covington till

Lacustrine deposits

Upper Malone till

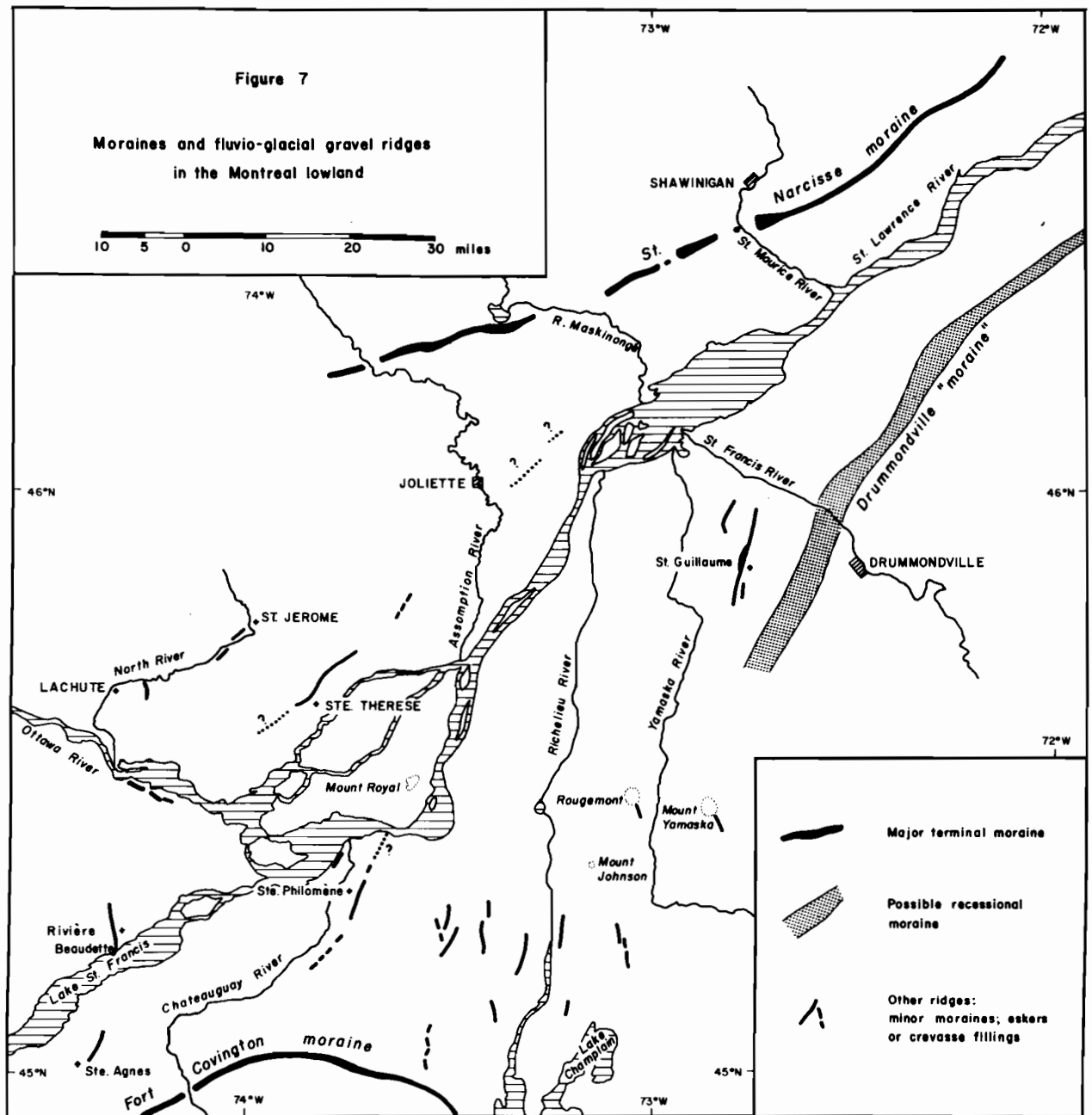
Stratified sand and varved clay

Lower Malone till

it with the pre-Wisconsin Sangamon interglacial. Nor does Terasmae's pollen analysis of the sediments, which indicates that the flora would have required summer temperatures 3-5°F. cooler than those experienced in the area today, as compared with the warmer conditions of the Sangamon (Terasmae, 1958). Terasmae suggests, therefore, that the St. Pierre interval represents an oscillation during the advance of the main Wisconsin ice sheet. During the interval drainage was carried to the northeast, with large streams meandering in broad channels in which sand was deposited (Gadd, 1955).

The non-glacial deposits grade conformably upward into the widespread varved deposits of Lake Deschaillons (Karrow, 1957) which appear to have filled the lowland to an elevation of about 150 feet above present sea level. Lake Deschaillons was held in by the main Wisconsin ice advancing up the St. Lawrence valley. This ice deposited the upper till of the area, the grey, sandy Gentilly till, which rests upon the lake sediments and extends beyond them. Glacial striae and pebble orientations associated with the Gentilly till range from S 10°E to S 40°W (Gadd, 1955).

The maximum extent of the Gentilly ice has been a matter of some debate. Since the Gentilly till is overlain by the marine deposits of the Champlain Sea, the ice was capable of depressing the lowland by more than 500 feet, and probably extended to the Wisconsin end moraines in southern New England. However, grey till of the Gentilly type has not been recognized beyond the northeasterly trending belt of country known as the Drummondville moraine (Figure 7). Gadd at first (1955) regarded the Drummondville moraine as the limit of the Gentilly ice, ascribing the red till of the Appalachian piedmont, to the east, to the earlier Bécancour ice advance (1960b). He has subsequently modified his interpretation of



the moraine, and now regards it as a recessional feature, reinforcing this view by his recognition of the "highland front moraine," which lies where the Appalachian piedmont merges with the Appalachian highland (Gadd, 1964). He has not, as yet, carried the argument to its logical conclusion with respect to the red till of the Appalachian piedmont. It is now suggested that this red till should be regarded as Gentilly rather than Bécancour. Its colour is explained by its derivation from red shales of the piedmont.

The discussion outlined above revolved about the importance of the Drummondville moraine as a significant terminal or recessional feature. It seems to the writer that its significance has been overrated. It consists of an assemblage of "much modified ridges that are elongated north-easterly" (Gadd, 1960b); reference to the map of soils of Drummondville county (Choinière, 1960) reveals that many of the ridges are cored with bedrock (Figure 8). Moreover, the "moraine" is aligned with, and in close proximity to Logan's Line. East of the thrust fault the bedrock surface of the Appalachian piedmont is at a greater elevation than that of the lowland to the west, and it may well be that the till ridges here are similar to those which at lower elevations are obscured by marine deposits. Indeed, Gadd himself (1960c) comments upon the probability of bedrock control.

b. The upper St. Lawrence valley and adjacent areas

Both MacClintock and Gadd have suggested that in the southwestern part of the lowland the correlative of the Drummondville "moraine" is the Fort Covington moraine (Table 2), which lies along the northern flank of the Adirondacks (Gadd, 1960a). More recent work on the penetration of the Fort Covington ice into northern Vermont (Stewart and MacClintock, 1964) and on the significant "highland front moraine" which is traced from

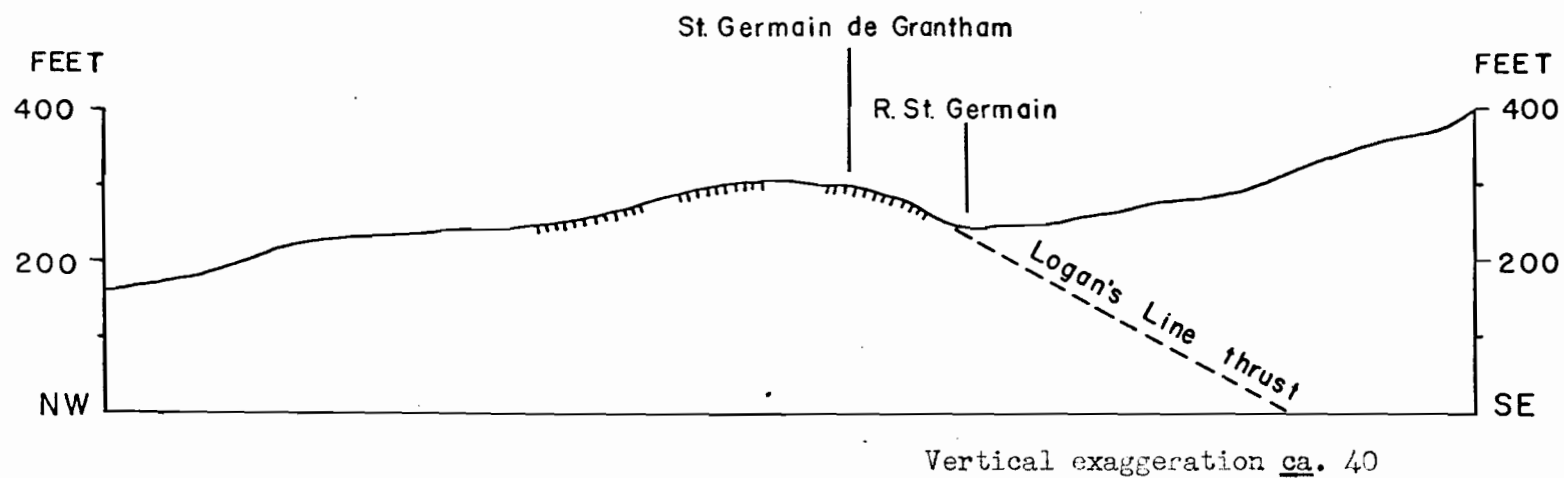


Figure 8. Section across the Drummondville "moraine", along Highway 22

The hatched line indicates that bedrock is within three feet of the surface (Choinière, 1960). Position of Logan's Line from Houde and Clark, 1962.

Granby to Rivière du Loup (Gadd, 1964) suggests that it is the latter, rather than the Drummondville "moraine" which may prove to be the correlative of the Fort Covington moraine.

The Fort Covington ice, of probable Mankato age, advanced across the lowland in a southeasterly direction, and extended as a lobe into the Champlain valley. Its terminal moraine may be traced as a low ridge north of Covey Hill, rising to a maximum elevation of 1,000 feet (Figure 7). The ridge appears to have controlled the courses of Mitchel Brook and the east branch of the Outarde River, causing them to flow obliquely down the slope of the hill (MacClintock and Terasmae, 1960). While till fabric orientation north of the moraine is southeasterly, in the older Malone till exposed south of the moraine it is dominantly southwesterly. Earlier work by MacClintock suggests that the leaching of gravels associated with the Malone till has extended to a depth of 5-7 feet; in gravels associated with the Fort Covington till leaching has penetrated to a depth of only 1-2 feet, indicating a significant lapse of time between the deposition of the two tills (MacClintock, 1954).

However, Terasmae (1960b), in his study of the surficial geology of the Cornwall area, notes that lacustrine deposits separating the two till sheets pinch out west of Cornwall, and concludes that this marks the extent of the retreat of the ice front between the deposition of the two tills. Prest (1962) suggests that the oscillation reached as far as the City of Montreal, where two tills are separated by "a complex of intercalated stratified sediments and till" (Prest and Keyser, 1961b). In addition, contorted laminated clay has been exposed in the lower Ottawa valley near Lachute; this clay may have been deposited in the same proglacial lake, and disturbed by the advancing Fort

Covington ice. It may be, then, that during the Malone - Fort Covington oscillation the ice front lay along the arc Cornwall-Lachute-Montreal.

Evidence of the change in the direction of ice advance after the lacustrine episode is found not only in striae and till fabric orientations, but in the moulding of till ridges (Terasmae, 1960b; MacClintock and Dreimanis, 1964). Only locally is the southeasterly trend of the later Fort Covington advance dominant; occasionally minor ridges with the Fort Covington trend are plastered on larger ridges with the earlier southwesterly trend of the Malone advance, but more often the Malone trend remains dominant. Glacial moulding has influenced the details of the drainage pattern, and may even have controlled the courses of major streams such as the Châteauguay.

The Malone till itself is twofold. Its upper and lower components are separated by stratified sand and varved clay (MacClintock, 1958). Thus in the southwestern part of the lowland there were three known ice advances, separated by lacustrine episodes. It is not known which of the lacustrine phases, if either, should be correlated with the St. Pierre and Deschailions sediments of the lower St. Lawrence valley. Correlation of the tills themselves presents some difficulty, for there is little evidence of southeastward-moving ice in the central part of the lowland. It is possible that the Fort Covington ice lobe in the Champlain valley was fed both by southeastward-moving ice from the Ottawa valley and by south- or southwestward-moving ice in the St. Lawrence valley. Thus the Gentilly till may prove to be the correlative of both the Fort Covington and the upper Malone tills.

The Fort Covington ice by impinging against the Adirondacks impounded Lake Iroquois in the Ontario basin. During the northward retreat

of the ice front drainage from Lake Iroquois or its successor passed through the Covey Hill spillway into the Coveville stage of Lake Vermont, a proglacial lake in the Champlain basin (MacClintock and Terasmae, 1960). Further withdrawal of the ice front permitted the lakes west and east of Covey Hill to fall to a common level, initiating the Fort Ann stage of Lake Vermont (Chapman, 1937). The lake persisted and expanded north-eastward until the withdrawal of the ice permitted the Champlain Sea to enter the lowland. According to Antevs (1925, 1928) this occurred when the ice front lay along the lower Ottawa valley and eastward toward Sherbrooke. Gadd, however, has recognized lacustrine sediments between the Gentilly till and the marine deposits far to the northeast of Antevs' line, and suggests (1964) that the sea entered the lowland when the ice withdrew from the south side of the St. Lawrence valley near Quebec City.

c. Glacial retreat

MacClintock and Terasmae (1960) suggest that the ice in the Champlain valley retreated by calving into the water of Lake Vermont, since there is no loop of drift to mark the limit of the ice in the valley, and since the lake clays contain a large number of striated stones, presumably ice-rafted. However, there is evidence to suggest that the Champlain ice lobe decayed in situ, a hypothesis which is not in conflict with the facts cited by MacClintock and Terasmae.

The evidence for decay in situ is provided by a series of low gravel ridges, which lie in a belt on either side of the Richelieu valley, trending radially southwest, south and southeast (Figure 7). The ridges vary in plan from almost straight to somewhat sinuous, and range in length from two to six miles. Some are continuous; some appear as chains of low

hills, such as the southern part of the Ste. Philomène ridge, east of the Châteauguay River. Others are topographically inconspicuous, since they lie below the marine limit and have been subjected to wave attack and burial by marine deposits. They may, however, be readily identified on air photographs from their light tone, and may also be recognized on maps of soils.

Some of the ridges appear to be related to bedrock highs; this is clearly the case with those trending southeast from Yamaska Mountain and Rougemont, and Elson (1962) suggests a similar relationship of the Ste. Philomène ridge with Mount Royal. Gravel workings in the Ste. Philomène ridge appear to have penetrated to its core, where the bedding is southward, along its axis. The constituent sands and gravels of the Yamaska ridge similarly dip along the axis, away from the mountain.

The disposition of the ridges in this belt and their relation to bedrock highs suggest that they were formed as crevasse fillings in a stagnant ice lobe saturated with the water of Lake Vermont. Baril and Mailloux (1950) and Mailloux and Godbout (1954) suggested a similar origin for the ridges west of the Richelieu River, but considered that the water body was the Champlain Sea. Although the Ste. Philomène ridge appears, in plan, to be a member of the group of features just described, it may prove, in fact, not to be so. Some patches of till-like material overlie the gravel in the ridge (Elson 1962), suggesting an origin within or beneath the ice. Its trend, moreover, is oblique to the southeasterly direction of advance of the Fort Covington ice, which fed the Champlain lobe.

There are other gravel ridges in the lowland in addition to the group just described. One of these, at Ste. Thérèse, north of Montreal, is roughly parallel with the Ste. Philomène ridge. Antevs (1928)

interpreted the Ste. Thérèse ridge as a recessional moraine deposited in the Champlain Sea, a conclusion followed by Byers (1933) who traced the feature northeastward. Elson (1962) traces it still farther to the northeast, but is uncertain of its origin. By analogy with the St. Jérôme moraine at the edge of the Shield, Antevs' interpretation seems the most likely. The St. Jérôme ridge is a minor topographic feature some twelve miles northwest of the Ste. Thérèse ridge; Parry (1963) puts forward evidence that it resulted from a minor oscillation of the ice margin into the Champlain Sea, although it had earlier been interpreted as an esker (McGerrigle, 1938). It seems probable, therefore, that the Ste. Thérèse ridge, also, was formed at the ice margin, during a minor readvance or during a halt in the retreat. It may thus be suggested that after the stagnation of the Champlain lobe the ice front regained its coherence and retreated with a calving front first in an expanded Lake Vermont and later in the Champlain Sea.

There are other ridges which may be recessional moraines. Parallel sand and gravel strings mapped by the Geological Survey of Canada on the clay plain between the Yamaska and St. Francis rivers near St. Guillaume are the surface expression of buried southwest-trending ridges (Figure 7), which can be interpreted as recessional moraines formed during the retreat of the ice from the line of the Drummondville "moraine." Not all the halts or oscillations of the ice front are expressed in the present landscape, however, for Prest (1962) notes an exposure on Montreal Island, not associated with a ridge, which suggests a readvance of the ice front into marine water.

Yet other ridges exist, which can be classified neither as crevasse fillings nor as recessional moraines. Those in the lower Ottawa valley

trend southeast, in a direction normal to the retreating ice front, and have been interpreted as eskers (McGerrigle, 1938; Lajoie and Stobbe, 1950). Two ridges are aligned north and south of Lake St. Francis in the upper St. Lawrence valley. That at Rivière Beaudette, north of the lake, is described as an esker (Lajoie and Stobbe, 1950). That to the south, at Ste. Agnès de Dundee, is interpreted as a crevasse filling (Mailloux et Godbout, 1954), but the presence of till-like material overlying well-sorted bedded material suggests an origin similar to that of the Ste. Philomène ridge. Much of the original structure has been destroyed by wave action, however, and neither existing exposures nor the location of these ridges provides more than tentative evidence of their origin.

d. The St. Narcisse readvance

The final glacial event in the lowland was the deposition of the St. Narcisse moraine, north of the lower St. Lawrence River. The moraine may be traced as a conspicuous, almost straight ridge for a distance of 60 miles across the lowland embayments drained by the Ste. Anne and St. Maurice rivers. To the southwest, within the Shield upland, it has been traced toward the massive proglacial delta at St. Gabriel de Brandon and thence to the moraines marking the culmination of the St. Faustin readvance in the Laurentians (Parry, 1963).

Osborne (1950a, 1950b, 1951) suggested that the lowland section of the moraine was deposited at the northern margin of an ice lobe moving up the St. Lawrence valley after an early marine episode. Indeed, all exposures on the northwestern flank of the moraine show northwesterly bedding, as if the material were deposited into a water body held between the ice and the Shield upland (Figure 9). There is, however, ample



A. General view of the exposure. Note the coarse morainic material to the right (south).



B. Detail of the laminated beach deposits

Figure 9. Crudely laminated northward-dipping beds on the northern slope of the St. Narcisse moraine, near St. Narcisse village

evidence that the St. Narcisse moraine, like the St. Faustin moraine with which it is aligned, was deposited at the margin of southward-moving ice. Glacial striae near the moraine trend southeastward; underlying marine sediments are contorted as if by southward-moving ice; the moraine is somewhat lobed at the mouths of valleys; Palaeozoic sedimentary erratics are known to occur only where the moraine overlies sedimentary bedrock, and glacial outwash occurs south of the moraine (Karrow, 1955).

Since the moraine overlies marine sediments the ice readvanced into the Champlain Sea. Hence the northward-dipping gravels on the north side of the moraine are to be interpreted as beach deposits, formed as the crest of the ridge rose sufficiently high to be subjected to wave attack. The lamination of some of these deposits may be attributed to seasonal variation in conditions; silt was deposited during the winter, when wave action was inhibited by ice, and gravel during the summer.

Following the radiocarbon dating of shells from Champlain Sea sediments, which indicated their equivalence in age with the Two Creeks interval, and the confirmation of the dates by the dating of organic sediments, Terasmae (1959) suggested that the St. Narcisse readvance may have occurred at the same time as the Valders readvance in the Great Lakes region. Evidence to support this conclusion will be put forward in the following section.

The St. Narcisse moraine is the site of a number of diversions of drainage. It also provides evidence of the maximum extent of the Champlain Sea. These aspects will be discussed in the following section and in Chapter VI.

e. Glacial erosion and deposition

The degree of glacial erosion in the lowland is not easily determined. The total mass of till and marine clay is immense, and implies the removal of much bedrock. However, where the form of the buried surface has been studied in detail, it is still possible to recognize the preglacial valley pattern and even remnants of the "Quebec platform," as was demonstrated in an earlier section.

Local glacial overdeepening of the preglacial valleys may be recognized. In the Vaudreuil area, enclosed basins within the valleys are attributed to such gouging, and it is of interest that the deepest points occur where, according to seismic evidence, the bedrock is resistant Potsdam (Nepean) sandstone (Hobson, 1962). The overdeepening of the basin in which Lake St. Peter lies was on a much larger scale. At Berthierville the bedrock floor may be as much as 550 feet below sea level (Blanchard, 1948), and it is below sea level over a wide area. The depression lies almost wholly within the outcrop of the weak Lorraine shale, which trends roughly parallel to the direction of glacial advance. Glacial erosion would thus have been facilitated. The depression has been almost filled with glacial and post-glacial deposits, so that a navigable channel through the lake must be maintained by dredging. Rivers tributary to the St. Lawrence in the area of the depression have been able to cut down quickly through this unconsolidated material, and their lower reaches are close to base level. The Yamaska River, for example, has no discernible gradient for the last 20 miles of its course.

In the centre of the lowland constructional glacial features have been largely buried by marine deposits. Where the bedrock base is higher, toward the margins of the lowland, glacial deposits outcrop more

frequently, but below the upper marine limit the outlines of the features have been modified by wave action. Nevertheless, a variety of constructional forms may be recognized:

- i. Moraines. There are several terminal or recessional moraines in the region. The oldest is the Fort Covington moraine, north of Covey Hill. The Canadian section of the moraine lies mainly above the marine limit, and consists of a low ridge of boulders, running obliquely up the hillside. The ridge has caused the diversions of Mitchel Brook and the Outarde River, noted by MacClintock and Terasmae (1960). The Ste. Thérèse moraine (or gravel ridge) caused the deposition of considerable depths of marine sediment, in which it is almost buried, and as a result of which it exerts little direct influence upon the drainage pattern (Chapter IV). Small sections of the St. Narcisse moraine are similarly buried, but where it forms a significant topographic feature it may be seen to have had a more direct effect upon the drainage pattern, and a number of diversions of drainage are associated with it (Chapter VI). This moraine retains its topographic significance despite its almost complete submergence by the Champlain Sea and the extensive reworking of its material by wave action. Locally the ridge appears to have been turned inside out, with large boulders resting upon finer northward-dipping beach deposits. The St. Jérôme moraine is limited in extent and topographic significance.
- ii. Ground moraine. The thickness of ground moraine is very variable. Not only is its base irregular, but where the deposit is deep the upper surface has been moulded into ridges in the direction of glacial flow. Extensive till sheets with unmoulded upper surfaces may occur, but if so, they are buried beneath marine sediments. The dominant trend of the morainic ridges is south to southwest. McGerrigle (1938) suggested that

the ridges in the Lachute map area were recessional moraines, but more recently till fabric analysis (MacClintock 1958; MacClintock and Terasmae, 1960; MacClintock and Dreimanis, 1964) has confirmed Taylor's earlier view (1924) that the ridges in the upper St. Lawrence valley were moulded by glacial flow. Terasmae (1960b) has identified southeastward and southward moulding, superimposed upon the dominant southwestward trending ridges in the Cornwall area, and has related the later moulding to the Fort Covington readvance, the earlier to the Malone advance. A southeastward trend of moulding is dominant in the Ottawa valley above the Lake of the Two Mountains. This trend also may have been caused by the Fort Covington readvance.

Where morainic ridges have been subjected to wave action their crests have been smoothed. Fines washed from the till have been formed into beaches on the slopes or deposited in the intervening depressions, and the coarser material remains as a boulder concentrate. Despite the lowering of the ridge crests and the infilling of the depressions the pattern of ridges determines the courses of many minor streams. The east-northeast components of the drainage pattern in the Châteauguay valley, and the north or south components in the upper Richelieu valley may be cited as examples. In parts of the Richelieu valley marine clay forms a thin surface layer. The influence of the trend of the morainic ridges upon the drainage pattern is clearly visible, and it may be that they were never completely obliterated by the deposition of marine sediments.

Tails of till appear to have accumulated in the lee of most of the Monteregian hills. The detailed mapping of the Montreal area (Prest and Keyser, 1961b) shows that the tail of drift extending southwest from Mount Royal is partly covered with Champlain sands and gravels, probably

redeposited components of the drift. The corresponding drift tails south of Mont St. Bruno, Mont St. Hilaire and Rougemont appear to have experienced even more wave sorting and redeposition.

iii. Fluvio-glacial deposits. Since the ice in the lowland retreated by calving there are few deposits of outwash. A proportion of the extensive spreads of sand in the lowland must have originated as outwash in tributary valleys; this sand has been redeposited, perhaps several times, by fluvial and marine action. Sand from the upper St. Maurice and Assomption valleys accumulated as deltas at the valley mouths. The St. Francis and other rivers from the south also have high level deltas, evidence of a residual ice mass in the Appalachian upland.

Mention has already been made of the radial pattern of gravel ridges which occur in a belt across the southern part of the lowlands. These crevasse fillings or eskers were probably formed near the margin of a retreating Champlain valley ice lobe. Similar features in the Ottawa valley are also known. The ridges trend generally with the glacial moulding of the ground moraine, and reinforce its effect upon the drainage pattern.

It is convenient at this point to discuss some of the difficulties of mapping superficial deposits in the St. Lawrence lowlands. One of the sources of difficulty has already been indicated—the reworking of the upper layers of deposits by wave action. Within wave-worked areas of till there is a rapid variation of surface material. Sand washed from the till may form a beach deposit, which may feather out as a very thin layer over the remaining till. A decision must be made whether to map the whole area as till, or whether to map the sand separately. In the second case it must be determined whether the whole spread of sand should be mapped as

such, or whether it should be mapped as sand only where it exceeds a certain thickness. The policy of the Geological Survey of Canada seems to have been to map the actual surface material, however thin. As a result some of the maps of surficial geology are misleading. The case of the Drummondville "moraine" has already been cited. Many of the "till" ridges shown on the Aston sheet (Gadd, 1960b), for example, consist of no more than a few feet of till plastered on a bedrock core. The soils map of Drummondville county (Choinière, 1960) has sufficient categories to enable areas of shallow and thicker till to be distinguished, and in this respect is of more use to the geomorphologist than is the geology map. The soils map, however, cannot be used to distinguish tills of different ages. Another instance of the way in which the geology map may mislead occurs in the Upton map area (Gadd, 1960c). Parallel belts of sand are shown crossing a plain of marine clay, following the contours, and giving the impression of raised shorelines. Field examination reveals that the sand forms a thin layer above buried till ridges, and any coincidence of a sand belt with a former stand of sea level is fortuitous. A subjective element also comes into play; it is almost inevitable that different workers will make different decisions in a complex area, such as a wave-washed till area. Hence the geological boundaries on adjacent map sheets do not always coincide.

3. THE CHAMPLAIN SEA

a. The age of the Champlain Sea

Radiocarbon dating has necessitated a revision of theories regarding the Champlain Sea, and there is now a substantial body of evidence to show that the marine episode was, in part, contemporary with the Two Creeks

interval, and was not a post-glacial phenomenon. The integration of various lines of evidence, to be attempted below, indicates that marine and glacial conditions interlocked in the St. Lawrence lowland.

The earliest evidence for what now appears to be the correct age of the Champlain Sea was in the form of radiocarbon ages of shells, of about 11,000 years (Preston, Person and Deevey, 1955). The dates were rejected by Flint (1956) and Hough (1958) as they did not agree with the established chronology for the Great Lakes, according to which the marine inundation occurred 7,000 or 8,000 years ago. When Terasmae (1959) published the radiocarbon age ($9,430 \pm 250$ years; L441-C) of the basal organic sediment of the St. Germain bog, 300 feet above sea level, it became clear that the Champlain Sea was withdrawing before the classical hypothesis would have it enter the lowland. The dates from shells have now been generally accepted, and they are confirmed by archaeological evidence (Mason, 1960).

A recent catalogue of shell dates reveals a remarkable similarity of age of shells taken from near the marine limit (Gadd, 1964): at St. Epiphane, near Riviere du Loup, where the limit of the Champlain Sea lies at 375 feet, shells at 310 feet above sea level are $11,410 \pm 150$ years old (GSC-63); at Kingsey Falls, in the valley of the Southwest Nicolet River, shells at 400 feet above sea level, perhaps 75 feet below the marine limit, have been given the date of $11,410 \pm 150$ B.P. (GSC-187); shells on Mount Royal at an elevation of 545 feet, 60 feet or so below the marine limit, are $11,370 \pm 360$ years old (Y-233); and shells from 500 feet at Kingsmere, north of Ottawa, 190 feet below the marine limit, are dated at $11,320 \pm 200$ B.P. (L-639B). As it is not clear whether the shells were deposited before or after the sea had attained its maximum it is a

reasonable approximation to place the maximum at about 11,400 B.P..

The question of the age of the Champlain Sea is closely linked with that of Lake Iroquois. MacClintock and Terasmae (1960) suggest that the lake was impounded by Fort Covington ice; radiocarbon ages of Lake Iroquois sediments range from $12,660 \pm 400$ years (W-861) to $11,510 \pm 240$ years (Y-691) (Karrow, Clark and Terasmae, 1961) and lend support for the Mankato and post-Mankato age of the lake. As the ice front withdrew northward the level of the lake water fell to that of Lake Vermont in the Champlain basin and finally the sea gained entry to the isostatically down-warped lowland. It would thus appear that Lake Iroquois predates the Champlain Sea.

However, the earliest dated sediment attributable to the present Lake Ontario was deposited as recently as $10,150 \pm 450$ years ago (TB-50) and Karrow et al. suggest that either Lake Iroquois did not drain until 10,600- 10,400 years ago, or that there was a second stage of the lake, impounded by Valders ice, at that time. In either case it would be necessary to place the margin of the Valders ice sheet south of the St. Lawrence River in eastern Ontario, where it would have remained until the Champlain Sea had begun to retreat from its maximum.

A considerable body of evidence can be brought forward to dispute such a late date for the final draining of Lake Iroquois. Examination of the evidence set forth by Karrow et al. suggests, contrary to their conclusions, that the ice dam could have given way as early as 11,600 years ago. Terasmae, in fact, states in personal communication (1964) that the lake drained earlier than 10,500 years ago. The date of $11,510 \pm 240$ B.P. was obtained from samples of wood from lagoon sediments which were subsequently over-ridden by the advancing Iroquois beach bar. The true age of

the wood could be as much as 11,750 years; the following 150 years could possibly have seen the construction of the beach bar over the site and the draining of the lake. The lake could thus have drained before the highest water marks of the Champlain Sea were registered.

Nevertheless there would still be a large number of events to fit into a short period of time. The faintness of the shorelines of the lake stages following Lake Iroquois indicates that these water bodies were of very short duration, as Karrow et al. point out. However, when the last of these lakes in the upper St. Lawrence valley drained, its floor was above the sea level of the time, for the upper part of the lacustrine sediments is dried, broken, partly oxidized and in places fluviially eroded (MacClintock and Terasmae, 1960). The sediments lie at an elevation of about 200 feet above present sea level. They are overlain by the bottom sediments of the Champlain Sea, which reached its maximum at an elevation of about 525 feet on the slopes of Covey Hill (Goldthwait, 1911). Dating the marine maximum at 11,400 B.P. allows only 200 years for the draining of Lake Iroquois and its successors, and for the submergence of the lake floor beneath 325 feet of sea water. This length of time is almost certainly too short, but it is the best available approximation. The depth of the marine submergence, however, is the equivalent of the whole of the eustatic rise which followed the maximum of the Wisconsin glaciation (Fairbridge, 1960, 1961), and could not, therefore, have been achieved without the aid of renewed isostatic depression.

This evidence of the rise of the Champlain Sea upon the land is reinforced by Parry's work at the northern limit of the lowland (1963). Deltaic outwash deposits at St. Jérôme, at an elevation of 350 feet, were laid down during a minor readvance of the ice front into the Champlain Sea.

The ice subsequently withdrew up the North River valley while the sea rose to its maximum at about 750 feet above present sea level shortly after the maximum of the St. Narcisse - St. Faustin glacial oscillation. A submergence of 400 feet is indicated, which may well have been synchronous with that of at least 325 feet in the upper St. Lawrence valley.

Again, in the Ottawa area, Gadd's work (1961, 1963) indicates a submergence of more than 400 feet. He postulates a short-lived glacial lake in the Rideau valley "before the Champlain Sea progressively flooded into this part of the Ottawa - St. Lawrence system" (1963, p. 2). The lacustrine deposits he describes lie at an elevation of between 250 and 275 feet; the marine limit at Kingsmere, to the north at the Shield edge, lies at 690 feet above present sea level (Johnston, 1916).

There is strong evidence, therefore, that the Champlain sea attained its maximum at about 11,400 B.P. in response to rapid isostatic downwarping of the crust, shortly after the ice front had begun to withdraw from the St. Narcisse - St. Faustin moraine. It may be deduced further that it was the St. Narcisse - St. Faustin readvance which caused the depression of the crust. The inability of the retreating Mankato ice to have been responsible for the greatest depth of the Champlain Sea may be explained by the isostatic recovery which had occurred before the sea entered the lowland.

Broecker and Farrand (1963) have set back the date of the termination of the Two Creeks interval by 450 years to 11,850 B.P.. This may necessitate setting back the date of the Valders maximum in its turn from the calculated date of 11,000 B.P. (Flint and Deevey, 1951). If the date of the Valders maximum should be revised to 11,450 B.P., there could be no doubt that the St. Narcisse - St. Faustin readvance was the equivalent of

the Valders readvance in the Great Lakes region, and that the Champlain Sea attained its maximum in response to crustal depression at the margin of the Valders ice. Thus Valders ice could have played no part in the damming of Lake Iroquois. This interpretation of the sequence of events is, moreover, in keeping with the date of 10,970-9,275 B.P. suggested by Terasmae and Hughes (1960) for the opening of the North Bay outlet.

b. The history of the marine episode

The Champlain Sea did not enter the lowland until the ice had withdrawn from the St. Antonin moraine near Rivière du Loup (Lee, 1963), and probably not until it withdrew from the south side of the St. Lawrence valley near Quebec City, an event which occurred at least 11,500 years ago (Gadd, 1964). While the ice was standing at the St. Antonin moraine (of possible Mankato age) the Fort Covington ice was retreating from Covey Hill and a proglacial lake extended over much of the lowland, for varved clay overlies till as far east as the Bécancour map area (Gadd, 1960a). Lake sediments in the upper St. Lawrence valley were raised above the sea level of the time. When the sea entered the lowland the fresh water of the proglacial lake in the Bécancour area merged with the salt or brackish water for the varved lacustrine sediments grade up into massive marine clays.

It is possible to calculate the rate of isostatic uplift immediately following the withdrawal of the ice in the Rivière du Loup area. The marine limit beyond the St. Antonin moraine lies at an elevation of 550 feet, and shells from near the limit have been dated at $12,720 \pm 170$ B.P. (GSC-102) (Lee, 1963). The marine limit within the moraine, in the area occupied by ice while the sea beyond stood at 550 feet, is at 375 feet

above present sea level, and shells from 310 feet are dated at $11,410 \pm 150$ B.P. (GSC-63) (Gadd, 1964). The eustatic rise of sea level in the period between the two shell dates was 50 feet (Fairbridge, 1960); thus total isostatic recovery during the same interval was 290 feet, at a rate of more than 20 feet per century. Since the initial rate of isostatic recovery was so much greater than the eustatic rise of sea level the submergence of the upper St. Lawrence valley, the Ottawa area and the valleys of the Laurentians, noted above, must have been due to renewed isostatic depression of the crust in response to the readvance of the ice front to the St. Narcisse - St. Faustin moraine. There appears to have been considerable downwarping beyond the ice margin, to account for the high sea levels south of the St. Lawrence River.

This argument leads to the conclusion that the highest marine water marks were registered simultaneously north and south of the lowland; this is borne out by the similarity of radiocarbon ages of shells from near the marine limit (p. 48). The highest water marks, of about 750 feet above present sea level, occur in the Laurentian valleys, where the ice front was not in contact with the sea (Parry, 1963). Where the ice advanced into the sea it prevented the registration of the highest water mark upon the land, but there are some constructional features, such as the proglacial delta at St. Gabriel, at 700 feet above present sea level, which lie close to the marine limit.

There have been conflicting views of the mode of regression of the Champlain Sea. Antevs (1928) proposed a complicated sequence of relative oscillations of land and sea which he has recently abandoned in favour of a hypothesis of only one deep water phase (1962). Elson suggests, from a study of littoral molluscs, that a sub-Arctic *Hiatella* phase was brought

to an end 10,600 years ago when sea level had fallen to 140 feet. There followed the much warmer Mya phase, with a eustatic rise of sea level to 200 feet. Subsequent emergence created a freshwater lake, the Lampsilis Lake, in the St. Lawrence valley (Elson, 1959, 1962). Prest (1962) has criticized the evidence upon which Elson based his conclusions. Palynological investigations, to be discussed in the following chapter, indicate no discontinuity in the emergence of the lowland, and for the purposes of the present work it will be assumed that, following the retreat of the ice from the St. Narcisse - St. Faustin moraine the land emerged with no major relative oscillations of sea level. There were probably occasional relative stands or even minor oscillations of sea level when the rates of eustatic rise and isostatic uplift were approximately equal.

c. The marine limit

The recognition of the marine limit is of considerable importance in the present work, for the differential uplift of the highest marine plane establishes the maximum degree of tilting which may be invoked to account for changes in the evolving drainage pattern. Numerous factors make this recognition difficult. The first is the difficulty of locating the water marks. Isostatic recovery was rapid in the early stages of the regression of the sea, and only faint shorelines were registered on the slopes of scoured or shattered bedrock or bouldery till. These slopes are today, moreover, generally forested. Even on Mount Royal there is no generally accepted elevation of the marine limit. The second difficulty concerns the differentiation between marine shorelines and those of the earlier, higher proglacial lakes. The absence of marine molluscs is an insufficient criterion for judging a shoreline to be of lacustrine origin,

for the littoral environment near the upper limit of the sea was unfavorable for their growth. In addition, shells which may have been deposited in certain non-calcareous beach deposits may have been leached away.

Elevations of the marine limit are shown on the map, Figure 10, which is based largely upon the work of Goldthwait (1911, 1913, 1914a, 1933), and have also been tabulated (Table 3). The map differs in detail from that previously published by the writer (Brown, 1962); further elevations in the Shield area have been plotted following the work of Parry (1963) and from other observations. The isobases on the upper marine plane swing round parallel with the edge of the Shield, indicating a dome-like uplift. The differential uplift along the approximately north-south direction of maximum tilt through Montreal is of the order of 3 feet per mile, becoming somewhat greater near the edge of the Shield.

d. Marine deposits

The deposits of the Champlain Sea have been objects of study for more than a century. The most recent summary has been given by Karrow (1961). The bottom deposit of the sea was a clay, or rather a silty clay, which varies in depth from 200 feet at Ottawa to 100 feet and less in the St. Lawrence valley. The clay may be massive, but near the mouths of rivers, such as the St. Maurice, fine partings of sand give it a laminated appearance. The original surface of the clay was not horizontal, but sloped gently down toward the centre of the depression in which it was being deposited; compaction may have emphasized the original slope.

The clay is very sensitive, a characteristic which is attributed to the lack of clay minerals, and to the leaching out of the salt which was incorporated during the deposition of the clay. As a consequence it

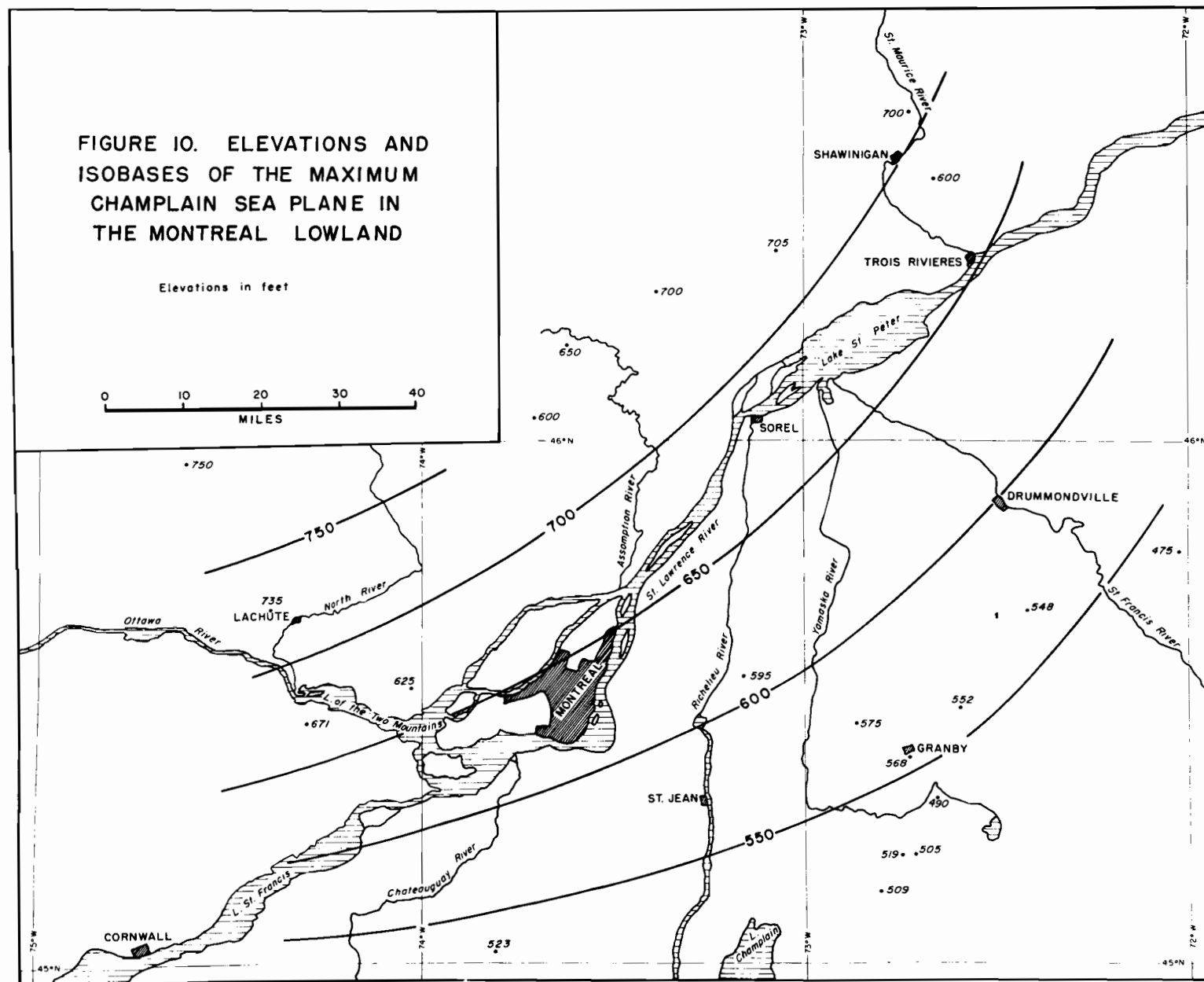


Table 3

Elevations of the Champlain Sea maximum

<u>Location</u>	<u>Elevation(feet)</u>	<u>Feature</u>	<u>Source</u>
<u>Northern margin of lowland</u>			
Kingsmere	690	Terrace	Johnston, 1916
Arundel	750	Delta	Parry, 1963
Dalesville	735	Delta	Wilson, 1924
Rawdon	600	Delta	R. Béland, 1960
Ste. Béatrix	650	Delta	Parry and Macpherson, in press
St. Gabriel	700	Delta	Elson, 1962
Prémont	705	Terrace	Macpherson
St. Maurice valley	700	Highest mapped marine clay	J. Béland, 1961
Mount Carmel	600	Delta	Osborne, 1950a
<u>Southern margin of lowland</u>			
Covey Hill	523	Beach	Goldthwait, 1911
Dunham	509	Beach	Goldthwait, 1914a
Sweetsburg	505	Delta	Goldthwait, 1914a
Cowansville	519	Beach	Chapman, 1937
West Shefford	490	Beach ridge	Goldthwait, 1911
Granby	568	—	Goldthwait, 1933
South Roxton Station	552	Beach	Goldthwait, 1914a
Danby	548	Beach ridge	Goldthwait, 1911
Danville	475	Unmodified topography	Gadd, 1964
<u>Hills within lowland</u>			
Rigaud Mountain	671	Beach ridge	Johnston, 1916
Oka Mountain	625	Beach	Romaine, 1951
Mount Royal	617	Marine shells	Stansfield, 1915
	568	Beach	Goldthwait, 1913
Mount St. Hilaire	595	Beach	Macpherson
Yamaska Mountain	575	Terrace	Goldthwait, 1911

has a tendency to fail in steep slopes, and landslips have occurred frequently along the banks of deeply incised streams.

While clay was being deposited on the bed of the Champlain Sea, brought in by rivers and washed by waves from the shoreline, beach and delta deposits were accumulating nearer sea level. Deltaic deposits are associated with the Ottawa, l'Assomption, St. Maurice, St. Francis and Nicolet rivers and with the St. Lawrence River itself. The sand may have been eroded and redeposited several times as the rivers extended their courses across the emerging sea floor. Beach deposits are found principally where wave action attacked masses of till, such as the St. Narcisse moraine, the Drummondville "moraine" and the slopes of the Monteregian hills. The thoroughness of the resorting of the material on the hill slopes testifies to their double exposure to wave attack, during both the transgression and the regression of the Champlain Sea. Wave and current action spread the coarser material over the bottom sediments, so that areas mapped as sand are frequently underlain with clay at depth.

CHAPTER III

Palynological studies

1. EARLIER PALYNOLOGICAL STUDIES IN THE ST. LAWRENCE LOWLAND AND THEIR PHYSIOGRAPHIC IMPLICATIONS

The emerging floor of the Champlain Sea provided a variety of sites for the development of bogs: depressions in bedrock or till, depressions on clay or sand plains, abandoned drainage channels and river terraces. Bogs may be used to provide evidence of the chronology of the emergence in two ways: by radiocarbon dating of organic sediment and by pollen analysis. The significance of the radiocarbon ages of the basal organic sediments of certain bogs in confirming the glacial age of the Champlain Sea has already been mentioned (Chapter II). The first bog to be dated in this way was at St. Germain, 300 feet above sea level, the basal organic sediment of which was given a radiocarbon age of $9,430 \pm 250$ years (L 441-C; Terasmae, 1959). Support for this date has been provided by two others. A bog at St. Adelphe, 420 feet above sea level, has been given an age of $8,480 \pm 80$ years (GR0 1922; Gadd, 1960a); while the radiocarbon age of the Newington bog, 325 feet above sea level, is $9,430 \pm 140$ years (GSC-8; Dyck and Fyles, 1962).

Terasmae employed pollen analysis in his investigations of bogs in the St. Lawrence lowland between Sorel and Quebec City (1960a). The relative dates provided by his pollen profiles enabled him to demonstrate that, in general, older bogs lie at higher elevations, and, more importantly, that bogs of the same age tend to lie at higher elevations at the northern margin of the lowland than at the southern margin. Pollen analysis was

thus demonstrated to be a tool which might be employed in the calculation of differential uplift.

Earlier palynological investigations in the lowland were of a botanical nature, directed to the establishment of the sequence of vegetation, and related to Pleistocene geological history only in the broadest sense. The earliest work was that of Auer (1930). Potzger (1953) and Potzger and Courtemanche (1956) followed, and the pollen zones they established were subsequently subdivided and renumbered by Terasmae (1959, 1960a). Their published pollen profiles, together with those of Auer, may be re-interpreted in the light of Terasmae's work. Table 4 lists the characteristics of the pollen assemblages of Terasmae's pollen zones.

Table 4

Pollen zones after Terasmae, 1959

Probable age. Years B.P.	Pollen zones.
	I Decline of hemlock and pine; increase of spruce.
2,000	II High beech, hemlock; decline of pine; slight increase of spruce, fir and birch.
5,000	III High white pine, QM ^x ; low spruce, fir, hemlock, beech.
7,500	IV High jack pine, fir; low birch, QM. Decline of spruce.
8,500	V Spruce maximum
9,500	VI Low spruce; high pine, birch, alder.
10,000	

^xQM = quercetum mixtum, mixed hardwood pollen

The table also indicates the probable ages of the pollen zones. The ages given for the earlier pollen zones are confirmed by radiocarbon dating; those for the higher zones have been suggested by Terasmae (1960a) in accordance with the assumed correlation of the pollen zones of the lowland with the radiocarbon-dated sequence established for the northeastern United States. Terasmae (personal communication) believes that the extent of the lowland is small enough for vegetational changes to have occurred simultaneously, rather than by the gradual advance and retreat of species. Synchronicity of the pollen zone boundaries is of the utmost importance in the application of palynological evidence to physiographic and geological questions.

In his work on the northeastern part of the St. Lawrence lowland Terasmae (1960a) determined the pollen zone of the basal organic sediment of a number of bogs, and hence their relative ages. These in turn provided rough estimates of the relative dates of emergence of the bog sites, either from the marine water or by the abandonment of drainage channels. Closer dates were obtained in many cases by sampling the underlying inorganic sediment for its pollen content. The presence of pollen and other indicator fossils in such sediment, coupled with geological evidence, indicates its deposition in fresh water, and suggests that the depression in which the bog was to develop was occupied at that time by a pond.

Terasmae studied a sufficient number of bogs to be able to show that where the site was a bedrock depression or a sandy area there was likely to be a considerable delay before the beginning of the accumulation of pollen-bearing sediment. By eliminating such exceptional cases he was able to suggest a differential uplift of about 200 feet between the oldest bogs in the Drummondville area and those 70 miles to the north. He

demonstrated in addition that the emergence of the lowland from the Champlain Sea had been effectively completed early in pollen zone III, for the bottom sediments of bogs 50 feet above sea level were deposited at that time.

For the purposes of the present study it was decided to extend Terasmae's work into the lower Ottawa valley where the pollen dating of a number of abandoned drainage channels might provide evidence of the sequence of their development. The possibility also existed of correlating the successive abandonment of these channels with changes in the outlets of the upper Great Lakes. In addition, samples were taken from bogs in the Richelieu - Lake Champlain valley in order to date the abandoned channels there and to provide a basis for the calculation of differential uplift in a north-south direction.

2. NEW POLLEN PROFILES

a. Sampling techniques

It was decided, for a number of reasons, to obtain peat samples mainly but not exclusively from bogs in abandoned drainage channels. It was considered that the channel bogs would provide more direct evidence of the relative dating of events in the evolution of the drainage pattern than would the more extensive bogs developed in depressions in morainic areas. In addition the channel bogs present fewer difficulties for sampling. Access is easy, since many of these bogs are crossed by roads; their restricted width simplifies the task of finding the deepest point of the cross-profile, and generally the depth of the organic deposits is less than that in the more extensive bogs. The practice of taking the peat samples close to a road instead of searching the length of the bog for the

deepest part is a possible source of error, although the selected sampling site was generally close to the central part of the bog. Most of the channel bogs appear to have developed from a residual pond, and the presence of organic lacustrine deposits between the peat and the underlying inorganic sediment is clear evidence that the deepest part of the bog is being sampled. Even so, the results obtained from treating the samples may be misleading. For example, the Beech Ridge bog was sampled at two sites, listed as B and C in Table 5. Organic lacustrine material (gyttja) is present at the base of both borings, but examination of the gyttja from the western site (B) (Figure 13) indicates that it accumulated in pollen zone IV, while that from the eastern site (C) appears to date only from pollen zone III (Figure 14). It would thus appear that to be sure of the earliest pollen zone represented by a bog a number of profiles should be constructed from the central area. In some instances the sampling site revealed no gyttja beneath the peat, and the apparent date of origin of such bogs may be too recent. Moreover, no samples were taken from the basal inorganic sediments, but this is not likely to have been a source of any considerable error, since in every instance it was either clay, assumed to be of marine origin, or till or bedrock, all of which would have proved to be devoid of contemporary pollen.

To obtain the samples for treatment, borings were made with a Hiller sampler with a 30 cm. chamber. Samples were generally taken at intervals of 10 cm.. Pollen slides were prepared from the samples by treatment with potassium hydroxide, followed by acetolysis. Generally at least 200 pollen grains were counted from each sample. No systematic count was made of non-arboreal pollen and spores, as the pollen zones established by Terasmae are sufficiently well-characterized by their varying proportions

of arboreal pollen. Samples were worked up at 10 cm. intervals at the base of the profiles, and at wider intervals at higher levels. In all diagrams the hardwoods are grouped together as quercetum mixtum; this group includes Acer (maple), Fagus (beech), Fraxinus (ash), Quercus (oak), Tilia (basswood) and Ulmus (elm). The locations of the bogs studied by the writer and by other workers are shown on the map, Figure 11. Certain information about all these bogs is listed in Table 5 while descriptions of the newly studied bogs are given below.

b. Description of bogs

- A. St. Canut bog (31 G/9E, Lachute map area; air photograph A16140-36; elevation ca. 250 feet; Figure 12). This bog occupies a shallow depression on the crest of the St. Jérôme-Lachute morainic ridge, 2-1/2 miles south-southeast of the village of St. Canut. The boring was made just south of the intersection of the roads which lead north from Ste. Scholastique on either side of the Belle Rivière. The lacustrine deposits beneath the peat rest on till and began to accumulate late in pollen zone V.
- B. Beech Ridge bog: western site (31 G/9W, Lachute map area; air photograph A17993-107; elevation 187 feet; Figure 13). This bog has developed in an easterly trending channel north of the settlement of Beech Ridge. The boring was made east of the road linking Beech Ridge with Highway 8. The peat, overlying grey clay, began to form in pollen zone IV.
- C. Beech Ridge bog: eastern site. (elevation ca. 182 feet; Figure 14). This sampling site lies 1.2 miles east of the site described above. The boring was made in a wooded area north of a drainage

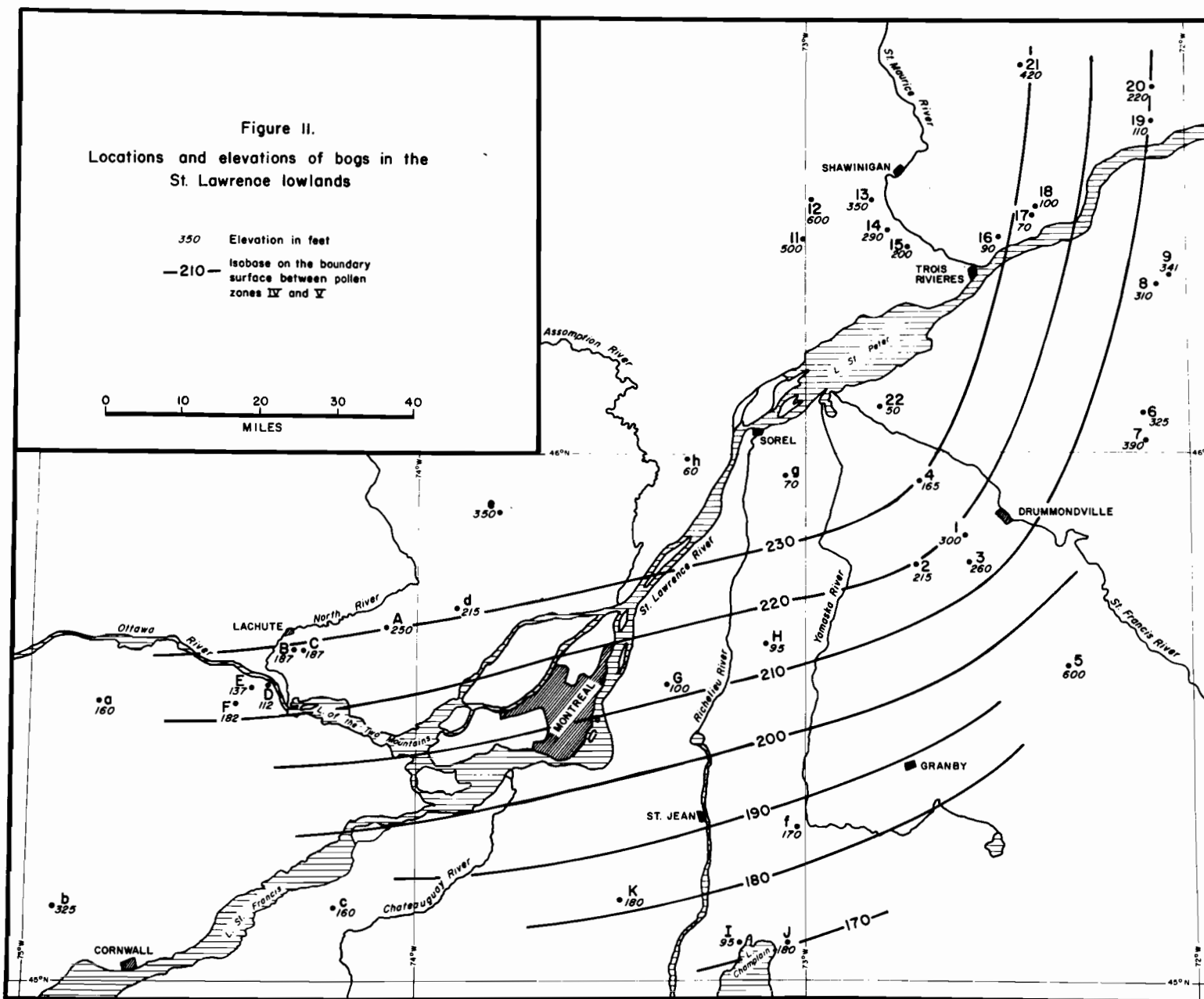


Table 5

Bogs of the St. Lawrence LowlandOttawa valley and adjacent areas

Worker	Bog (index letter or number as in Fig. 11)	Approximate elevation (feet)	Pollen zone	
			Organic sediment	Inorganic sediment
Macpherson	A. St. Canut	250	late V	—
	B. Beech Ridge west	187	IV	—
	C. Beech Ridge east	182	III	—
	D. Pointe Fortune	112	III	—
	E. "Cut-over"	137	IV	—
	F. St. Eugène (Prescott)	182	III-IV	—
Auer ^x	a. Alfred	160	III-IV	—
	b. Newington [†]	325	VI	—
	c. Large Tea Field	160	III-IV	—
Potzger ^v	d. St. Janvier	215	III	
Potzger and Courtemanche ⁺	e. St. Lin	350	IV-V	IV-V

Richelieu valley and adjacent areas

Macpherson	G. St. Bruno	100	III	—
	H. Ste. Madeleine	95	III	—
	I. Venise	95	III (IV?)	—
	J. Philipsburg	180	late V	—
Various	K. Napierville	180	III	—
Potzger ^v	f. Farnham	170	IV	

x from Auer (1930)

v from Potzger (1953)

+ from Potzger and Courtemanche (1956)

† Auer's pollen profile for this bog suggests that it began to form in pollen zone V. Terasmae and Mott (1959) propose that it dates from late in pollen zone VI; support for this view is provided by the radio-carbon age of 9430±140 years (GSC-8) (Dyck and Fyles, 1962).

Table 5 (Cont.)

St. Francis valley and adjacent areas

Potzger ^v	g. Ste. Victoire	70		III
	h. Lanoraie	60		II
Terasmae ^e	1. St. Germain	300	V	late VI
	2. St. Eugène de Grantham	215	early III	IV
	3. Birch	260	late V	V
	4. St. Bonaventure	165	IV	IV
	5. Wilson Pond ^ø	600	—	V
	6. St. Valère	325	V-VI	—
	7. St. Albert	390	—	V-VI
	22. Pierreville	50	—	III-IV

St. Maurice valley and adjacent areas

Terasmae ^e	8. Blandford	310	early V	—
	9. Louise Lake	341	late V	—
	10. Dosquet	480	VI	—
	11. St. Paulin ^ø	500	IV	IV
	12. Patterson Lake	600	late VI	—
	13. St. Boniface	350	V	V
	14. St. Etienne	290	IV	early IV
	15. Marchand ^ø	200	early II	late III
	16. Redmill	90	III	—
	17. Sherwin-Williams	70	early III	—
	18. Champlain	100	III-IV	—
	19. Grondines	110	late IV	early IV
	20. St. Alban	220	early IV	V
	21. St. Adelphe	420	V	V

^e from Terasmae (1960a). The numbers are those given to these bogs by Terasmae.

^ø Terasmae states that the development of these bogs was probably delayed.

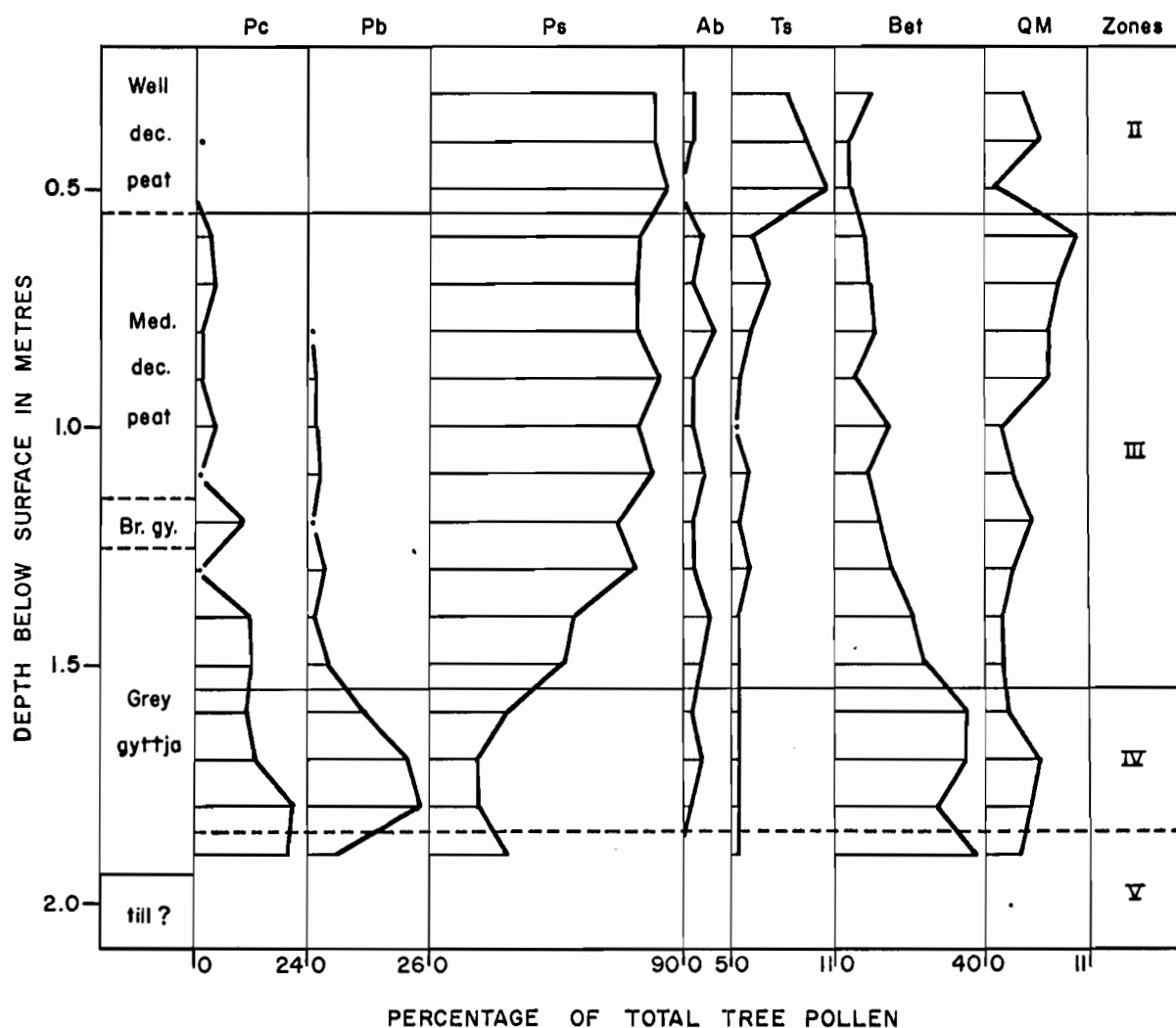


Figure 12. Pollen profile of St. Canut bog

Ab	<u>Abies</u> (fir)	Pb	<u>Pinus banksiana</u> (jack pine)
Al	<u>Alnus</u> (alder)	Pc	<u>Picea</u> (spruce)
Be	<u>Betula</u> (birch)	Ps	<u>Pinus Strobus</u> (white pine)
	QM		<u>Quercetum mixtum</u> (mixed hardwood)

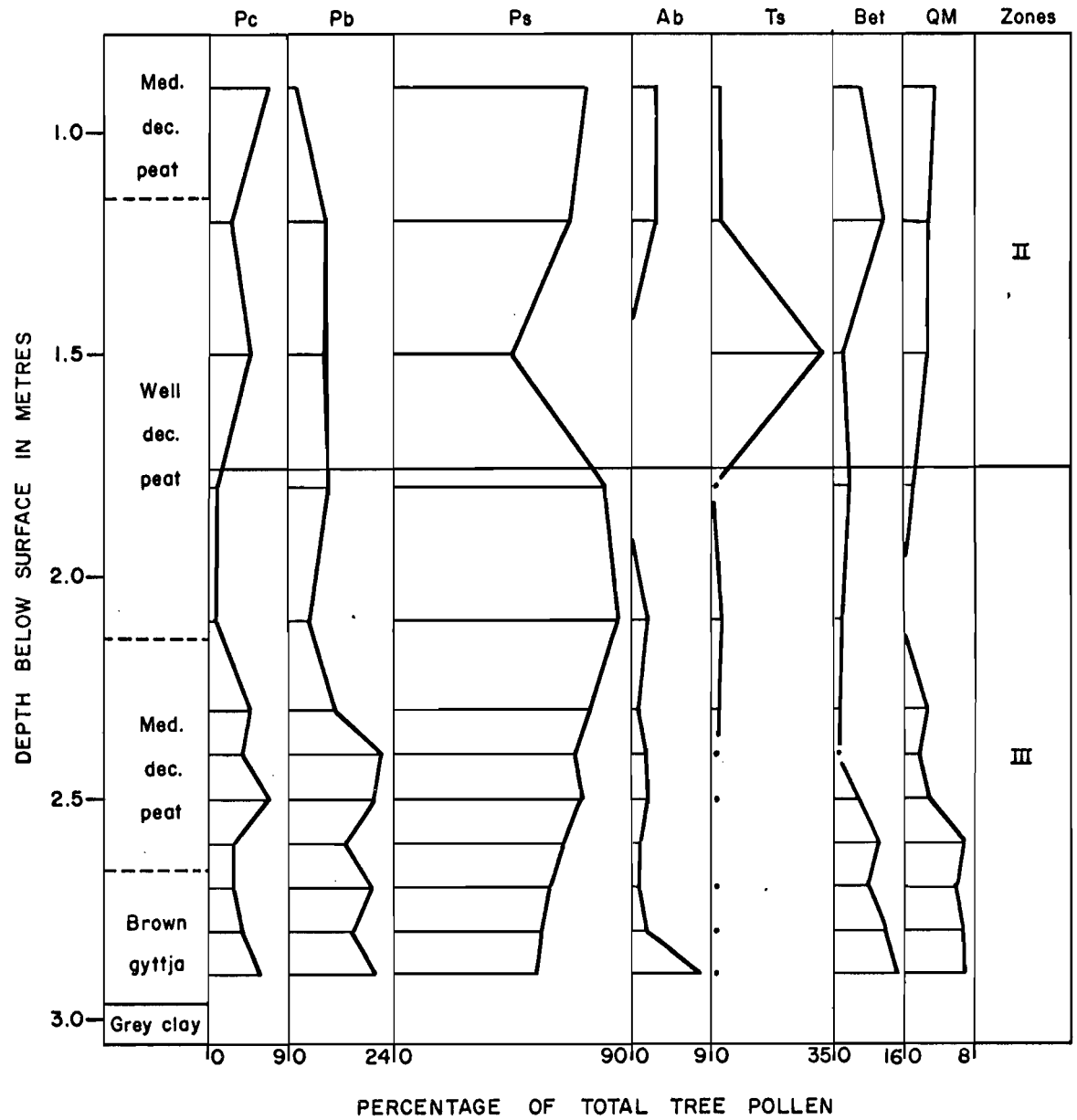


Figure 13. Pollen profile of Beech Ridge bog, western site

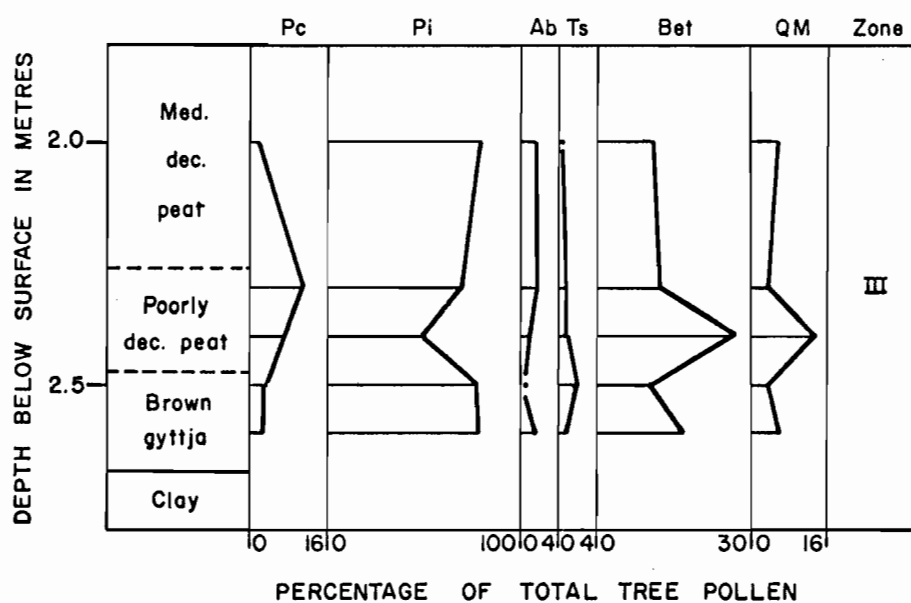


Figure 14. Pollen profile of Beech Ridge bog, eastern site

ditch. The basal organic deposits are lacustrine, and appear to have accumulated in pollen zone III.

- D. Pointe Fortune bog (31 G/9W, Lachute map area; air photograph A16140-137; elevation ca. 112 feet; Figure 15). The boring was made on the west side of the road, 500 yards south of Pointe Fortune village. The 1.8 m. of gyttja underlying the peat, and resting on till or bedrock, may have been deposited at the margin of an earlier and higher Lake of the Two Mountains. This lacustrine deposit began to accumulate in pollen zone III.
- E. "Cut-over" bog (31 G/9W, Lachute map area; air photograph A16140-137; elevation ca. 137 feet; Figure 16). This bog lies at the western end of an easterly trending channel cut in till, 1.6 miles west of Pointe Fortune village. The site has been submerged as the result of the construction of a dam at Carillon. The basal lacustrine deposit began to accumulate in pollen zone IV.
- F. St. Eugène (Prescott) bog (31 G/9W, Lachute map area; air photograph A16288-4; elevation ca. 182 feet; Figure 18). The bog lies in a north-south trending channel 1.6 miles north-northwest of the village of St. Eugène, in Prescott county, Ontario. The boring was made north of the road which crosses the bog. A layer of clean sand overlies the lowest 5 cm. of peat, which rests on clay, and may indicate a break in the development of the bog. The lowest peat began to develop late in pollen zone IV or early in pollen zone III.
- G. St. Bruno bog (31 H/11W, Beloeil map area; air photograph A17251-26; elevation ca. 100 feet; Figure 17). This rather extensive bog lies at the western intake of the channel north of St. Bruno

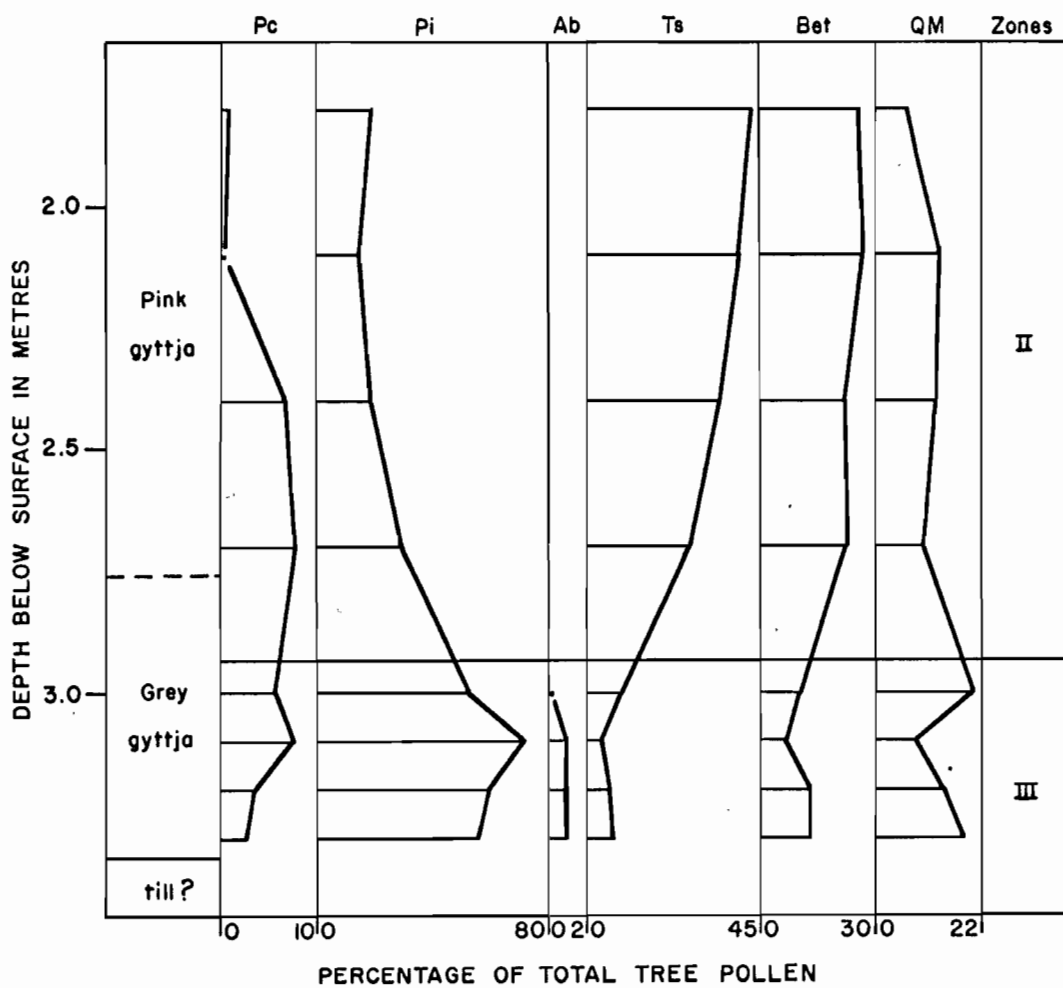


Figure 15. Pollen profile of Pointe Fortune bog

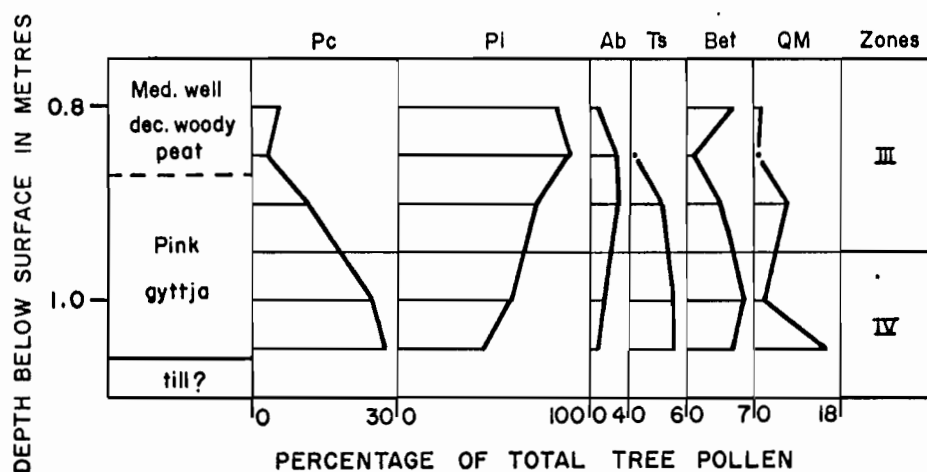


Figure 16. Pollen profile of "Cut-over" bog

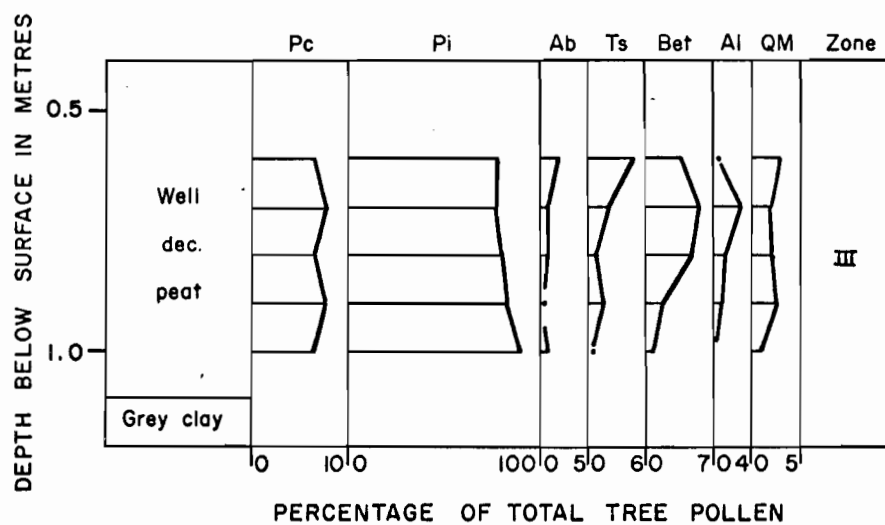


Figure 17. Pollen profile of St. Bruno bog

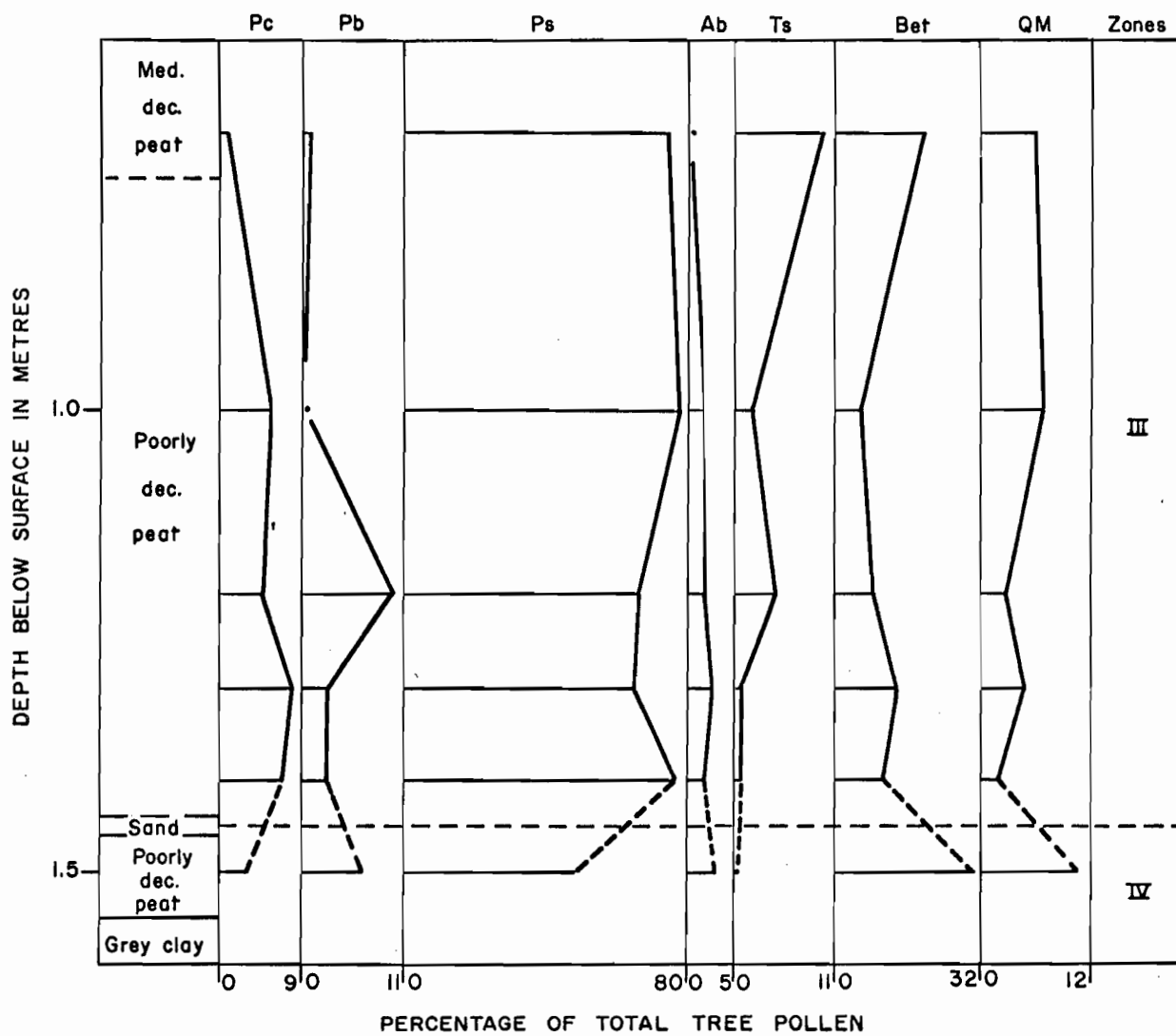


Figure 18. Pollen profile of St. Eugène (Prescott) bog

Mountain. The sampling site is east of a drainage ditch in the northwestern part of the bog, 3.2 miles north-northwest of St. Bruno village. It is not certain that this is the deepest part of the bog. Peat overlies clay, and began to form in pollen zone III.

- H. Ste. Madeleine bog (31 H/11E, Beloeil map area; air photograph A12464-433; elevation ca. 95 feet; Figure 19). The Ste. Madeleine bog occupies an abandoned clay-floored channel at the divide between the Rivière des Hurons and Rivière Salvail drainage. The boring was made south of the road which crosses the bog 2.5 miles north of the village of Ste. Madeleine. The basal peat began to develop in pollen zone III.
- I. Venise bog (31 H/3E, Lacolle map area; air photograph A16143-4; elevation ca. 95 feet; Figure 20). This bog has developed in a clay-floored channel leading northward from Missisquoi Bay to the valley of South River. The boring was made north of Highway 52, 2.2 miles southwest of Venise and 3.7 miles east of Clarenceville. An interesting feature of this profile is the sample at 1.9 m., where fragments of charcoal, indicating a forest fire, are accompanied by a sharp and unsustained rise in jack pine pollen and corresponding decreases in white pine and hardwood pollen. The interpretation of the pollen profile is disputed: Dr. Terasmae (personal communication) suggests that the basal pollen assemblage may have been deposited as early as pollen zone IV, while the present writer believes that it is attributable to pollen zone III.
- J. Philipsburg bog (31 H/3E, Lacolle map area; elevation ca. 180 feet; Figure 21). This bog occupies a narrow clay-floored depression between bedrock ridges. It seems unlikely that the channel was

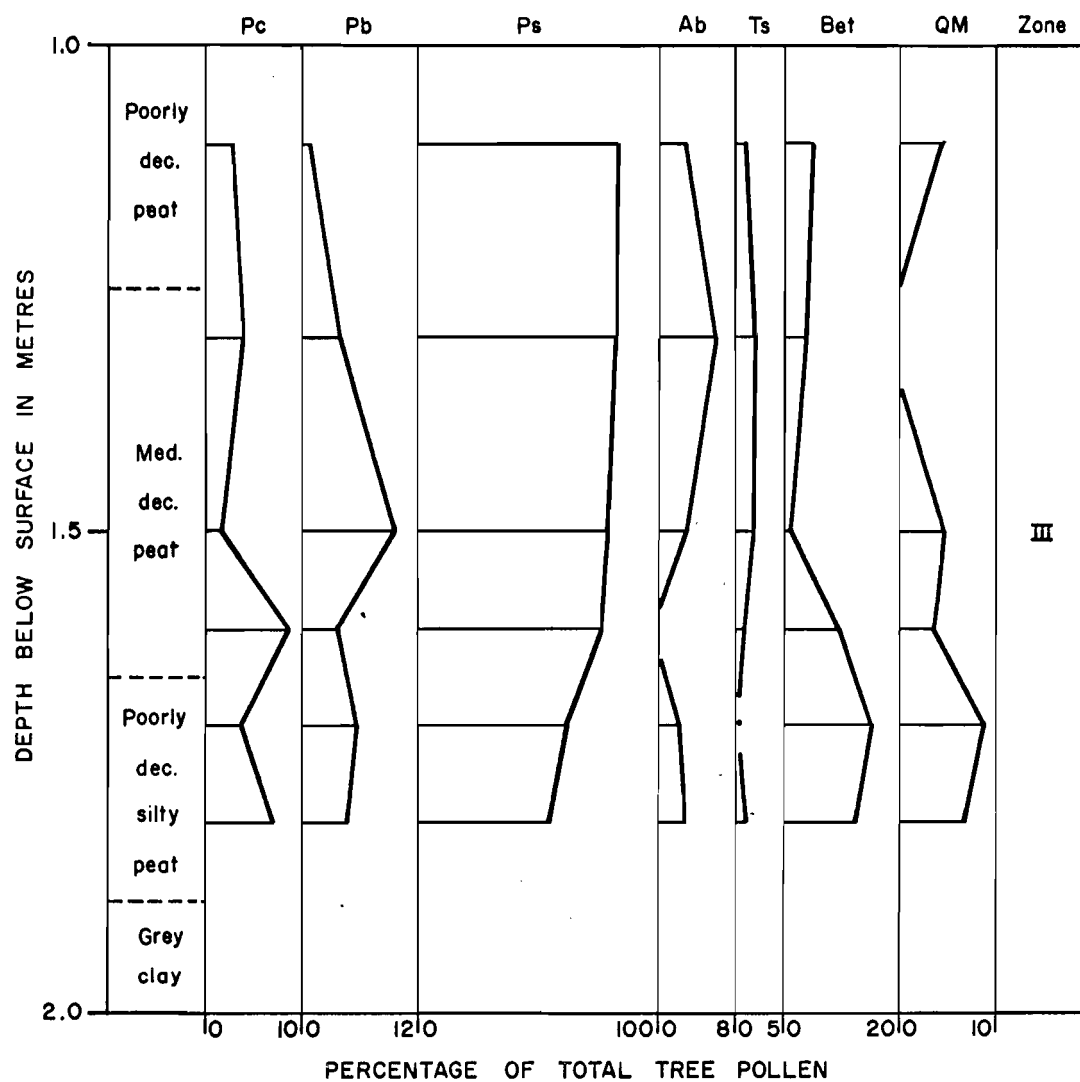


Figure 19. Pollen profile of Ste. Madeleine bog

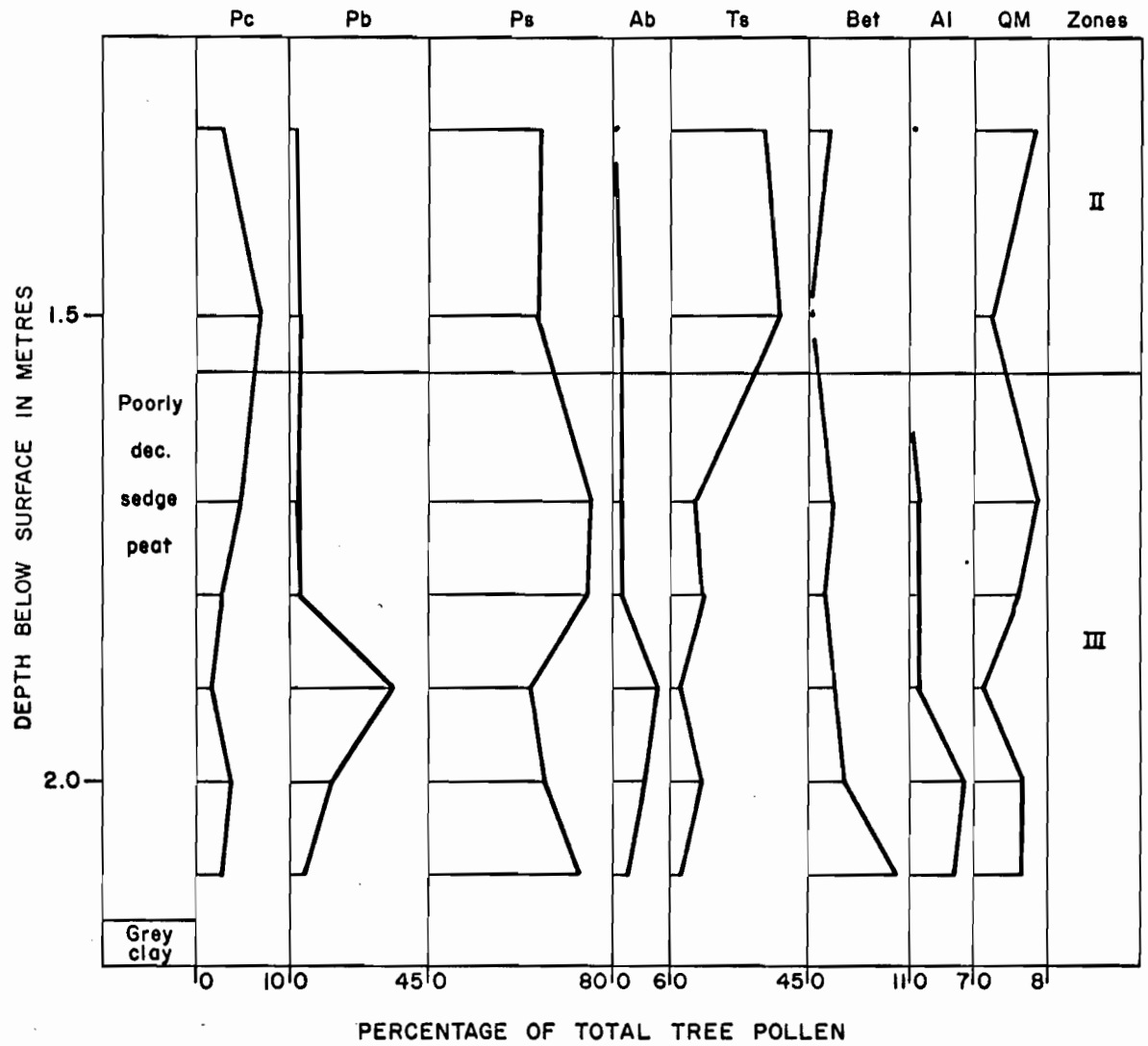
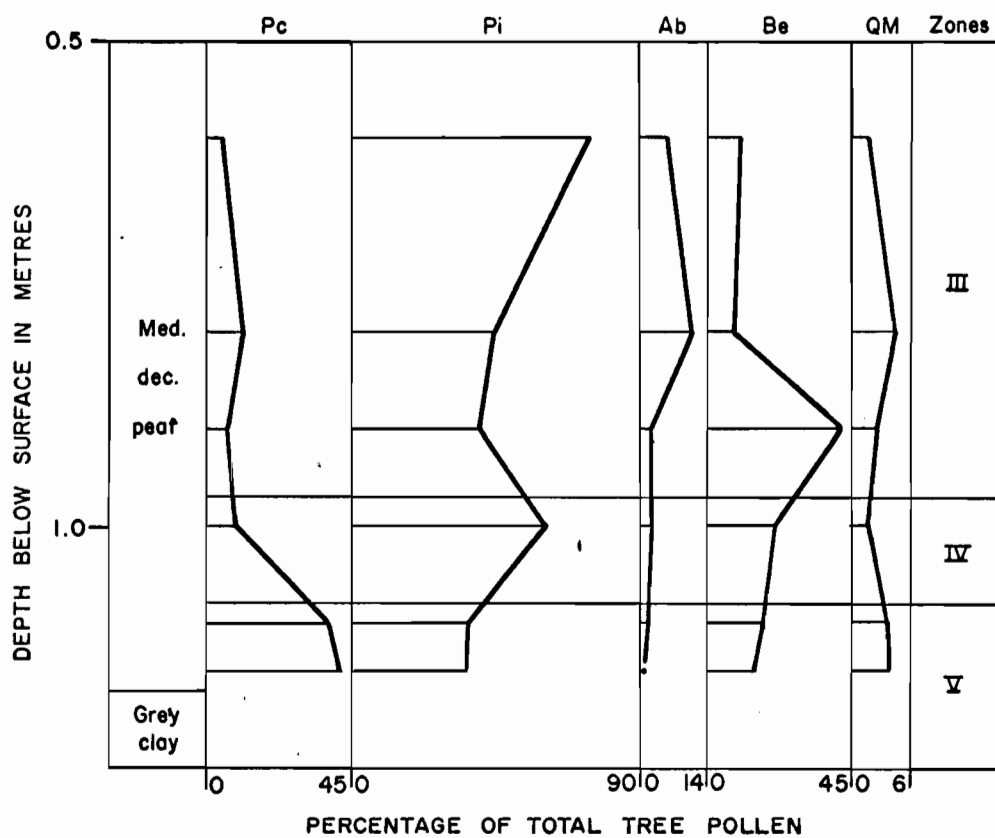


Figure 20. Pollen profile of Venise bog



excavated by flowing water. The boring was made east of a quarry near the northern end of the bog, 2.5 miles north-northeast of Philipsburg. The basal peat began to develop late in pollen zone V.

- K. Napierville bog (31 H/3W, Lacolle map area; air photograph A16279-73; elevation ca. 180 feet; Figure 22). This bog is described by Risi et al. (1955). The pollen profile of the lowest organic sediments has been worked out by the writer from samples kindly provided by Dr. J. Terasmae of the Geological Survey of Canada. The sampling site was adjacent to the residual pond, Lily Lake. Organic lacustrine deposits began to accumulate in pollen zone III.

c. Discussion of results

1. Ottawa valley. The pollen dates obtained by the writer in the lower Ottawa valley are mutually consistent and may be summarized diagrammatically (Figure 23). The crest of the St. Jérôme-Lachute morainic ridge had emerged from the Champlain Sea before the St. Canut bog began its development in pollen zone V. Subsequently the channels at Beech Ridge and St. Eugène, the floors of which lie respectively at elevations of 177 and 178 feet were eroded and then abandoned; bogs began to form in pollen zone IV. During pollen zone IV there was time also for the erosion and abandonment of the "Cut-over" bog channel, and the beginning of the accumulation of organic sediments on its floor at an elevation of 134 feet. The organic sediments of the Pointe Fortune bog, resting on till or bedrock at 102 feet, began to accumulate in pollen zone III. This bog lies on a terrace at the foot of a bluff cut by an earlier stage of the Lake of the Two Mountains, and may have begun to form in the shallow water at the margin

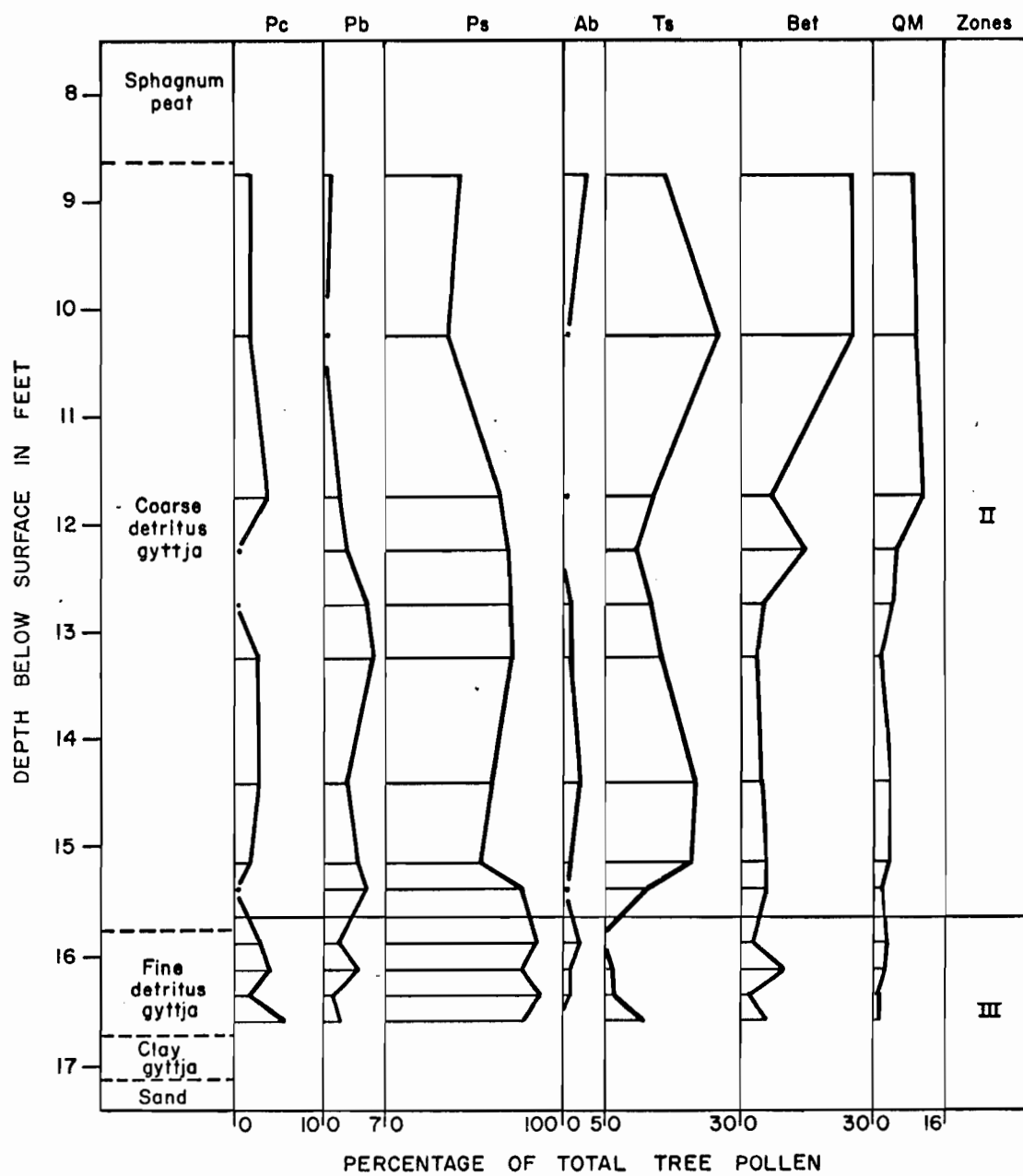


Figure 22. Pollen profile of Napierville bog

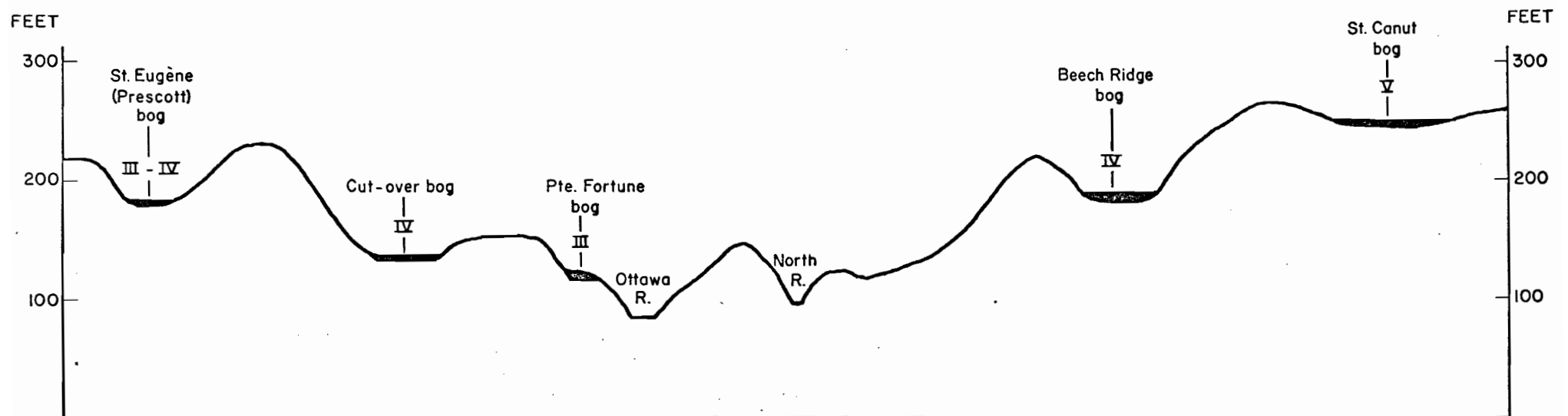


Fig.23 Diagrammatic profile illustrating the altitudinal and age relationships of bogs studied by the author in the lower Ottawa valley.

of this earlier water body.

In connection with these new profiles for the lower Ottawa valley, reference may be made to certain bogs in adjacent areas, studied by Auer (1930), Potzger (1953), Potzger and Courtemanche (1956), Terasmae and Mott (1959) and Dyck and Fyles (1962). These bogs are listed in Table 5. The Alfred bog (a) was investigated both by Auer and by Potzger and Courtemanche, but comparison of the two published profiles suggests that Auer obtained pollen from an earlier part of the bog, and his result is given in preference to that of the recent workers. The Newington bog (b), has been investigated several times. The most recent results (Terasmae and Mott, 1959; Dyck and Fyles, 1962) agree in indicating that organic sediments began to accumulate during pollen zone VI.

In general, the results obtained from the writer's profiles are in agreement with the earlier work. The St. Canut bog (A), dating from late in pollen zone V, lies at an elevation lower than those of the St. Lin (e) and Newington bogs, which date from the same or the preceding pollen zone. The Beech Ridge (B and C), St. Eugene (Prescott) (F) and "Cut-over" (E) bogs began to develop in pollen zone IV, as did the Alfred (a) and Large Tea Field (c) bogs at comparable elevations. The lowest bog examined in the area, the Pointe Fortune bog (D), dates from pollen zone III. This indicates that the St. Janvier bog (d) on the Terrebonne sand plain, which lies at an elevation some 100 feet greater than the Pointe Fortune bog, experienced delayed development, for an examination of Potzger's profile for the bog suggests an origin in pollen zone III.

ii. Richelieu valley. The lowest bogs investigated by the author in the Richelieu valley yield fairly consistent results. The St. Bruno (G) and Ste. Madeleine (H) bogs, the floors of which are both close to 90 feet

elevation, lie in abandoned channels west and east of the Richelieu River respectively. The basal peat in both cases contains a pollen assemblage of pollen zone III. The Venise bog (I), at the north end of Lake Champlain, lies at a similar elevation in a channel which was formerly an arm of the lake. Its lowest peat dates from pollen zone III or IV.

The Philipsburg bog (J) lies east of the lake, at an elevation of about 175 feet. It is the lowest bog in the lowland known to have begun its development as early as pollen zone V. If its bottom sediments were of lacustrine origin contamination by redeposited pollen might have been suspected. However, since the basal deposit is peat the result must be accepted as valid. The Farnham bog (F), to the north, investigated by Potzger (1953), lies in a depression the floor of which is at about 155 feet, and here the basal pollen bearing sediment (sand?) began to accumulate in pollen zone IV. It is possible that the accumulation of pollen-bearing sediment in the depression now occupied by the Napierville bog (K), west of the Richelieu River, was delayed, for the organic sediments which were investigated yielded a date no earlier than pollen zone III. However, the inorganic sediments might have given results comparable with those of the Farnham bog, since the floor of the depression is at almost the same elevation.

3. PALYNOLOGICAL EVIDENCE APPLIED TO THE PROBLEM OF DIFFERENTIAL UPLIFT

The foregoing discussion suggests that the results obtained by the writer are sufficiently accurate to be incorporated with the previously existing body of information on the bogs of the St. Lawrence lowland. Accordingly, the whole body of information was analyzed for the evidence it might yield of differential uplift. In order to minimize the possible

effects of differential uplift the bogs were grouped into four areas on the basis of their proximity to each other. For each area the elevations and ages of all the bogs known to have been investigated were plotted in a way which enables the altitudinal limits of the pollen zones to be determined (Figure 24). The age of the bog is the pollen zone of the lowest pollen-bearing sediment to be examined. In most cases this sediment is organic, although in a few cases it has been possible to plot the pollen zone of the underlying inorganic sediment. Where this differs from the pollen zone of the basal organic sediment, the date of the latter is given in parentheses. Within each area it is the elevation of the lowest bog dating from a particular pollen zone which determines the altitudinal limit between that zone and the next younger pollen zone. Thus, in the Ottawa valley area the lower limit of pollen zone V is placed just below the elevation of bog A, the St. Canut bog, as the bog began to develop late in the pollen zone, and no other bog dating from the same pollen zone occurs at a lower elevation. By the time that land at lower elevations had emerged from the sea the vegetation had changed, and lower bogs have in their basal sediments the pollen assemblage of pollen zone IV. The highest elevation of a bog dating from a given pollen zone is of little significance, for bog development is known to be retarded in certain environments. For example, in the St. Francis valley area, the Wilson Pond bog (5), at an elevation of 600 feet, began to develop later than bogs at elevations of between 300 and 400 feet (Terasmae, 1960a). Figure 24 enables bogs with delayed development to be easily identified, since they occur interspersed in elevation with bogs of earlier pollen zones.

The first deduction which may be made from a study of Figure 24 is the apparently almost horizontal boundary between pollen zones III and IV

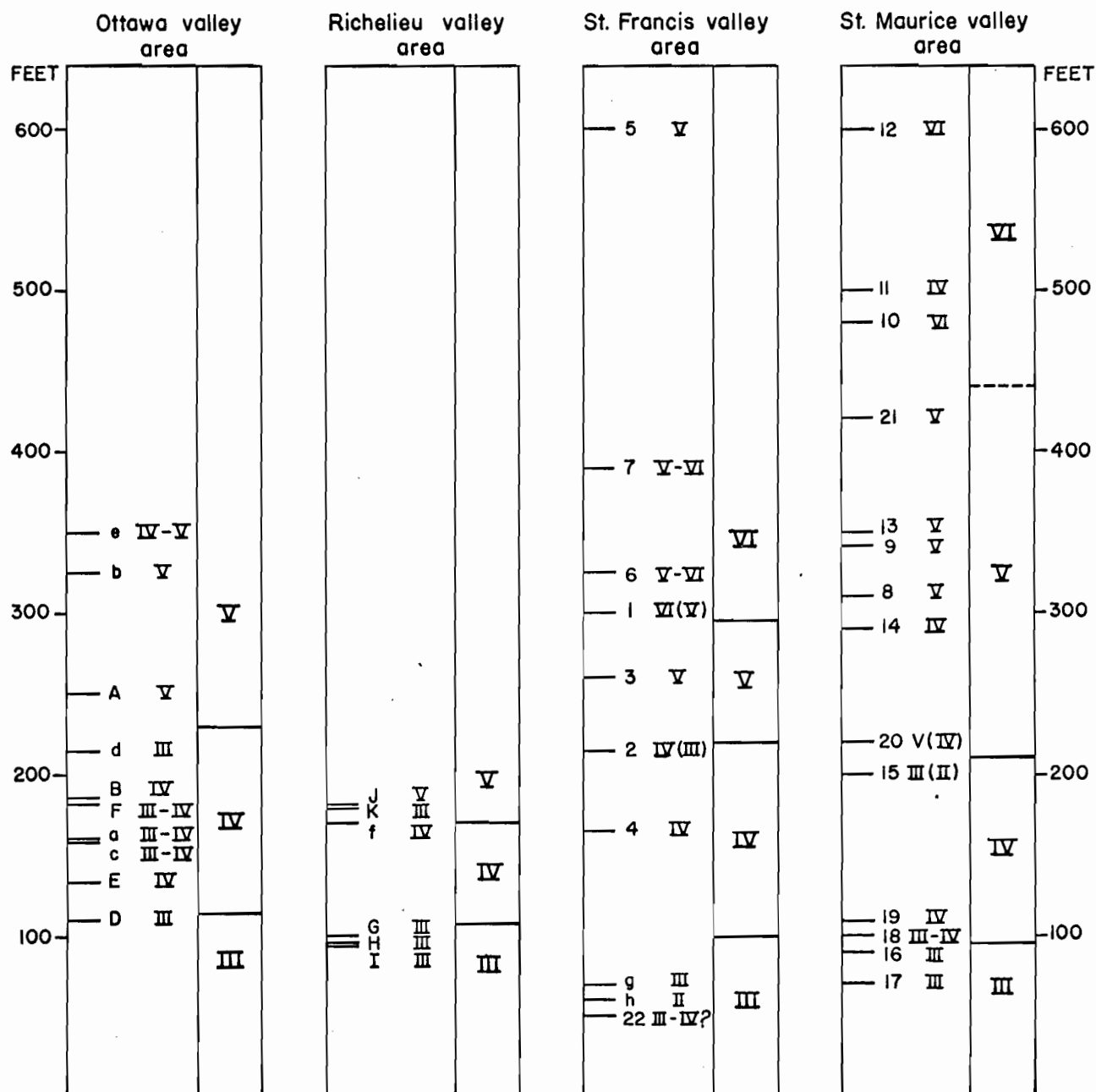


Fig.24 Altitudinal and age relationships of bogs in four areas
of the St. Lawrence Lowland

Reference letters and numbers as in Table 5 and Figure 11

throughout the lowland. In the widely separated Ottawa and St. Maurice valleys the boundary may be drawn with some precision at a little above and a little below 100 feet respectively. A boundary drawn at a similar elevation in the area of the St. Francis valley is in accord with the palynological evidence, with the apparent exception of the Pierreville section (22). Here the pollen assemblage of the lowest part of the section was tentatively ascribed by Terasmae to pollen zone IV. The elevation of the section is 50 feet, and the material of which it is composed is of fluvial origin. Hence contamination by redeposited pollen is possible, and even if the material does date from pollen zone IV it was deposited beneath the water level of the time and does not indicate emergence. The section is therefore disregarded in drawing the IV-III boundary.

In the Richelieu valley the age of the Venise bog (I) is of critical importance in establishing the elevation of the IV-III boundary surface at the southern limit of the lowland, an importance which is obscured by the method of construction of Figure 24. Ideally, the lower and upper sections of the Richelieu valley should have been considered separately, as differential uplift in a north-south direction would have affected the present elevations of the bogs. However, there was evidence from an insufficient number of bogs to make this possible. Since both the St. Bruno (G) and the Ste. Madeleine (H) bogs, adjacent to the lower Richelieu valley, date from pollen zone III, it is probable that the boundary surface passes above them, at an elevation of about 100 feet. In the upper valley, however, at the north end of Lake Champlain, the evidence of the Venise bog is less definite. The elevation of this bog is about 95 feet above sea level; if its basal peat dates from pollen zone III the boundary may well pass above it. If, on the other hand, peat began to accumulate

in pollen zone IV, as Terasmae suggests, the boundary must lie at a lower elevation than the bog. The basal pollen assemblage cannot be checked by comparison with pollen profiles from other bogs, since other depressions at the same elevation in the vicinity are occupied by swamps rather than bogs (Cann, Lajoie and Stobbe, 1947). The possibility that the boundary surface between pollen zones III and IV has been deformed in a north-south direction cannot, therefore, be entirely eliminated. It may be concluded, however, that in general only the land at elevations below 100 feet remained to emerge at the beginning of pollen zone III (ca. 7,500 B.P.). It is significant that there is a shoreline at an elevation of about 100 feet in many parts of the lowland.

Figure 24 shows that the boundary between bogs dating from pollen zones IV and V is quite evidently no longer horizontal, indicating that differential uplift occurred during the millenium 8,500 - 7,500 B.P., the duration of pollen zone IV. The delimitation of the altitudinal range of this pollen zone hinges upon a few critical bogs, whose pollen profiles merit very careful consideration. The reasoning which leads to the determination of the elevation of the boundary in each area will therefore be discussed in some detail. In the area of the lower Ottawa valley the St. Canut bog (A), at an elevation of 250 feet, is the lowest dating from pollen zone V, and began to develop late in that zone. The highest zone IV bog at lower elevations is the Beech Ridge bog (B), at 187 feet. Since it appears that the development of this bog began in the middle of zone IV, the elevation of the V-IV boundary should be placed closer to that of the St. Canut bog. Hence the boundary is placed tentatively at 230 feet.

In the Richelieu valley the critical bogs are the Philipsburg (J) and Farnham (f) bogs. The former, at 180 feet, dates from pollen zone V,

while the latter, at 170 feet, dates from pollen zone IV. The boundary is placed at an elevation of 170 feet, since the floor of the Farnham bog is at 155 feet. The inorganic sediment beneath the St. Alban bog (20), at an elevation of 220 feet, began to accumulate very late in pollen zone V; hence the boundary in the St. Maurice area is placed at 210 feet. Thus a northward tilt of the boundary surface is indicated, from 170 feet at Philipsburg to 210 feet at St. Alban.

Examination of the evidence from the St. Francis valley area does not confirm that this tilt was uniform. Birch bog (3), 260 feet above sea level, is the lowest in that area to date from pollen zone V; the St. Eugène de Grantham bog (2), 215 feet above sea level, is the next in elevation and dates from pollen zone IV. There is no evidence to suggest that the development of the St. Eugène bog was delayed. It occurs in a morainic depression, a site similar to others in the same general area, in which the accumulation of pollen-bearing sediment appears to have begun as soon as the condition of the water in the depression changed from salt to fresh. In addition, if the pollen profile of the bog is compared with that of the St. Bonaventure bog (4), 165 feet above sea level, it appears that the St. Eugène bog began to develop earlier in pollen zone IV. Therefore the V-IV boundary can be placed no lower than the elevation of the St. Eugène bog, and is, in fact, placed at 220 feet.

The V-IV boundary lies, then, at 230 feet in the lower Ottawa valley, at 170 feet in the Richelieu valley, at 220 feet in the St. Francis valley area, and at 210 feet in the St. Maurice valley area. The close approximation of the elevation in three of these areas casts doubt upon the elevation of the boundary obtained for the Richelieu valley. Reasons for accepting the evidence of the Philipsburg pollen profile as valid have

already been given, however. It is evident, then, that the originally horizontal boundary surface has been irregularly uplifted, and it would be of value in the definition of its present attitude to obtain the elevation of more points upon it. The only possible area where this might be done is the Three Rivers delta, where the St. Boniface bog (13), the St. Etienne bog (14) and the Marchand bog (15) lie in successively abandoned distributary channels of the St. Maurice river at elevations of 350, 290 and 200 feet. The accumulation of pollen-bearing sediments in the channels dates respectively from pollen zones V, early IV and late III. Terasmae suggests that the development of the Marchand bog was delayed owing to its location in an area with much windblown sand. The St. Etienne bog occupies a similar site, and, like the Marchand bog, has sand interbedded with the lower peat. There is therefore the possibility that its development was also delayed. If it is assumed that the bog developed without delay it becomes necessary to place the boundary at an elevation of about 300 feet, calling for much local deformation of the boundary plane. It is simpler to avoid this interpretation and to attempt to draw isobases on the warped surface using only well-founded evidence. This has been done in Figure 11.

The surface appears to have been domed, with the isobases swinging from an easterly trend in the lower Ottawa valley to a direction east of north below Lake St. Peter. The isobases are similar in general trend to those of the plane of the Champlain Sea maximum, although, as was to be expected, the slope of this later surface is smaller. In the lower Ottawa valley, for instance, the northward component of tilt on the upper marine plane is of the order of 3 feet per mile, while on the V-IV boundary plane it is 1.25 feet per mile (Figure 25). It is significant that in the same area the boundary plane between pollen zones V and IV is very close in

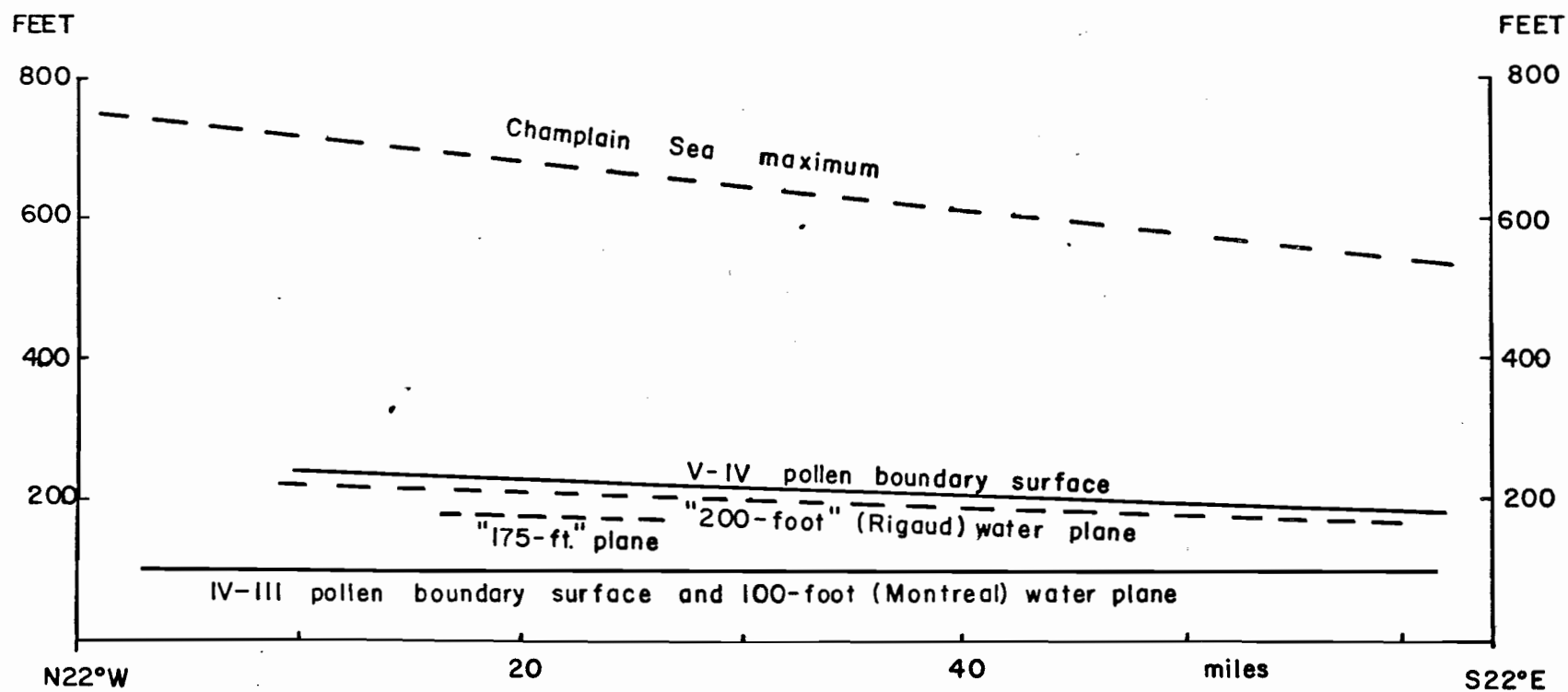


Figure 25. Water planes and pollen boundary surfaces in the lower Ottawa valley

elevation to a shoreline at 200 feet, and that its tilt is of the same order as the slope of 1.5 feet per mile which is calculated for the shoreline on purely physiographic evidence (Chapter IV). Hence the boundary plane may prove to be a valuable datum for the correlation of fragmentary shoreline features elsewhere in the lowland.

Palynological studies will not be able to provide useful evidence for differential uplift at higher elevations until more bogs near the upper limit of the Champlain Sea have been studied. From the evidence at present available, the elevation of the boundary surface between pollen zones V and VI may be determined only in the St. Francis and St. Maurice valley areas. The St. Germain bog (1), 300 feet above sea level, dates from late in pollen zone VI, while the neighbouring Birch bog (3), at an elevation of 260 feet, began to develop in pollen zone V. Thus the boundary lies at an elevation of about 280 feet in this area. To the north the boundary may lie at an elevation of 320 feet, between the St. Valère bog (6), 325 feet above sea level, which began to develop late in pollen zone VI, and the Blandford bog (8), at an elevation of 310 feet, dating from pollen zone V. North of the St. Lawrence valley the only bog known to date from pollen zone VI is that at Patterson Lake (12) at an elevation of 600 feet, and the highest bog dating from pollen zone V is the St. Adelphe bog (21), 420 feet above sea level. These bogs are widely separated, and it is possible only to suggest that the boundary surface lies in this area at an elevation greater than 420 feet. Although the evidence is insufficient to permit the construction of isobases on the boundary surface, it may be suggested that the VI-V surface in this northeastern part of the lowland is tilted up in a direction west of north at a rate of the order of 3 feet per mile. This conforms with tilts of about 4 feet per mile and 1.25 feet

per mile for the earlier Champlain Sea limit and the later pollen zone V-IV boundary surface, respectively, in the same part of the lowland.

In the western part of the lowland only the Newington (b) and St. Lin (e) bogs provide indications of the elevation of the VI-V boundary surface. Since the Newington bog, 325 feet above sea level, began to develop in pollen zone VI, the surface may lie in its vicinity at an elevation of about 300 feet. The St. Lin bog, to the northeast, dates from pollen zone V. The boundary surface here may, then, lie above the bog's elevation of 350 feet. A tilt to the north is indicated, but its rate cannot be estimated. However, it appears that the isobases on the VI-V boundary surface here may well be parallel with those of the marine maximum and also with those on the V-IV boundary surface.

4. OTHER IMPLICATIONS OF THE PALYNOLOGICAL EVIDENCE

a. Rate of uplift

Palynological evidence may be used in conjunction with radiocarbon dates to establish an uplift curve for the Montreal area (Figure 26). The tentative nature of the curve must be stressed. Of the numerous interpretations of Wisconsin sea level, the curve presented by Fairbridge (1960) has been used as a basis. The dates of the pollen zone boundaries are those suggested by Terasmae (1960a). The elevations of the pollen zone boundaries are derived from the available evidence, and may need modification as further evidence accumulates.

Shells at an elevation of 545 feet on Mount Royal were deposited approximately 11,300 years ago. The depth of water in which they were deposited is not known, and it will be assumed that they accumulated at the shoreline. The V-IV pollen boundary plane lies at an elevation of 210

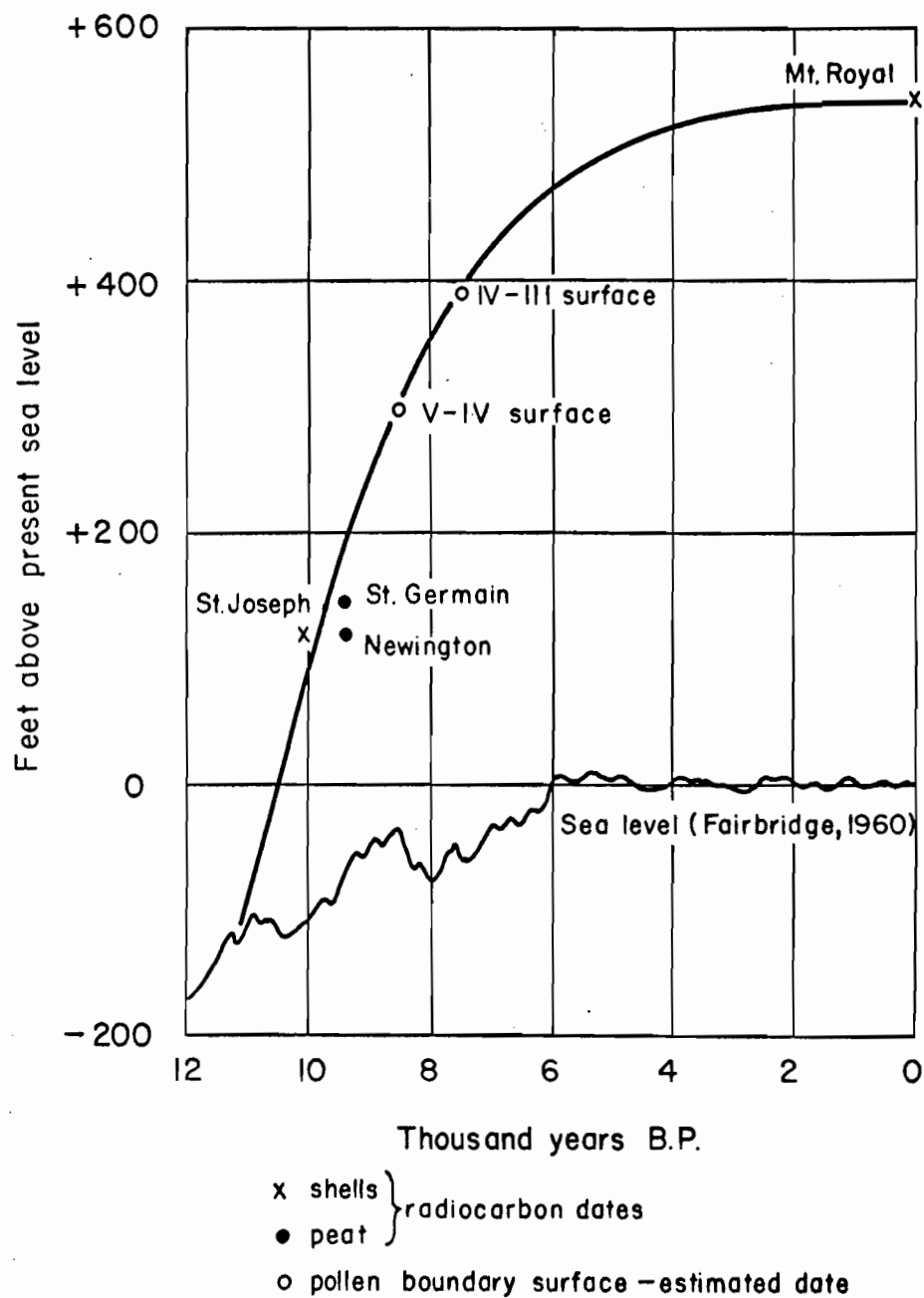


Figure 26. Uplift curve for the Montreal area.

feet (Figure 11), 335 feet below the dated shells, and dates approximately from 8,500 B.P.. The IV-III pollen boundary plane, similarly, lies 100 feet above present sea level, 445 feet below the shell site, and emerged about 7,500 years ago, when sea level was 45 feet lower than the present. These points define a curve, to which other points have been added. The radiocarbon dated bogs at St. Germain (300 feet) and Newington (325 feet) lie close to the pollen boundary isobase through Montreal, and have been given the same age of about 9,430 years. Marine shells at St. Joseph du Lac, on the slopes of Oka Mountain, at an elevation of 310 feet, date from about 10,050 B.P.. These points also lie close to the curve. Unfortunately, it has not been possible to add points between 7,500 B.P. and the present.

The curve indicates that following the emergence of the upper slopes of Mount Royal uplift was at the rate of about 20 feet per century, slowing down to half that rate between 8,500 and 7,500 B.P.. The average rate of uplift during the last 7,500 years has been two feet per century. During the early stages of the emergence the rate of uplift was always greater than the eustatic rise of sea level, and well-defined and continuous shorelines are not to be expected above 200 feet. Before the emergence of the IV-III pollen boundary plane at Montreal, however, sea level rose rapidly at a rate approximately equal to the rate of uplift, and this may account for the strength and persistence of the 100-foot shoreline, with which the pollen boundary plane corresponds.

At still lower elevations the possibility of relative stands of sea level, and even of minor oscillations, increases. The rapid rise in sea level at about 6,000 B.P. must almost certainly have caused the inundation of land which had previously emerged. In the absence of precise dates for the events at low elevations it is possible only to suggest that

a well-marked shoreline at 50 feet around Lake St. Peter may be attributable to the culmination of this oscillation.

b. Correlation with events in the upper Ottawa valley

Great volumes of water were discharged into the Ottawa arm of the Champlain Sea through the Fossmill and North Bay outlets when ice retreat released the waters of the upper Great Lakes. Deltas at elevations of between 500 and 550 feet occur at Petawawa and Mattawa where the channels opened into the sea. Terasmae and Hughes (1960) have estimated that the North Bay outlet was opened between 10,970 and 9,275 years ago, and Farrand (1962) suggests that the resulting low Stanley water level in the Huron basin occurred at about 9,600 B.P. .

The outflow from the upper Great Lakes continued to discharge through the Ottawa valley after the Stanley stage, but the volume was much reduced as the North Bay outlet rose and water was ponded back in the lake basins. At about 4,200 B.P. the water had attained the Nipissing level and the outflow was shared between the Ottawa, Chicago and St. Clair outlets (Farrand, 1962). The St. Clair outlet became dominant at about 3,200 B.P., according to Farrand, and at this time the Ottawa valley ceased to carry any of the discharge of the Great Lakes, while all the lake basins became tributary to the St. Lawrence River.

Despite the great reduction in the volume of Great Lakes water passing down the Ottawa valley after the Stanley stage, broad channels were eroded in the lower valley when sea level stood at about 200-175 feet (Chapter IV). The floors of some of the channels bear evidence of strong scouring, and indicate, therefore, that the flow of the Ottawa River was augmented from a source other than the upper lakes at the time of their

formation. The abandonment of the channels occurred during pollen zone IV, for the basal organic sediments of the Beech Ridge (B) and St. Eugène (Prescott) (F) bogs contain a pollen assemblage of that zone. Pollen zone IV lasted approximately from 8,500 B.P. to 7,500 B.P. and it is likely that the channels were abandoned before 8,000 B.P.. There is no evidence in the lower Ottawa valley of intensive channel cutting above the V-IV pollen boundary plane at 230 feet above sea level, and it may be suggested that the period of strong erosion began at about 8,500 B.P..

To discover the source of the temporarily increased discharge of the Ottawa River it is necessary to consider events in the area to the north of North Bay. As the ice retreated northward a sequence of lakes was formed at its margin. Lake Barlow, in the basin of Lake Timiskaming, was the first. Its waters extended over the present height of land with the continuing retreat of the ice front and eventually merged with those of Lake Ojibway. This lake had developed north of the divide and originally discharged into Lake Huron, but the combined waters of Lake Barlow-Ojibway discharged into the Ottawa valley (Antevs, 1925). The lake continued to expand eastward, north of the divide, so that it received the melt-water from an ever-increasing segment of the ice front. The increased discharge of the Ottawa River began, therefore, with the initiation of Lake Barlow-Ojibway, and ended when the lake ceased to discharge over the height of land. It is possible to ascribe tentative dates to these events (Table 6).

Antevs and Hughes have measured a total of 2,075 annual varves in the sediments of Lake Barlow-Ojibway (Terasmae and Hughes, 1960). The varve chronology may be linked with the general chronology of the deglaciation by means of radiocarbon dates. The minimum age of the uppermost

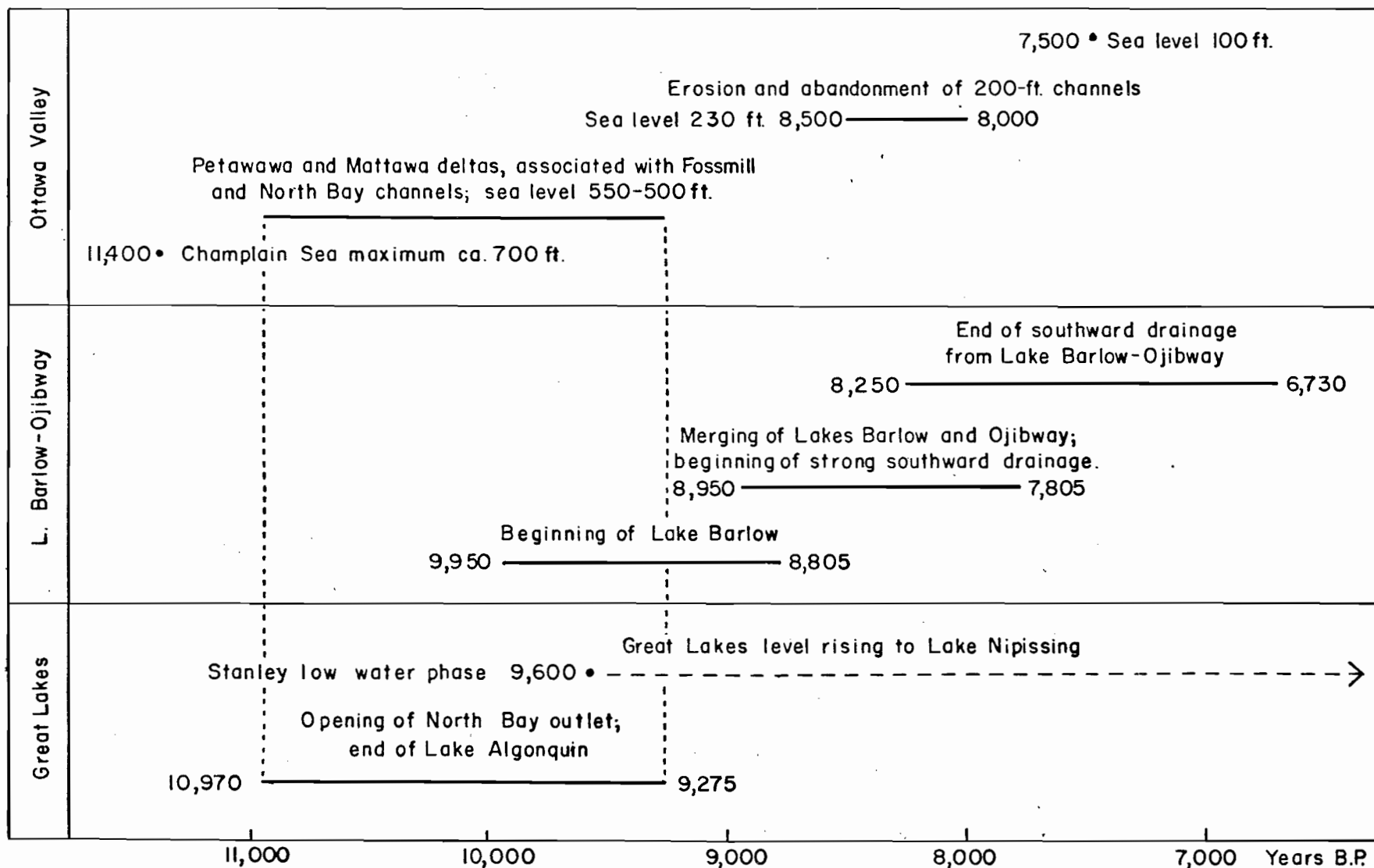


Table 6. Chronological correlation of stages of the Great Lakes, Lake Barlow-Ojibway and the Champlain Sea in the Ottawa valley

varve is given by the radiocarbon age of the basal sediments of a bog at Frederickhouse Lake, of $6,730 \pm 200$ or $6,970 \pm 310$ years (Y-222) (Terasmae and Hughes, 1960). However, if Antevs (1962) is correct in suggesting that the final draining of the lake coincided with the registration of the highest marine shorelines in the James Bay lowland, the minimum age of the highest varve is greater than the radiocarbon date of the Frederickhouse Lake bog would suggest, for marine shells from near the marine limit have been given radiocarbon ages of $7,280 \pm 80$ years (GRO-1698) and $7,875 \pm 200$ years (I-GSC-14).

It is not clear whether the lake continued to discharge southward until its final disappearance, for Antevs (1925) suggested that a lake in the Timiskaming basin may have been severed from the main water body north of the divide by a drop in water level in varve year 1650, 375 years before the end of the varve record. Thus Lake Barlow-Ojibway may have ceased to drain south as early as 8,250 B.P. ($7,875 + 375$ years ago), or southward drainage may have continued until some time before 6,730 B.P..

The merging of Lakes Barlow and Ojibway left no trace in the varve record. This event, which initiated the period of great southward discharge, must have occurred after varve year 1000, when the ice front passed over the divide, from an interpretation of Antevs (1925). Varve year 1000 was 1075 years before the end of the varve record, and its minimum age is 8,950 years ($7,875 + 1075$ years) or 7,805 years ($6,730 + 1075$ years). Thus the minimum age of the beginning of the southward drainage falls within the range 8,950-7,805 years, and the minimum age of its cessation within the range 8,250-6,730 years.

These dates are in fair agreement with the tentative date ascribed to the 200-foot channels in the lower Ottawa valley from palynological

evidence. The period of great discharge appears to be longer than that suggested for the cutting of the 200-foot channels, but a detailed examination of the morphological evidence indicates that a powerful current swept down the Ottawa River for some time after the 200-foot shoreline had emerged. Even when the shoreline stood at 100 feet the erosive power of the river was considerable, although less than at the 200-foot stage (Chapter IV). The 100-foot shoreline coincides with the boundary plane between pollen zones IV and III and is tentatively dated at 7,500 B.P..

CHAPTER IV

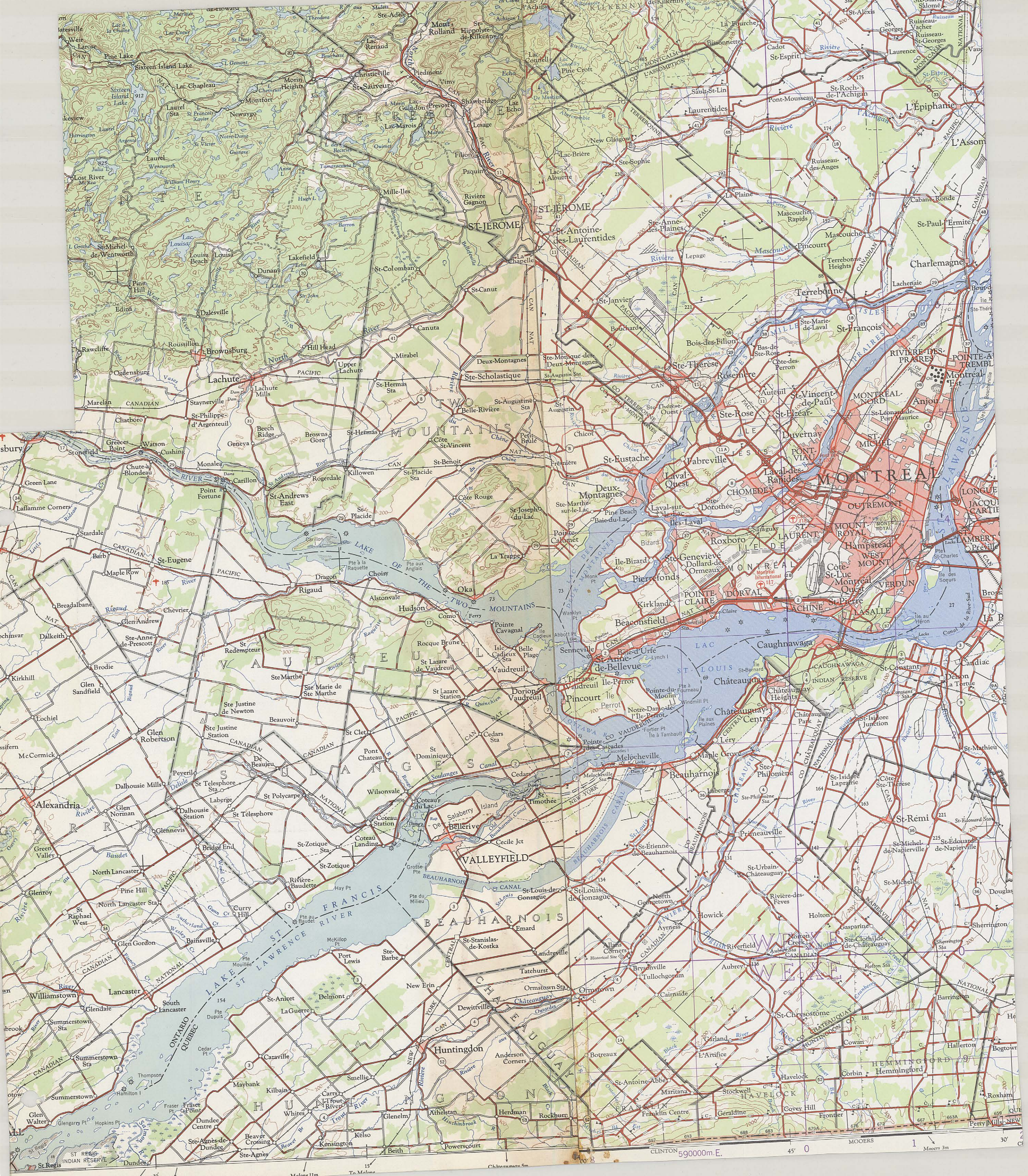
The development of the drainage pattern of the western Montreal lowland

1. THE LOWER OTTAWA VALLEY

a. Topography and present drainage pattern

The area adjacent to the Lake of the Two Mountains is one of the most distinctive sub-regions of the Montreal lowland. The lake derives its name from the two hills between which it lies, Oka Mountain to the north and Rigaud Mountain to the south (Figure 28). These hills are composed of resistant Precambrian rocks brought to the surface along the Oka-Beauharnois axis, and although their summits lie at only 855 and 708 feet respectively they rise impressively above the lake, of which the mean level is 73 feet. The surrounding Palaeozoic sedimentary rocks are almost completely masked by surficial deposits, which have been mapped in the Lachute area by McGerrigle (1938) and for part of the area south of the lake by Keele and Cole (1922). Throughout much of the lowland such deposits are monotonously flat-lying but here morainic ridges project through the later marine deposits and the topography of the area is further diversified by broad trough-like valleys cut in the surficial materials. The northern limit of the area is the linear edge of the Shield, but in other directions it merges with the adjacent, more typical sections of the lowland.

The Lake of the Two Mountains is the lowest of several lake-like expansions of the Ottawa River. It extends below the rapids at Carillon for some 25 miles, and is divided into an upper and a lower section by



narrows at Oka. Water discharges from the lake over four bedrock sills. Two of these lie on either side of Ile Perrot, and carry Ottawa water into the Lake St. Louis section of the St. Lawrence River. The two northern outlets, the Rivière des Prairies and the Rivière des Milles Iles, flow on either side of Ile Jésus to join the St. Lawrence River at the northern tip of the Island of Montreal.

It is only above the Oka narrows that the lake receives any significant affluents. The largest of these is the North River, which leaves the Shield at St. Jérôme where it changes direction abruptly to flow west-southwestward to Lachute between the scarp which bounds the Shield and a bedrock-cored morainic ridge to the south. In this section the longitudinal gradient of the valley floor is imperceptible, and the construction of a dam at Lachute has eliminated the gradient of the river, of which the low water level is 196 feet (Profile, Rivière du Nord, 1918). At Lachute the river turns away from the Shield to follow a devious but generally southerly course with an irregular gradient through morainic hills and bedrock outcrops.

About two miles above its entry into the lake the North River is joined from the east by the St. Andrews River, a sluggish, meandering stream which drains the St. Hermas basin. This basin lies parallel to the North River above Lachute, and is separated from it by the Lachute-St. Jérôme morainic ridge, from which the headwaters of the St. Andrews River drain southeastward into the basin before turning west toward the North River. The southern side of the basin is formed by a second major morainic ridge and by St. Andrews Mountain, a detached part of the Oka massif. The St. Hermas basin is floored with marine clay, but the parallel pattern of underlying minor morainic ridges is still visible and strongly influences

the detail of the drainage pattern.

The eastern end of the St. Hermas basin is drained by the Rivière du Chêne, which, instead of joining the St. Andrews River, flows out south-eastward through a belt of morainic country to enter the Rivière des Mille[^]s Iles. It is joined from the west by the drainage from the St. Benoît basin which lies north of Oka Mountain.

Rigaud Mountain, to the south of the Lake of the Two Mountains, forms a less effective barrier to direct drainage into the lake than does the Oka-St. Andrews upland to the north. The Rigaud River, which skirts the northwestern slope of the mountain, drains a considerable area in Glengarry County, Ontario. The Rivière Raquette, rising on the southern slopes of the mountain, curves northward through a broad valley cut in the bedrock of the mountain's eastern flank. Where it emerges into the lowland bordering the lake it is deflected northwestward into a well-defined valley, whose eastern end is drained by the Rivière Viviry.

b. Early physiographic development

Reference has already been made (Chapter II, Figure 3) to Hobson's map (1962) showing buried valleys east and south of Rigaud Mountain. Where the pre-Wisconsin valleys were deeply incised within the hill masses they persist to the present day, but in the lower areas they have been so completely obscured by glacial and marine deposits that their courses bear no relation to the present drainage pattern. Ellis (1901) suggested that the ancestral Ottawa flowed across the lowland between Oka Mountain and the edge of the Shield, but the existence of a deep valley through the Precambrian massif suggests that it was transected by a major stream. If the Ottawa followed this course, it may be suggested that it had been

superimposed from a cover, since removed, of sedimentary strata.

The elevation of the Quebec platform is indicated by occasional rock outcrops north of Oka Mountain, at between 150 and 170 feet above sea level. South of Rigaud Mountain a bedrock high rises to an elevation of a little over 150 feet. The incision of the stream valleys into the platform may have occurred in response to an early Wisconsin or pre-Wisconsin fall in sea level.

The course of events during the Wisconsin has been discussed, so far as it is known, in Chapter II. Within the lower Ottawa valley the features of glacial deposition trend in two dominant directions. Between Oka Mountain and the edge of the Shield the morainic ridges trend east-northeast - west-southwest, and this moulding may be ascribed to the Malone advance. Above the head of the Lake of the Two Mountains, however, in the Ottawa valley proper, a southeasterly trend is conspicuous, and this may be ascribed to the Fort Covington advance. The detail of the drainage pattern owes much to the trend of glacial moulding.

The Champlain Sea submergence followed the final withdrawal of the ice front from this part of the lowland into the Shield and reached its maximum shortly after the ice re-advanced to the St. Faustin moraine in the upper North River valley. An early report of the elevation of the marine limit in this area was given by Johnston (1916) who measured a beach on Rigaud Mountain at 671 feet above sea level. This figure was disregarded in previous work by the author (Brown, 1962) in favour of elevations given by Romaine (1951). He found beaches no higher than 600 feet above sea level on Rigaud Mountain and 625 feet on Oka Mountain; the similarity of the two figures was considered justification of their acceptance.

However, the recent work by Parry (1963) in the Shield has

necessitated a reconsideration of the evidence. In the upper North River valley the highest marine shoreline, associated with outwash from the St. Faustin moraine, was found to lie at an elevation of 750 feet, while a delta at the same elevation occurs at Dalesville, north of Lachute. The differential uplift of the upper marine plane across the whole of the lowland between Dalesville and Covey Hill, where the marine limit lies at 525 feet, is thus about four feet per mile. The tilt of the plane between Dalesville and Rigaud Mountain, calculated on the basis of Romaine's figure, is seven feet per mile. When the elevation given by Johnston is used the tilt between Dalesville and Rigaud Mountain is reduced to 3.5 feet per mile, a figure which is in better accord with the tilt across the whole of the lowland. Accordingly, in the present work, Johnston's elevation is accepted in preference to those given by Romaine. As a result, the writer's previous conclusions regarding the effects of differential uplift have required modification.

While the Champlain Sea was still at a high level the North Bay outlet was freed of ice and the Ottawa valley began to carry the discharge of the upper Great Lakes. Terasmae and Hughes (1960) suggest that this event occurred between 10,970 B.P. and 9,275 B.P.. The great volume of water carried much silty clay which was deposited on the sea floor of the time. This marine clay now underlies most of the level areas of the lowland and has been readily eroded by both fluvial and marine action. It therefore forms the majority of the channel, marine and lacustrine bluffs at lower elevations. As the sea became shallower littoral and off-shore sand deposits were laid down locally over the marine clay. The most extensive sand deposit is that which forms the St. Lazare sand plain, east of Rigaud Mountain. Like the clay, the sand offered little resistance to erosion,

and was frequently truncated to form bluffs.

c. The development of the drainage pattern during the Champlain Sea regression

Figure 26, drawn from palynological and radiocarbon evidence, indicates the rapidity of the early stages of the regional emergence from the Champlain Sea, which is borne out by the closely spaced cobble beaches at the Devil's Garden on Rigaud Mountain between 370 and 550 feet above sea level. The bluffs in the lower parts of the area occur at fairly consistent elevations, suggesting that the later stages of the emergence were interrupted by periods of relative still-stand. Although only one such stand, at about 100 feet, is indicated by the uplift curve, it has proved possible to correlate the various shorelines and channels at other elevations and to suggest a coherent sequence of events.

The record of former water levels and drainage courses is best preserved at lower elevations, where clay is more extensive, bluffs more continuous and shorelines relatively little undeformed (Figure 29). Consequently the sequence of events will be traced back from the present, beginning with the most well-defined and continuous of the lower shorelines surrounding the Lake of the Two Mountains.

i. The 100-foot or Montreal shoreline. At varying distances from the present shoreline of the Lake of the Two Mountains is a well-defined earlier shoreline, marked for the most part by a bluff cut in clay, or locally in sand. Highway 17, west of Dorion, follows the foot of the most striking section of this bluff. Near St. Andrews East the shoreline is marked by a boulder beach, a lag deposit formed by the removal of fines by wave action from a deposit of till. The elevation of this feature, and of



Figure 29. Bluff cut in marine clay north of
the Lake of the Two Mountains

The foot of the main bluff lies at an elevation of
140 feet; the "shelf" in the bluff face is at 165 feet.

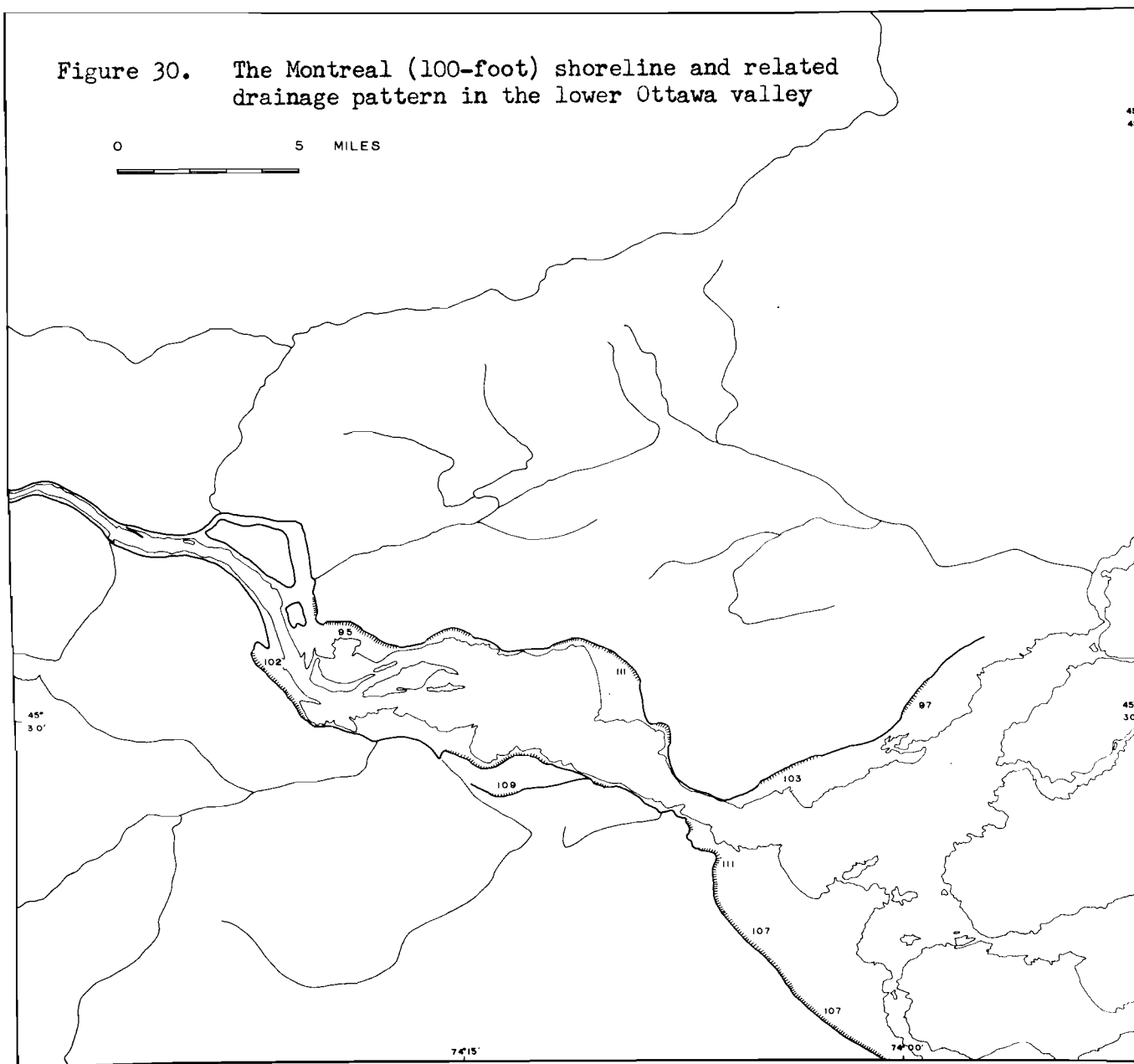
the bluff foot, taken as the water level of the time, is close to 100 feet above sea level. The 100-foot water body submerged the outlets of the present lake. Shorelines occur extensively in the St. Lawrence valley at the same elevation and may be traced downstream below the head of tide. The water body was almost certainly estuarine, although Mackay (1949a, 1949b), referred to it as "Lake Montreal." It seems appropriate to modify his nomenclature and to refer to the water body as the Montreal stage of the Champlain Sea. The head of the estuary at the Montreal stage lay in the Ottawa valley near the present head of the Lake of the Two Mountains.

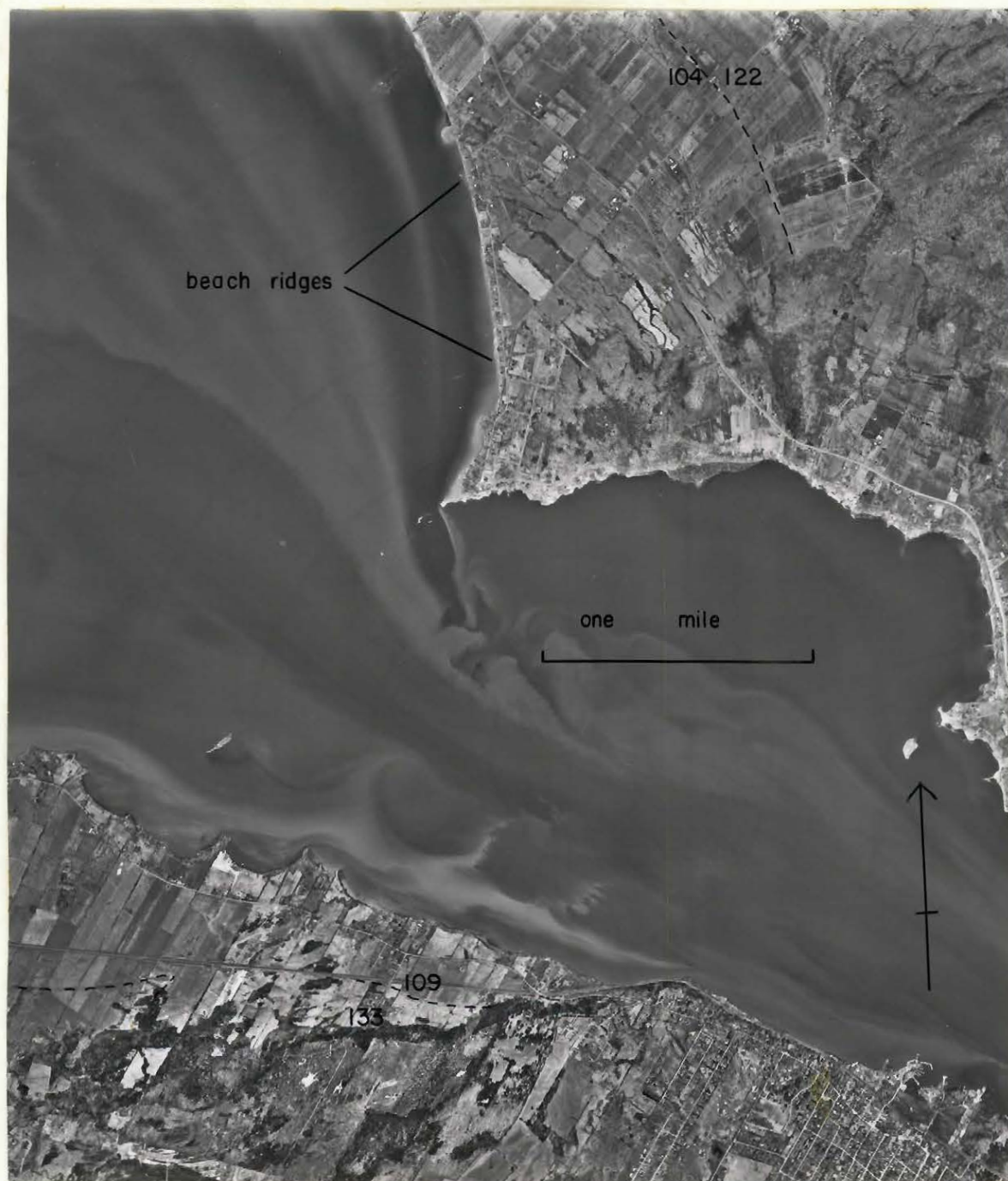
The elevation of the bluff foot lies generally between 95 and 110 feet (Figure 30). Between Cascades Point and Dorion a shelf is preserved in the face of the bluff at 107 feet, while the bluff foot is at an elevation of 90 feet. Here is evidence that there were two periods of stillstand involved in the formation of the shoreline; the water level stood for a time near 110 feet and then fell to 90-95 feet. Rarely are two bluffs at these elevations to be recognized one above the other. This is to be expected, for a fall in water level seems frequently to have resulted in the cutting down of the base of an existing bluff. Moreover, the shoreline of the present lake consists of bluffs alternating with gently sloping shores. Were the water level to fall once more new bluffs would be formed in places, but not necessarily below the present bluffs.

During the upper phase of the Montreal stage a series of offshore bars or beach ridges trending southeast-northwest were created west of Oka. The small streams flowing in the lows between the ridges have since incised their valleys in response to the fall in base level (Figure 31).

The pattern of drainage in the area adjoining the lake at the time the 100-foot shoreline was cut differed little from the present one. Not

Figure 30. The Montreal (100-foot) shoreline and related drainage pattern in the lower Ottawa valley





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Figure 31. Shoreline features, Oka narrows, Lake of the Two Mountains

Elevations in feet. The Montreal (100-foot) shoreline bluff is emphasized.

all the Ottawa water, however, entered the lake directly, for depressions between morainic knolls near Monalea and Carillon were eroded into channels leading into what is now the lower course of the North River.

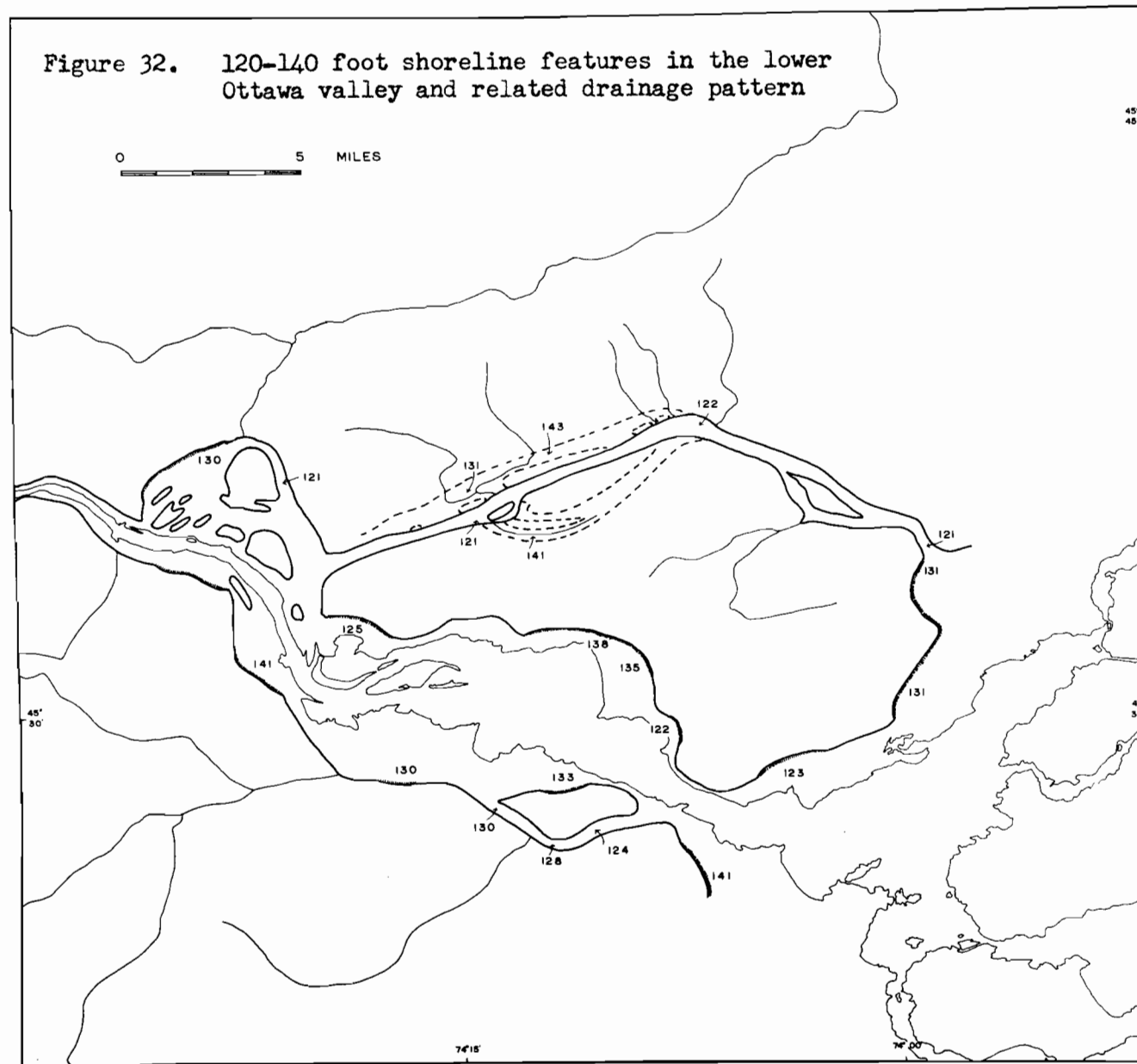
There is no evidence in this area of any tilting of the lowest shoreline.

ii. The 130-foot shoreline. An earlier stage is marked by less continuous bluffs with bases lying between 120 and 140 feet above sea level (Figure 31). Indirect evidence, discussed below, suggests that again there was not a single stand at this stage.

While the water level stood at 120 feet, and probably also while it was falling to 100 feet, the water entering the effective head of the water body below the gorge-like section of the Ottawa valley at Chute à Blondeau diverged into a number of channels between morainic islands (Figure 32). The abandoned floors of these channels are mantled with a concentrate of large boulders, the residue of a till from which the fines have been removed. The highest channel, the floor of which is at about 130 feet above sea level, leads from the Ottawa valley west of Monalea Station into an almost enclosed lowland. Bluffs indicate that the lowland contained a water body encircling a mass of till west of Geneva and communicating southward with the main water body through the North River valley.

Eastward from this small lowland the valley of the St. Andrews River leads into the St. Hermas basin, across the floor of which it is incised as a straight-walled trench. The floor of the trench is at an elevation of 122 feet east of St. Hermas village and at 118 feet west of the village, below St. Andrews Mountain; the westward gradient of the valley floor is thus less than one foot per mile. The current of the

Figure 32. 120-140 foot shoreline features in the lower Ottawa valley and related drainage pattern



meandering St. Andrews River is correspondingly sluggish and it appears unlikely that the floor of the trench is a flood plain created by lateral erosion. At its eastern end the trench continues into the valley of the Rivière du Chêne. The divide between the present westward and eastward drainage lies at a little over 120 feet, and the floor of the valley of the Rivière du Chêne is still at 121 feet below the northeastern point of Oka Mountain. It would appear, therefore, that the trench was formed as a single broad channel in the floor of the St. Hermas basin, functioning as an alternative route for the discharge of the Ottawa River.

The St. Andrews River flows now in the reverse direction from the current which shaped its valley. There is no incision to indicate that the river has reversed the drainage of the valley by headward erosion; indeed, near its mouth it is held upon bedrock at 114 feet. It is possible that the original gradient of the channel floor was not consistently eastward. However, differential uplift may have been a contributory factor to the reversal of flow. The divide between the St. Andrews River and the Rivière du Chêne lies at the most northerly point of the channel; demonstrable differential uplift at earlier stages in the emergence had its maximum effect in a direction west of north, and the trend may have continued at this late stage.

The final deepening of the St. Andrews channel evidently occurred as the water in the main valley fell from the level at which the 130-foot bluffs were cut. It was the survivor of a more widespread system of interconnecting channels which flanked it on both sides within the St. Hermas basin, and which must have drained eastward at the time of its formation. The floors of the flanking channels lie at elevations of between 140 and 150 feet, and the system may therefore be correlated with a 140-foot stage

in the main lake basin. A terrace at 145 feet above sea level in the St. Andrews River valley itself lends support for this correlation. The channels trend from west-southwest to east-northeast, controlled by parallel, low, till-cored ridges from which the marine sediments have not as yet been completely stripped away. The channels are floored with marine clay, which is locally veneered with alluvium or peat. The drainage pattern that has developed within the channels is complicated, and is not accurately portrayed by the 1:50,000 map. Figure 28 shows the drainage network, traced from aerial photographs, and includes a number of recently-constructed drainage ditches. The drainage in the western ends of the channels has been reversed, but this is almost certainly the result of an original backward slope of the floors of the channels, for their trend is such that differential uplift could have had no effect.

To the south of the Lake of the Two Mountains the 130-foot stage was the last during which an unusual channel operated. It is open to the lake at both ends and is drained today by the lowest section of the Rivière Raquette and by the Rivière Viviry. At the time of its formation a considerable current must have passed through the water body in the lake basin. The floor of the channel has an eastward gradient of two feet per mile, and lies at an elevation of 128 feet at the drainage divide. The reversal of drainage in the western half of the channel can only be ascribed to headward erosion by the lower Rivière Raquette.

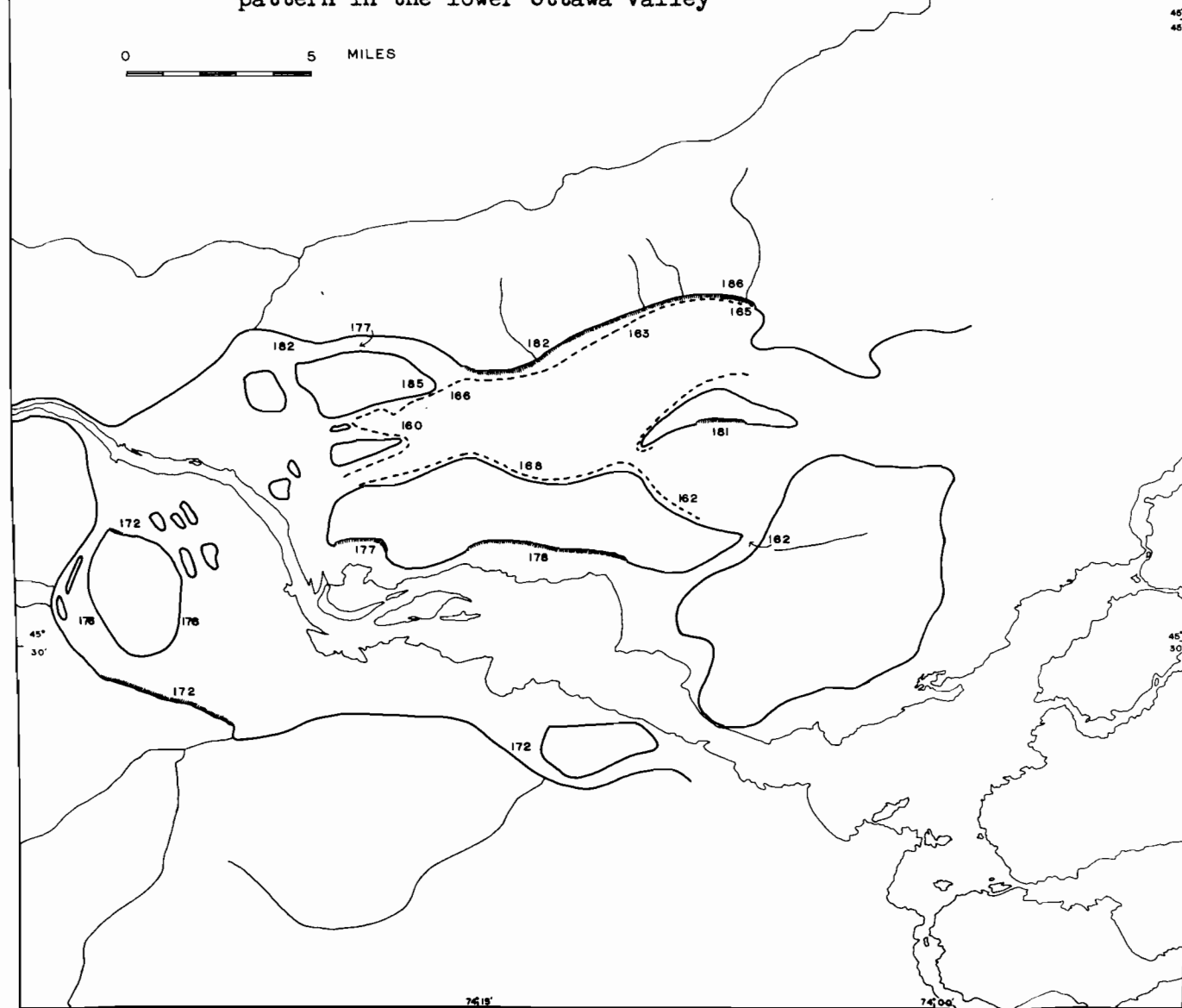
iii. The 175-foot shoreline. A higher bluff with its foot near 175 feet is locally conspicuous and marks a yet earlier water level in the basin of the Lake of the Two Mountains. Only doubtful traces of this shoreline have been found below the Oka narrows in this area, but since both higher and lower shorelines may be traced above and below the narrows it seems

unlikely that at this particular stage the narrows held a lake in the upper part of the basin.

The shoreline may be traced south of the lake at 171 or 172 feet along the northern slope of Rigaud Mountain and then trends west-northwestward as an almost straight bluff toward St. Eugène (Figure 33). On the north side of the lake it forms a striking feature south of St. Andrews Mountain at 177 or 178 feet. The northerly component of the tilt of this shoreline is thus of the order of one foot per mile, and this water plane projected to the north side of the St. Hermas basin lies at 184 feet. The morainic ridge which lies between the North river valley and the St. Hermas basin is flanked with marine clay, in which a well-marked bluff has been cut. North of St. Hermas village the bluff foot lies at 182 feet; toward the east its foot is at about 165 feet, but a shelf in the bluff face is preserved locally at the higher elevation. It seems probable, therefore, that at the time the water level in Lake of the Two Mountains stood at 175 feet, it was continuous with a water body at the same level in the St. Hermas basin. A strong bluff north of the village of St. Benoît, its foot at 182 feet, indicates that the same water body extended into the St. Benoît basin.

At Côte Double, on the south side of the St. Hermas basin, bluffs at two elevations were developed. The foot of the upper lies at 192 feet, of the lower at 168 feet. The latter may possibly be correlated with the 165-foot bluff on the north side of the basin, but the elevation of the former is too great for it to be correlated with the 182-foot bluff to the north. If the effects of tilting are taken into consideration the discrepancy between the two elevations becomes even greater. However, at two points on the north side of the St. Hermas basin benches in the bluff face

Figure 33. The 175-foot shoreline and related drainage pattern in the lower Ottawa valley



were measured at 192 and 197 feet. It may be that it is these shoreline remnants which should be correlated with the continuous bluff at Côte Double. Wave action at the later, lower shorelines on the north of the basin may have all but destroyed the evidence of the uppermost, while on the south side evidence of the middle, or 175-foot shoreline has been completely removed by the development of the lowest bluff.

The ground evidence suggests, therefore, that three distinct water planes left shoreline traces in the St. Hermas basin during this period of the emergence. The lowest will be termed the 165-foot water body, from the elevation of its northern shoreline. It submerged the whole of the floor of the basin, and extended through the valley of the Rivière du Chêne into the St. Benoît basin, where a bluffed shoreline at its western end lies at 162 feet. This part of the water body was for a time in communication with the water body in the basin of the Lake of the Two Mountains by a channel at 165 feet northwest of Oka Mountain. However, in the main lake basin only one observation of a faint shoreline at this elevation was made.

The 165-foot water body received Ottawa water through two channels. The more southerly was the valley of the St. Andrews River, which was subsequently deepened further. The more northerly channel, south of the morainic hill upon which the settlement of Beech Ridge is situated, had an irregular floor, but at its eastern end its lowest point is at an elevation of 160 feet. To the west, near its intake, the channel is split in two by a mound of till. The two branches of the channel lie at different elevations. The southern branch is floored with boulders, and erosion into the underlying till ceased at 175 feet. The northern branch, by contrast, has a flat floor at 144 feet while only a mile to the east the channel

floor is almost 20 feet higher. While it is not impossible that the channel floor rose downstream, it almost seems as if a westward flowing stream of considerable volume, if short duration, is necessary to account for the observed facts, for the present stream, draining westward, is clearly incapable of having excavated the channel. It is possible that a sudden lowering of water level in the Lake of the Two Mountains basin would have cut off the supply of water to the St. Hermas water body which would then for a short time have drained through its former intake. The fall in the water level from the 165-foot shoreline marked the end of an extensive water body in the St. Hermas basin.

The extent of the earlier 175-foot water body (182 feet in the St. Hermas basin) has already been discussed. This water body had a number of intakes (Figure 34). In addition to those which later fed the 165-foot water body a third, lying north of Beech Ridge, led into the St. Hermas basin. Its floor, now obscured by a peat deposit, was deepened to 175 feet and then abandoned. The difference in elevation of the floors of the channels on either side of Beech Ridge results principally from the continued deepening of the more southerly channel after the northern one had been abandoned by through drainage, for the eastern end of the northern channel is cut off by a bluff which continues into the southern channel. It is possible, however, that differential uplift caused the abandonment of the northern channel, and thus a small part of the difference in elevation may be attributed to this cause. There is evidence of this stage in the channel south of Beech Ridge along the line of the levelled profile (Figure 35), where the irregular floor of the northern side of the channel lies close to 170 feet. In the St. Andrews River valley a terrace remnant with its back at 178 feet may also be attributed to this stage.



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Figure 34. Channels south of Lachute

Elevations in feet. Channel bluffs are emphasized. B and C are the sites of the borings for the pollen profiles of Beech Ridge bog. The dotted line is the line of the levelled profile (Figure 35).

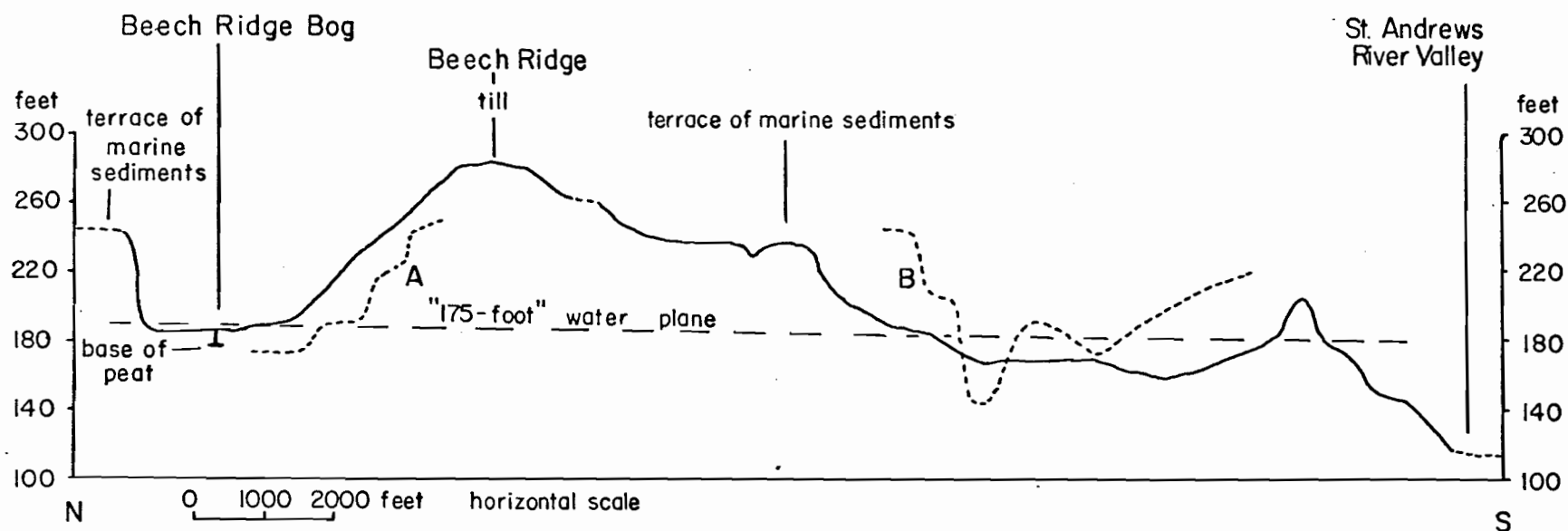


Figure 35. Levelled profile across the channels south of Lachute

The profile illustrates the contrast between slopes cut in till and marine deposits. This is seen in the northern channel (site of Beech Ridge bog), the north side of which is cut in marine clay, the south side in till. No stages are visible on the steep undercut north side of the channel, but the broken line A shows the general stepped form of the south side of the channel where it is cut in marine deposits east of the line of profile. Till, with a thin veneer of marine clay, underlies the irregular floor of the central channel. The broken line B indicates the still greater irregularity of the floor of this channel west of the line of profile. The "175-foot" water plane is indicated, illustrating the successive abandonment of the channels.

South of the Ottawa River a broad channel, its floor near 175 feet, sweeps in an arc to open to the 175-foot shoreline near St. Eugène (Figure 36). Evidence of a shoreline at this elevation in the lower Raquette and Viviry valleys is wanting, but as this depression formed a strait at earlier and later stages it must have been occupied by water at this time.

The clearest evidence for the existence of an earlier, 195-foot water body in the St. Hermas basin is the well-marked upper bluff at Côte Double. In addition to traces of a shoreline at this elevation on the north side of the St. Hermas basin, a bluff southeast of Beech Ridge has its base at 197 feet and in the channel south of Beech Ridge a terrace is preserved with its back at 191 feet. No shorelines have been observed in the Lake of the Two Mountains basin which could be correlated with this water body. This is not surprising for the subsequent 175-foot stage was evidently of longer duration, and its bluffs extend through the range of elevation at which the earlier shoreline might be expected.

iv. The 200-foot or Rigaud shoreline. At higher elevations traces of shorelines are less widespread, since much of the area was submerged. However, Johnston (1916) and Goldthwait (1933) noted strong evidence of a shoreline at about 200 feet on Rigaud Mountain. The water body responsible for this shoreline will be referred to as the Rigaud stage of the Champlain Sea. Water marks at similar elevations occur to the west, above the series of rapids at the head of the Lake of the Two Mountains. Goldthwait asserted that these resulted from later fluvial erosion, but it seems more likely that at the Rigaud stage the head of the estuary lay at a considerable distance farther up the Ottawa valley. The correlation of the 200-foot shoreline with the beginning of drainage from Lake Barlow-Ojibway indicates that the estuary carried a strong seaward current at this time (Chapter III).



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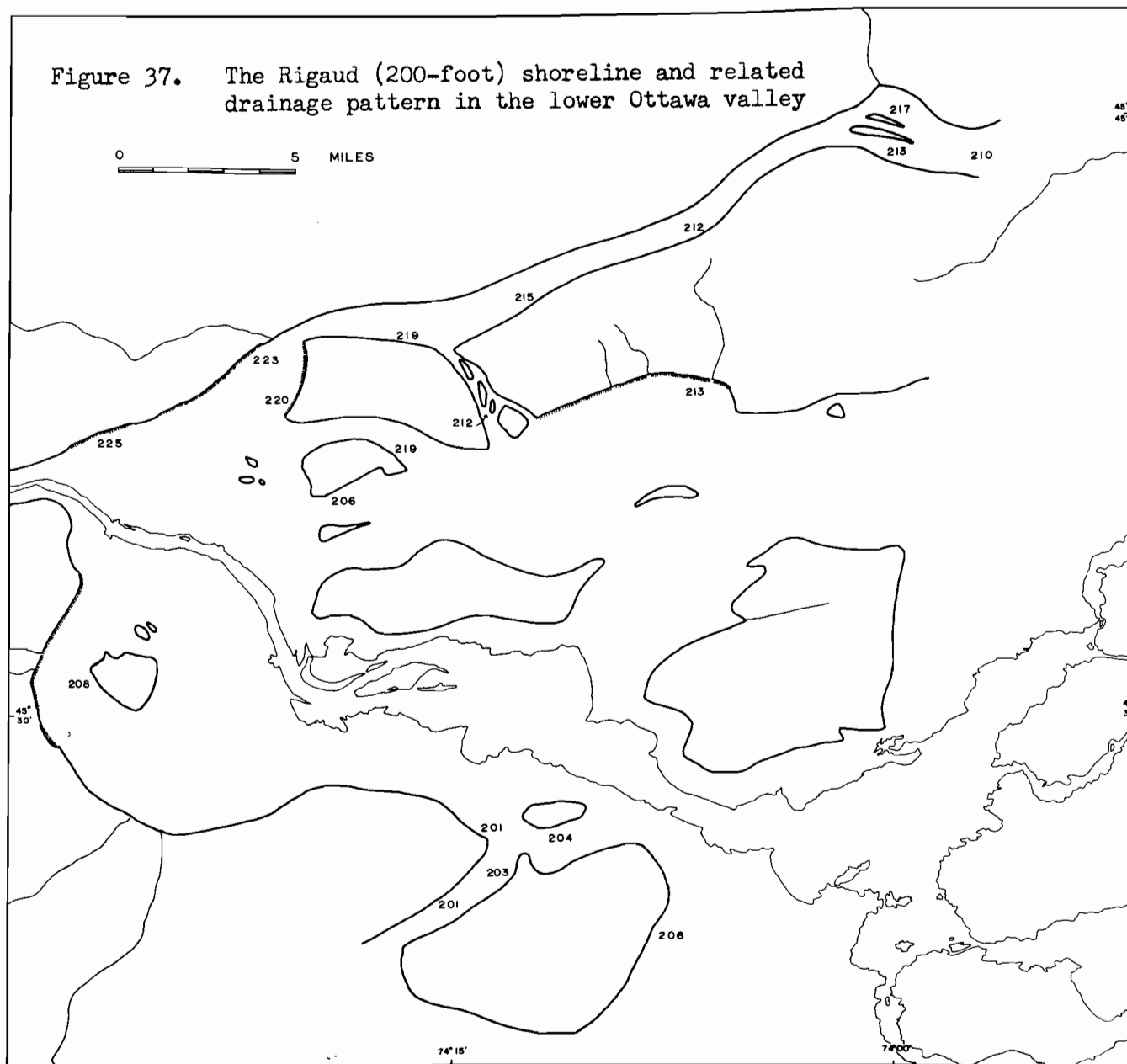
Figure 36. Channels above the head of the Lake of the Two Mountains. Elevations in feet. Significant bluffs are emphasized. Channels (arrows) at higher elevations are controlled by southwesterly moulded till; those at lower elevations by southeasterly moulded till. E (now submerged) and F are the sites of the borings for the pollen profiles of "Cut-over" and St. Eugène (Prescott) bogs.

The shoreline features on Rigaud Mountain are best developed on its northeastern slopes, and consist of concentrations of boulders and bluffs similar to those which are conspicuous at lower elevations. The shoreline may be traced into the middle section of the valley of the Rivière Raquette, which thus formed a strait between water bodies north and south of Rigaud Mountain (Figure 37). Here the shoreline has been measured at elevations of from 196 to 203 feet. In some cases this is the elevation of a break in slope between a boulder beach above and a sand flat below, while elsewhere it is that of the base of a series of sandy beach ridges. The channel which is drained today by the lower Rivière Raquette and by the Rivière Viviry was also a strait, for facing bluffs, the feet of which have been measured at 202 and 204 feet, occur on the slopes.

The shoreline of the Rigaud water body at the northwestern limit of the area of this study may be traced in a bluff between St. Philippe and Lachute. The foot of the bluff lies close to 220 feet above sea level, and if it is correlated with the water marks on Rigaud Mountain the northerly component of tilt of the water plane is of the order of 1.5 feet per mile. This is of the same order as that of the surface separating pollen zones V and IV, which lies at a slightly higher elevation (Figure 25).

South of Lachute, on the east side of the North River valley, a well-marked bluff with its base near 220 feet faces the bluff already mentioned. It may be traced eastward up the North River valley, where it bounds the valley floor. As there is frequently a visible slope toward the river from the feet of the bounding bluffs, it appears probable that at the Rigaud stage the whole valley floor formed a channel. A series of

Figure 37. The Rigaud (200-foot) shoreline and related drainage pattern in the lower Ottawa valley



terraces on the south side of the valley, of which those at about 232 and 247 feet are most conspicuous, mark earlier, wider stages of this channel. As the water level fell the channel drained, and today its floor is occupied only by the underfit North River.

Both the flanking terraces and the valley floor have so little longitudinal gradient that it is difficult to determine the direction of the final draining of the channel. In addition, although the valley trends obliquely to the isobases on the V-IV pollen boundary surface, its direction is such that the apparent tilt would be very small and well within the limits of error of instrumental observation. However, there are a number of factors which suggest that for a time the valley was occupied by a broad, east-flowing stream. The foot of the bluff which bounds the valley floor declines gently eastward from 219 feet near Lachute to 212 feet near St. Canut, and south of St. Jérôme parallel channels with floors at 213 and 217 feet lead from the North River valley into the head of the Mascouche valley. Thus it appears probable that for a time the middle section of the North River valley functioned as an outlet for Ottawa water, in a similar manner to the smaller channels to the south, and similarly, that its abandonment as a route for eastward drainage resulted from differential uplift and the concentration of flow in lower channels to the south.

In an earlier paper (Brown, 1962) the writer explained the present westward course of the North River by differential uplift, but this hypothesis must now be abandoned. The revised map of isobases on the marine limit (Figure 10) and the map of isobases on the boundary surface between pollen zones V and IV (Figure 11) both indicate that differential uplift could have played very little direct part in such a diversion. Evidence

to be put forward in the following section suggests that for a time, following the abandonment of the North River channel by Ottawa water, a part at least of the flow of the North River issuing from the Shield continued to be carried eastward into the Terrebonne sand plain. However, the floors of the channels through which it passed, at 217 and 213 feet above sea level, were at higher elevations than the floor of the North River channel to the west, which lies generally less than 210 feet above sea level. It was inevitable, therefore, that the whole of the flow of the North River should eventually find its way westward. The diversion is thus to be ascribed to the form of the channel floor, which lay at a higher elevation where it entered the sand plain. This conclusion supports Blanchard's view (1953) that the apparent reversal of the North River was the result of adjustment to the form of the emerging sea floor.

For a time some of the water flowing eastward along the North River valley spilled south across the Lachute-St. Jérôme morainic ridge. Four miles east of Lachute the bluff south of the North River leads into a channel which may be traced to the northern limit of the St. Hermas basin. Here its floor, at about 210 feet above sea level, is cut off by a later shoreline bluff. The course of the channel is controlled by a ridge of bedded sand and gravel, partly buried in marine clay. In places the channel branches on either side of segments of the ridge. After this drainage route had been abandoned a branch of the current in the North River valley cut an ill-defined clay-floored channel across its trumpet-shaped intake. This channel is separated from the present North River by a deposit of sand with a wind-blown surface, which may have developed from an alluvial island.

Traces of the Rigaud shoreline in the St. Hermas basin have almost

all been demolished by the formation of later bluffs. However, there is a narrow bench in the northern boundary bluff at 213 feet at the extreme northeast of the basin, and a well-defined terrace at the northeastern side of the Beech Ridge hill at 219 feet may be related to the same shoreline.

v. Higher shorelines. With rare exceptions, erosional terraces are absent above the Rigaud shoreline in this area. Flat surfaces of marine sediments do exist, backed by rising ground, but in most cases the flat is a depositional surface, and the rising ground a bedrock or till mass emerging from beneath the marine sediments. An attempt to correlate such depositional flats can only lead to error, for they were originally neither horizontal nor continuous. Shorelines at these elevations take the form of boulder concentrations and gravel or sand ridges, in contrast to the bluffs at lower elevations.

The change in the nature of the shorelines at about 200 feet above sea level reflects the nature of the deposits, the rate of emergence and the increased discharge of the Ottawa River. The marine clay at lower elevations is especially susceptible to the formation of bluffs, and such bluffs were formed when the rate of emergence had diminished and when there may have been some temporary relative stands of sea level. The existence of a single bluff does not, however, necessarily imply that the water level stood at its foot during the whole of its formation. On the bluff face which forms the northern boundary of the St. Hermas basin numerous benches are preserved, marking minor stabilities of water level while the bluff was being cut. Adjacent stretches of the bluff show no such benches, but must have been formed in a similar way. Hence emergence did not proceed by a few major episodes at low levels, but rather by a series of

smaller ones. To deny the existence of any significant periods of relatively stable water level and alternating periods of emergence, would, however, invalidate the foregoing correlations of water levels.

2. THE TERREBONNE SAND PLAIN

a. Topography and present drainage pattern

The Terrebonne sand plain lies between the Shield and the Rivière des Milles Iles (Figure 38). Its southern boundary, a conspicuous bluff known as the Grand Coteau, overlooks a belt of morainic country along this most northerly branch of the Ottawa River draining from the Lake of the Two Mountains. The Grand Coteau corresponds with the bluff north of the St. Hermas basin, which bounds the marine deposits adjoining the Lachute - St. Jérôme morainic ridge, but the continuity of the two features is lost in an area of morainic topography extending southward from the ridge and marking the western limit of the sand plain.

The greater part of the sand plain consists of three island terraces, the largest and most southerly of which is bounded by the Grand Coteau. Broad, shallow, interconnecting channels, drained by the Rivière Mascouche and its tributaries, separate the sandy island terraces, and their floors reveal the thick spread of marine clay upon which the sand rests (Figure 39). Beyond the most northerly channel the deposit of sand feathers out toward the Rivière l'Achigan (Osborne and Clark, 1960).

The intensity of marine deposition in the area of the sand plain appears to result from a number of factors, of which the presence of the Ste. Thérèse gravel ridge was perhaps the most important. Although the ridge, which lies obliquely across the southern island terraces, has been almost buried by marine sediments, it must have been a significant feature

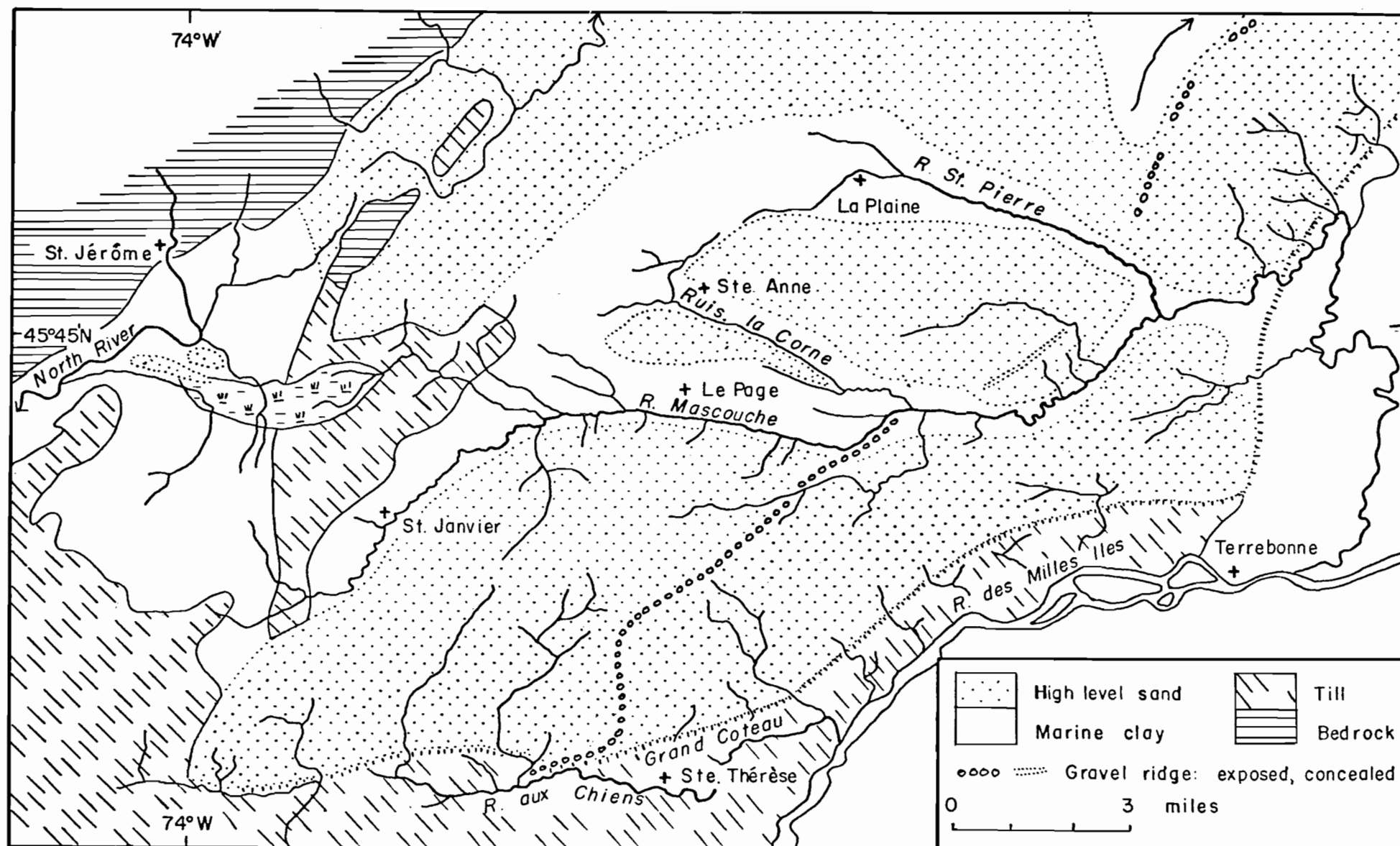


Figure 38. Surface deposits of the Terrebonne sand plain



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Figure 39. Junction of the Mascouche and la Corne channels

of the floor of the Champlain Sea. Beyond the Rivière St. Pierre, which drains the northern channel across the sand plain, a line of less deeply buried gravel hillocks continues the trend of the Ste. Thérèse ridge to the northeast, while a low bluff traversing the larger of the two central island terraces may mark an intervening buried section of the ridge. Thus the combined feature is almost twenty miles in length; moreover, a line of morainic hills continues its trend toward the southwest. The area between the ridge and the edge of the Shield would have functioned as a settling trap for marine bottom sediments, and it seems likely that the more limited area of relatively sheltered water outside the ridge also encouraged the deposition of marine clay.

The overlying sand is of shallow water origin (Byers, 1933), and its thickness varies from 35 feet to only a few feet. Two possible routes exist for its transportation into the shallowing marine embayment behind the Ste. Thérèse ridge. A poorly defined channel, drained now by the upper course of the Rivière Mascouche, leads into the sand plain at the western end of the southern island terrace, near St. Janvier. This channel is unlikely to have been a significant source of sand, for water entering it would have spilled from the relatively still water body in the St. Hermas basin. It was the channel leading from the North River valley near St. Jérôme which would have carried most of the sand, whose provenance was the fluvio-glacial deposits of the valley of the North River and of other streams draining from the Shield. As relative sea level fell the spread of sand extended eastward, probably by repeated episodes of erosion and deposition. Thus it is that the highest parts of the sand plain, west of the Ste. Thérèse ridge, are more than 230 feet above sea level, while the surface declines gently to an elevation of 160 feet in the east. The

eastern end of the sand plain is truncated by a bluff, the continuation of the Grand Coteau which swings northward near the town of Terrebonne. The position of the bluff appears to be close to the original margin of the area of deposition, for the slope of the surface of the sand plain falls off more rapidly toward the lip of the bluff.

The channels which cross the sand plain provide evidence of the sequence of stages in its development, but before examining this evidence it is necessary to describe in more detail the present drainage pattern. A few streams drain southward, cutting through the Grand Coteau, and northward, into the Rivière l'Achigan, but the greater part of the drainage is gathered by the Rivière Mascouche. The St. Janvier channel provides a route for the headstream of the Rivière Mascouche, leading it into the channel which formerly carried water from the North River valley. Minor tributaries of the Rivière Mascouche continue to follow the former direction of drainage in the North River channel, the intake of which now drains in the reverse direction, into the North River. The broad single channel formed by the junction of the St. Janvier and North River channels divides eastward into three branches. The Rivière Mascouche follows the southern branch, flowing close to its southern margin. The broad northern branch is followed by no single stream, and the lack of surface drainage resulted in the accumulation of up to ten feet of peat, the burning of which since the early days of settlement has, by lowering the surface, increased the drainage problem (Lajoie, 1960). The headwaters of the Ruisseau la Corne rise within the northern branch channel, however, and the stream is carried to the Rivière Mascouche through the central branch which lies between the two smaller island terraces of the sand plain. The eastern end of the northern branch provides a route for the Rivière

St. Pierre, the last significant tributary of the Rivière Mascouche before it breaks through the eastern bounding bluff. The Rivière Mascouche crosses the low ground east of the sand plain in a series of zig-zags, apparently determined by former drainage lines, to flow into the Rivière des Milles Iles above its confluence with the Rivière des Prairies.

It is obvious that streams generated within the present Mascouche drainage basin would have been inadequate to have eroded the channels which determine their courses. The present streams flow in narrow V-shaped valleys incised within the floors of the channels. Some lateral erosion is taking place, but there are only meander scrolls and no continuous flood plains within the valleys, nor do there appear to be terraces marking stages in the incision. From the outline of the development of the Terrebonne sand plain given above it may be concluded that it evolved as an emerging estuarine delta, and that only its final fashioning occurred sub-aerially.

b. The development of the drainage pattern during the emergence of the sand plain

At the time of the "200-foot" or Rigaud stage which was recognized in the area of the Lake of the Two Mountains, parts of the Terrebonne sand plain had already emerged. The Rigaud shoreline lies at 215-225 feet above sea level in this area and may be traced eastward from the North River valley at St. Jérôme along the margin of the northern branch channel at elevations of 220-225 feet (Figure 40a). The area between this channel and the edge of the Shield was above sea level, as was much of the western part of the main, southern island terrace. A bench at 217 feet at the western nose of the larger of the two central island terraces indicates

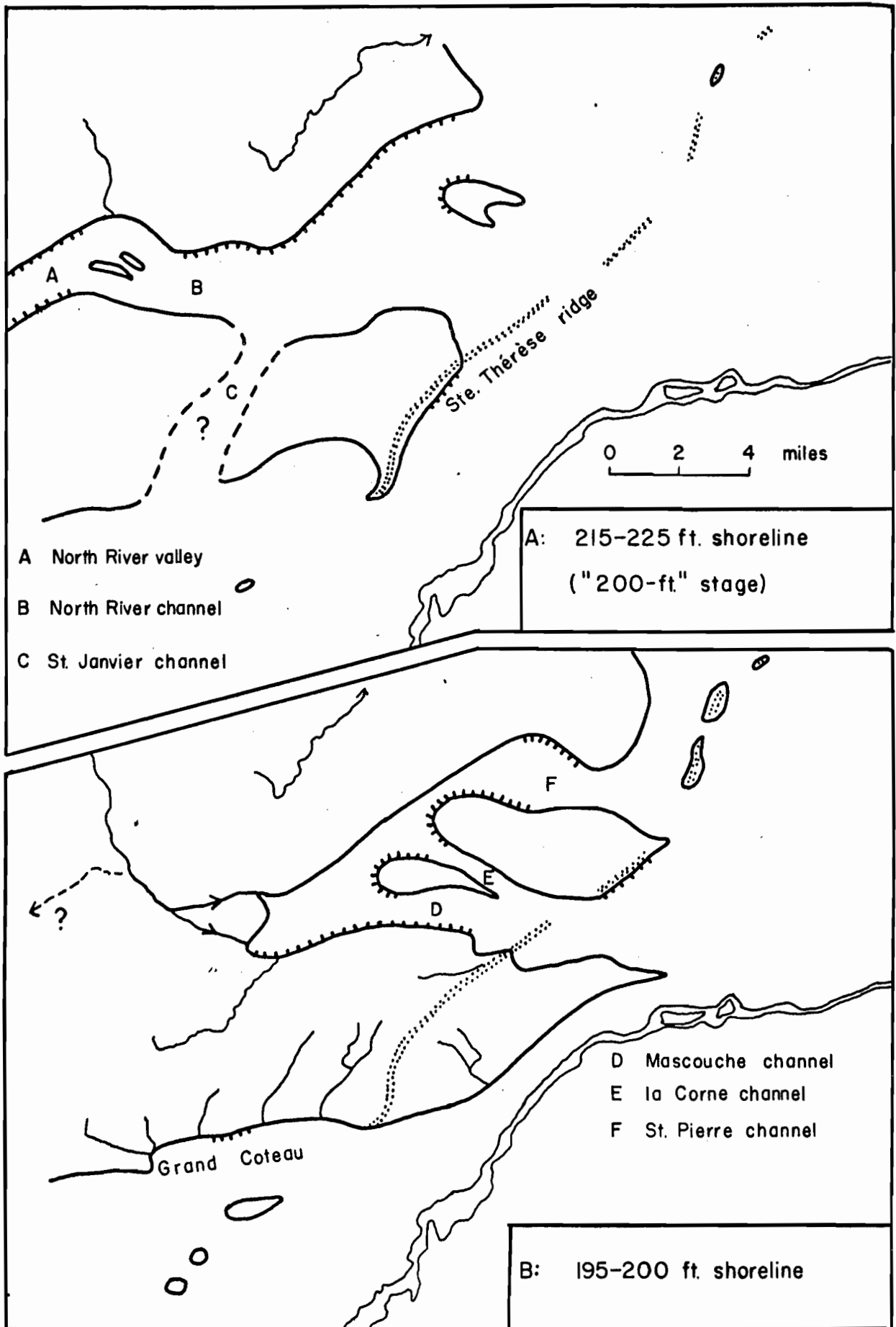


Figure 40. Stages in the emergence of the Terrebonne sand plain

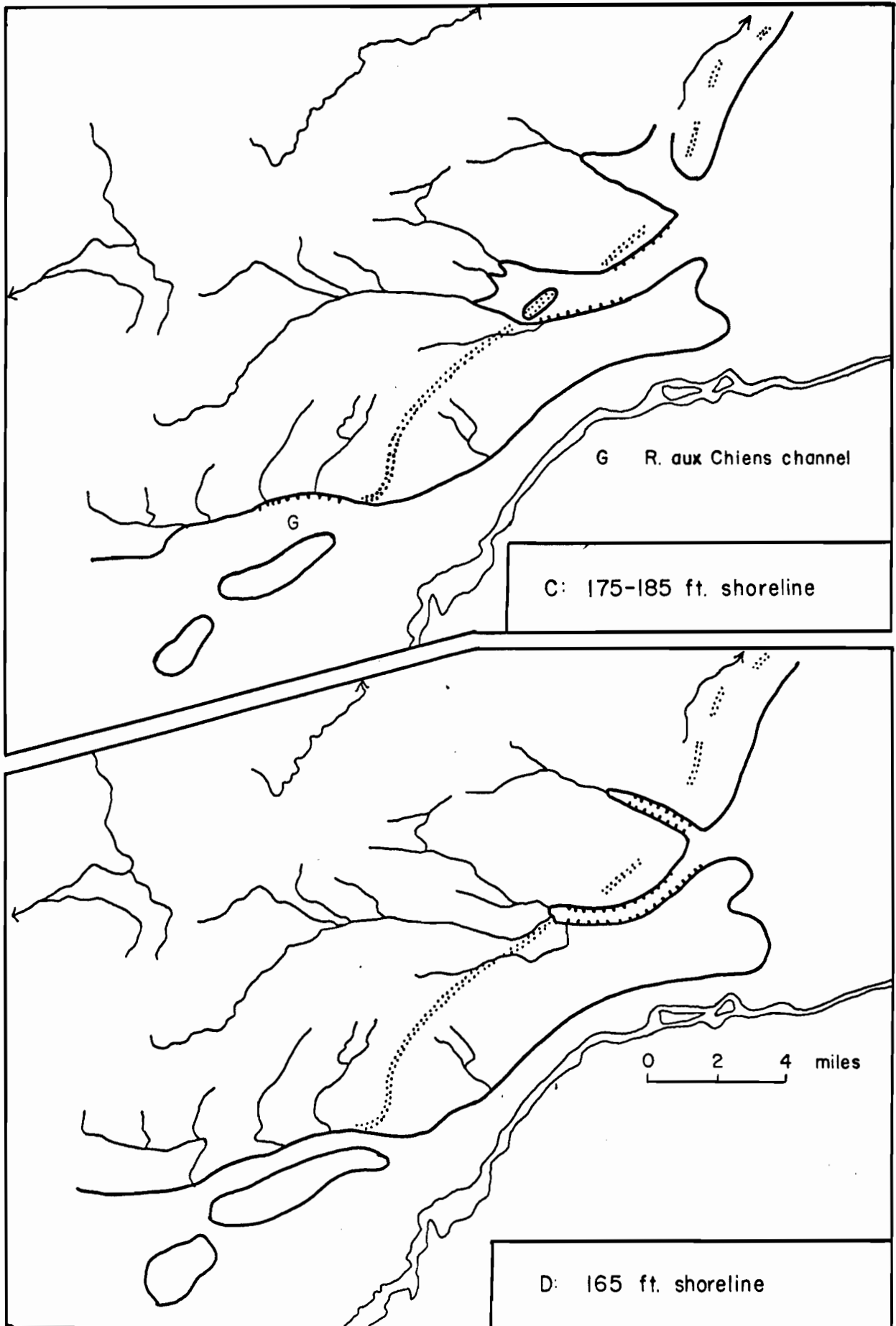


Figure 40 (continued)

that its crest had emerged, but the summit of the smaller island terrace, at 218 feet, was scarcely more than a wave-washed sand bank.

The condition of the St. Janvier channel at this stage is uncertain. Its floor, at elevations of 216-218 feet, may have been just awash. The margins are not clearly defined and there are no well-marked bluffs to indicate the relative level of the final water body to occupy the channel. A flat at the same elevation as the channel floor extends eastward above the southern bluff of the Mascouche channel and may also be traced east of the Ste. Thérèse ridge, but only where it adjoins the ridge is it backed by a bluff. Conditions in this southern part of the sand plain at this time clearly differed from those to the north, where erosion of a conspicuous bluff was proceeding.

By the time of the next recognizable stage in the emergence the St. Janvier channel was undoubtedly dry, for the water level in the channels of the sand plain lay at about 200 feet above present sea level (Figure 40b). During the emergence from the 220-foot to the 200-foot level the northern end of the St. Janvier channel was truncated by the current flowing from the North River valley. The foot of the truncating bluff lies at 214 feet above sea level north of St. Janvier. The southern end of the St. Janvier channel, also, was truncated, by the western extremity of the Grand C[^]oteau, a low bluff at an elevation of 207 feet.

It is probable that the water marks at 200 feet above sea level in the channels of the sand plain correspond with those at about 195 feet in the area of the Lake of the Two Mountains. By that time water had ceased to drain eastward at the Shield edge along the North River valley, but there appears to have been continuing flow into the sand plain from the upper North River valley above St. Jérôme. The present divide in the

channel which leads into the sand plain lies in an area of till which is traversed by water-scoured trenches which today provide routes for minor left-bank tributaries of the Rivière Mascouche. The trenches must have been cut by North River water descending the slope of the area of till to the water level at 200 feet in the sand plain. It is possible that part of the flow of the North River was carried westward at the Shield edge at the same time. The channels draining eastward were soon abandoned, for the floor of the North River valley to the west lay at a lower elevation. A depression in the floor of the channel west of the area of till is now the site of a bog, which drains both eastward and westward; it is unfortunate that pollen samples were not obtained from the bog, for they may well have provided evidence of the date of the abandonment of the channel by through drainage.

Within the sand plain the arms of water in the channels had diminished in width by the time the water level had fallen to 200 feet. That in the northern channel was reduced to half its width by the withdrawal of the shoreline from the northern bluff, leaving a broad terrace which slopes from 220 feet to a little more than 200 feet above sea level, and which is bounded by a minor bluff descending to the channel floor at 195 feet. The emergence of the smaller of the two central islands defined the channels now drained by the Ruisseau la Corne and the Rivière Mascouche. The bluffs bounding the western ends of the two central island terraces descend to 200 feet, as does that to the south of the Mascouche channel. While these bluffs were being formed the depth of water in the channels was uniform over a broad area. The floor of the northern channel lies close to 195 feet above sea level as far east as La Plaine, a condition which aided the accumulation of peat. The intake of the central channel

is at the same elevation, and the same surface extends in the southern channel as far east as Le Page. At this point, however, the 195-foot surface remains only in the centre of the channel floor. The margins have been cut down to 186 feet above sea level, possibly in response to concentration of currents on either side of small gravel islands to the east where the Ste. Thérèse ridge projects into the channel.

East of Le Page the floor of the southern channel descends to an elevation of 160 feet at the confluence with the Ruisseau la Corne; a similar gradient of 10 feet per mile occurs in the channel followed by the latter stream. The floor of the St. Pierre channel descends likewise to its confluence with the Mascouche channel, but with a lesser gradient. These sloping sections of the floors of the channels must have been formed before emergence, for only minor streams developed on the 195-foot flats and they were inadequate to have produced broad smooth slopes across the whole width of the channels. Osborne and Clark (1960) comment, for example, on the anastomosing pattern of minor stream courses in the St. Pierre channel in the vicinity of La Plaine.

At its confluence with the Ruisseau la Corne the Riviere Mascouche is diverted away from the southern margin of its channel by the Ste. Thérèse ridge (Figure 39) and from that point eastward flows in a narrow trench the floor of which is close to 160 feet until it widens out to a flat at the same elevation at the eastern margin of the sand plain. A similar inner trench extends into the St. Pierre channel (Figure 40d). These trenches, like the broader channels at higher elevations, appear to have been of estuarine origin, for the floors are U-shaped rather than flat, and there was in any case no stream of a size sufficient to have formed them. The bluffs at the margins of the 160-foot channels were cut

when water level stood at about 165 feet above present sea level, a stage which may be correlated with bluffs at similar elevations in the area of the Lake of the Two Mountains. A relative still-stand intervened between this stage and the earlier 195-200 foot stage. Terraces and bluffs at 170-185 feet lie on either side of the Mascouche channel east of the Ste. Thérèse ridge, and may be traced into the St. Pierre channel (Figure 40c). These features were probably formed at the same time as those at 175 feet above sea level in the basin of the Lake of the Two Mountains.

The actual courses followed by the present streams across the floors of the channels show one common factor. The Rivière Mascouche for much of its length, the Ruisseau la Corne and the headwaters of the Rivière St. Pierre all flow close to the southern margins of the channels which they follow. The possibility of differential uplift as the causative factor at once suggests itself, and there is no doubt that tilting was still operative during the early stages of the emergence of the sand plain. Support for this hypothesis is found in the decrease in erosive activity in the northern branch channel and the corresponding increase of erosion in the southern channel while the water level fell from 220 feet to 200 feet. However, other factors cannot be entirely excluded. Marginal depressions occur on both sides of the Mascouche channel at Le Page, and the river may have been directed into the more southerly by the form of the floor upstream, which had been moulded by the southeasterly current emerging from the North River channel. Such factors cannot, however, be invoked to account for the southerly positions of the other streams, and differential uplift must remain as at least a contributory factor.

The evolution of the Grand C[^]ôteau merits some consideration. Goldthwait (1933) suggested that the bluff was river-cut, but its sloping

base is simply a reflection of the general slope of the till surface underlying the marine sediments which are exposed in its face. The shoreline retreated from the bluff in sequence from west to east, and stages in its formation may be linked with those within the sand plain. At its western extremity it truncates the St. Janvier channel at 207 feet above sea level. The bluff here is only about ten feet high and may not be referable to either of the major stages represented in the sand plain by bluffs at 215-225 feet and 200 feet above sea level. When the shoreline stood at the 207-foot bluff, however, a line of morainic islands continued the trend of the Ste. Thérèse gravel ridge toward Oka Mountain. The islands increased in area as the shoreline withdrew to 195 feet, a stage which is marked by a small section of the Grand Côtéau bluff and by features at 200 feet above sea level in the sand plain (Figure 40b). Further withdrawal to about 175 feet reduced the width of water between the islands and the Grand Côtéau to a narrow channel, drained now by the Rivière aux Chiens (Figure 40c). The section of the foot of the Grand Côtéau at 175 feet above sea level may be correlated with features at similar elevations in the sand plain and with features at 170-180 feet in the lower Ottawa valley. As emergence continued the channels between the morainic islands were abandoned, and the sea was in contact with the Grand Côtéau only to the east of the Ste. Thérèse ridge. Water-cut features along the Grand Côtéau which could have been correlated with the 165-foot bluffs within the sand plain have been destroyed by subsequent erosion, and east of the town of Ste. Thérèse the bluff foot is below an elevation of 150 feet. These later stages can more appropriately be discussed in connection with the Montreal area as a whole.

It is unlikely that the Grand Côtéau bluff resulted from any

extensive back-wearing of the margin of the island terrace which it borders. The outline of the island terrace is of the typical modified aerofoil form of such features, and if the deposition resulted from the presence of the Ste. Thérèse gravel ridge, it could well be expected to have extended little beyond the end of the ridge. The slight embayments on either side of the ridge near Ste. Thérèse may indicate the total amount of back-wearing which has occurred.

3. THE LAKE ST. FRANCIS BASIN AND THE LOWER CHATEAUGUAY VALLEY

a. Topography and present drainage pattern

Between Rigaud Mountain and Covey Hill there extends an almost undissected plain diversified by till ridges which have the dominant west-southwesterly trend of the Malone glaciation. Lake St. Francis, an expansion of the St. Lawrence River, lies with the same trend across the centre of the sub-region (Figure 27). The lake extends from Cornwall to Côteau Rapids, a distance of about 30 miles, and attains a maximum width of more than four miles. Its existence results from the accident of the superimposition of the St. Lawrence River upon a bedrock high at Valleyfield (Figure 3). The river drains from the lake down the eastern slope of the bedrock high, falling from the lake level of 151 feet above sea level,¹ to Lake St. Louis at an elevation of 69 feet, in a distance of 12 miles, mainly in the Côteau, Cedars and Cascades rapids.

A number of streams, chief among them the rivers au Baudet and Delisle, drain the triangular plain north of Lake St. Francis. The upper reaches of these streams lie within the area of till which bounds the

¹The lake is artificially maintained at a level of 154 feet by sluices above the Côteau Rapids.

plain on the west, and here their courses are controlled by the glacial trend. Their courses across the plain are southeasterly, with the slope of the clay surface. This slope is not uniform, however. The area south of Rigaud Mountain is drained northward by the headwaters of the Rivière Raquette, and since there is no evidence of the extension of this drainage basin by capture, there must have been an original northward slope in this area. The lower course of the Rivière au Baudet is influenced by a partially buried and wave-spread esker or crevasse filling which may be traced for 8 miles in a southeasterly direction, terminating at Pointe au Baudet on Lake St. Francis (Figure 7). The river breaks through the ridge about 3 miles inland from Pointe au Baudet, and the lowest reach flows along the eastern side of the ridge.

The area south of Lake St. Francis consists largely of the basin of the lower Châteauguay River, and only a limited area drains directly into the lake. A massive compound till ridge, rising to more than 250 feet above sea level, forms the divide between the St. Lawrence and Châteauguay drainage. The till area incorporates an area of horizontally bedded sand and gravel northwest of Ste. Agnès; from the sand area there extends to the south and southwest a conspicuous sand and gravel ridge, rising 50 feet and more above the plain. It is significant that the ridge continues the trend of that which controls the course of the Rivière au Baudet north of Lake St. Francis (Figure 7). The general southerly trend of the ridge suggests its deposition within or beneath the Fort Covington ice, yet it is closely associated with a mass of till with a direction of moulding attributable to the earlier Malone glaciation. It may be suggested that the sand and gravel of the ridge and the more extensive area of bedded material from which it extends were deposited during the later

glaciation, filling a gap in the till mass deposited during the earlier Malone episode.

Lower, more isolated till mounds rise through the clay close to the lake. The intervening depressions are drained by tributaries of Rivière à la Guerre, or are occupied by the extensive Large and Small Tea Field bogs. The Rivière St. Louis, now paralleled by the Beauharnois Canal, rises between till ridges at the eastern end of the lake. The river descends below the 150-foot contour within two miles of the lake, and this elevation appears to be that of the original surface of the plain. The divide between the Rivière St. Louis and Lake St. Francis is only a few feet above the level of the lake; indeed, a small feeder canal leads from the lake into the river. It is understandable that a course close to the Riviere St. Louis was selected for the Beauharnois Canal. Had the elevation of the bedrock sill of Lake St. Francis been only a few feet higher the lake water would have spilled naturally eastward to follow the course chosen for the canal. The level of the lake cannot be allowed to rise, therefore, more than a few feet above its natural level.

The Châteauguay River rises in the Adirondack upland of New York State, and flows in a general northwestward direction, descending rapidly through the belts of marine shorelines and till which flank the upland to enter the lowland south of Huntingdon. Below Huntingdon the river changes direction to flow northeastward along a clay-floored depression which lies between the main mass of till and the Adirondack slopes. The drainage of the western part of the depression is carried into the Châteauguay system by Trout River and Beaver Brook. These streams are but little incised within the floor of the depression, which, unlike the channels of the lower Ottawa valley, bears no evidence of erosion by a former large stream.

Below Huntingdon the Châteauguay River is more deeply incised, reaching bedrock locally, and slip-off terraces ("basses platières" or "terres de pointe": Baril et Mailloux, 1950) may be seen within meanders. The terraces are of restricted development, and their development was more probably in response to a local bedrock base level than of cyclic significance.

Low till ridges with the Malone trend project through the clay of the Châteauguay depression. A line of such ridges forms a minor divide along the centre of the depression east of Huntingdon. The Châteauguay River drains the northern part of the depression here, while the southern part is drained by the west branch of the Rivière aux Outardes.

Tributaries of the Rivière aux Outardes drain an area of the Adirondack slope extending as far east as the intake of the Covey Hill gap. The most easterly tributary, the east branch of the Rivière aux Outardes, was deflected obliquely westward down the slope by the Fort Covington moraine (MacClintock and Terasmae, 1960), and would normally have drained into the English River system. The headwaters of the English River, draining the eastern section of the Adirondack slope, form a fan-like pattern similar to those of the Rivière aux Outardes. Within the lowland the divide between the two systems is formed by a low plateau of Potsdam sandstone ("le Rocher": Baril et Mailloux, 1950), glacially scoured, and only thinly and locally veneered with till. Within this area Elson (1962) records crescentic glacial fractures and striae with the southwesterly Malone trend, and also with a trend almost due west. This westerly trend is not recorded elsewhere in the lowland and may result from a deflection of the lower layers of ice along the Adirondack flanks. Such deflection may account in part for the scarcity of glacial deposits upon the plateau.

In addition, its greater initial elevation would have rendered the plateau more vulnerable to glacial erosion than the surrounding lowland. Much of its surface lies between elevations of 225 and 250 feet, while the buried bedrock surface to the north lies less than 100 feet above sea level. The bedrock surface declines more gently in an easterly direction, and has impeded downcutting by tributaries of the English River. Artificial deepening of stream beds has been undertaken in a number of places in an attempt to improve the drainage.

Just above the confluence of the Châteauguay and English rivers the main stream makes the first of two right-angled bends, the second of which occurs at the confluence. An abandoned channel with bedrock exposed in its floor extends northeastward from the upper elbow, and Elson (1962) ascribes these features to capture of the Châteauguay River by a gully tributary to the English River.

Below the former confluence of the Châteauguay and English rivers the eastern side of the Châteauguay valley is formed by the Ste. Philomène gravel ridge (Figure 7), although a tributary, the Sturgeon River, rises east of the ridge and breaks through it to flow southward along its western side. The soils map of Châteauguay County (Baril et Mailloux, 1950) indicates that the ridge extends as far as Howick, but that it is here almost entirely buried by marine clay.

Above Châteauguay the river turns northwestward to cross a belt of till, the western extremity of the mass which underlies the Caughnawaga Indian Reserve. At the angle of the river above Châteauguay a tributary enters from the northeast, draining a channel which may be traced across the Reserve and whose northeastern end drains into the St. Lawrence River above the Lachine Rapids. The channel overlies a drift-filled valley

noted by Freeze (1964) (Figure 4) and it appears to have carried Châteauguay water into the St. Lawrence for a time. The angle above Châteauguay may indicate that the river was captured by a gully eroding back from the shore of Lake St. Louis across the narrow till belt, or that both channels functioned simultaneously until the eastern branch was abandoned owing to the greater difficulty of downcutting through the more extensive reach on till. This channel appears to have been the last to function of a series of less well-defined depressions between the till ridges of the Caughnawaga area.

The present mouth of the Châteauguay River is a delta, its surface at about 75 feet above sea level. The absence of traces of a delta at higher elevations is evidence rather of the temporary nature of earlier stages, than of the date of the change in the river's course. Evidence of higher water levels is however found west of the delta where shorelines at about 85 feet and at the lower and upper Montreal levels may be traced as far as the Cascades Rapids.

b. Stages in the emergence

The 100-foot and lower bluffs are the only useful evidence in this extensive sub-region of definite stages in the evolution of the drainage pattern applicable to the lowland as a whole. Elsewhere the clay plain bears no traces of shorelines, and its surface, presumably the original depositional surface, is dissected only by the valleys of the present streams. No continuous bluffs exist to provide clear evidence of earlier stages of Lake St. Francis, in contrast to the abundant evidence around the Lake of the Two Mountains. The shoreline of the present lake is varied, particularly on the north, while the southern shore is composed of till

outcrops alternating with areas of swamp; bluffs at the present shoreline are very rare. Shortly before the lake came to occupy its present limits the basin of the Large Tea Field Bog emerged and paludification began. The basal sediments of this bog date from pollen zone IV (Chapter III), or about 8,000 years B.P.. It is probable, then, that the lake has washed against its present shores for the greater part of post-glacial time. If conditions are such as to have inhibited the formation of bluffs during this prolonged period, it is hardly surprising that no bluffs occur at the temporary shorelines at higher elevations. The absence of well-defined bluffs above the present lake level may also be in part attributable to the fact that at the time the lake was isolated by the emergence of its sill the outflow from Lake Barlow-Ojibway was carried through the Ottawa valley, and it was not until 3,200 B.P. that the St. Lawrence River carried the drainage of all the Great Lakes (Farrand, 1962, and Chapter III).

The only evidence of a distinct earlier stage in the evolution of Lake St. Francis is a shallow deposit of sandy loam overlying the marine clay at elevations generally below 165 feet north of the lake (Lajoie and Stobbe, 1950), and of deposits said to be lacustrine at elevations below 155 feet south of the lake (Mailloux et Godbout, 1954). On both sides of the lake the eastern limit of the alluvial deposit lies in the vicinity of Coteau Rapids; it may be that the deposit marks an initial stage of the lake before downcutting at the rapids. It may, however, simply represent the final stage of the shallowing of the estuary before the emergence of the rapids. The absence of the deposit east of the rapids indicates that it does not represent a widespread stage in the lowland. Palynological evidence suggests that the lake was isolated at about the time of the 175-foot stage in the lower Ottawa valley. From the evidence of the elevation

of the alluvium which was deposited before the lake was confined within its present shores it appears that the former water level has been tilted up to the north at a rate comparable with that of the 175-foot shoreline in the lower Ottawa valley, although owing to the nature of the evidence a precise figure for the rate of tilting cannot be given. The effect of differential uplift upon the shoreline of the lake has been flooding and the consequent formation of swamps in the southwestern part of the basin.

The till ridges and the more local sandy slopes which rise above the surface of the marine and lacustrine deposits are ribbed with shoreline features, some of which are visible on the ground, and which are very conspicuous on aerial photographs (Figure 41). The shorelines extend down to the level of the plain, and probably indicate rapid uplift at least until the sea floor in the area emerged. It must be borne in mind, however, that till ridges are less susceptible to wave action than slopes in clay, and that a relatively narrow wave-cut bench in till may represent a longer period of relative stability of water level than a feature of larger size cut in clay. However, if the tilts calculated for the Ottawa valley are extrapolated, the Rigaud shoreline would lie at an elevation of about 170 feet at Cornwall, and it is perhaps significant that a well-marked shoreline terrace has been measured at several places on the Huntingdon till ridge at elevations between 171 and 175 feet.

4. THE MONTREAL ARCHIPELAGO AND ADJACENT AREAS

a. General description

The summit of Mount Royal, at 759 feet above present sea level, formed an island above the highest level of the Champlain Sea. On the other hand, the mean elevation of the water level in Montreal Harbour, 22



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Figure 41. Shoreline features south of Lake St. Francis

feet above sea level, is as low as any of the abandoned shoreline features within the area of this study. Thus it should be possible to find on Montreal Island and the adjacent islands traces of all stages of the emergence of the land from the sea. For a number of reasons, however, the evidence is not as clear as might be expected.

The islands of the Montreal archipelago lie on the eastern flank of the Oka-Beauharnois axis, almost entirely within outcrops of limestone. Only the northern tips of Ile Jésus and Montreal Island, and a narrow strip on the east side of Montreal Island are underlain with more easily erodible shale (Figure 2). The islands are separated from each other, and from the mainland to the north, by channels which discharge Ottawa water from the Lake of the Two Mountains (Figure 27). Bedrock sills hold the lake water at a mean elevation of 73 feet, and create rapids at the heads of the channels. The two northern channels, the Rivière des Mille Isles and the Rivière des Prairies, which lie on either side of Ile Jésus, have further rapids associated with the descent from limestone to shale. These streams unite to enter the St. Lawrence River at the northern tip of Montreal Island, at an elevation of 15 feet. The remainder of the Ottawa water discharges through rapids on either side of Ile Perrot, to mingle with the St. Lawrence River in Lake St. Louis, at 69 feet above sea level. Lake St. Louis lies between the long series of rapids through which the St. Lawrence River descends from Lake St. Francis, and the Lachine Rapids, where the river crosses the Delson Fault and descends from limestone to shale. The Laprairie Basin, at about 30 feet above sea level, lies at the foot of the Lachine Rapids; the river discharges from the basin through minor rapids caused by an outcrop of intrusive rocks in the bed near the head of Montreal Harbour. From the harbour downstream the river follows a

preglacial valley cut in the outcrop of the Utica shale. The headward extension of this preglacial valley may be traced along the line of the Rivière St. Pierre (Figure 4), supporting the view put forward by Stansfield (1915). The valley has been partly re-excavated by a branch of the St. Lawrence River since the withdrawal of the Champlain Sea.

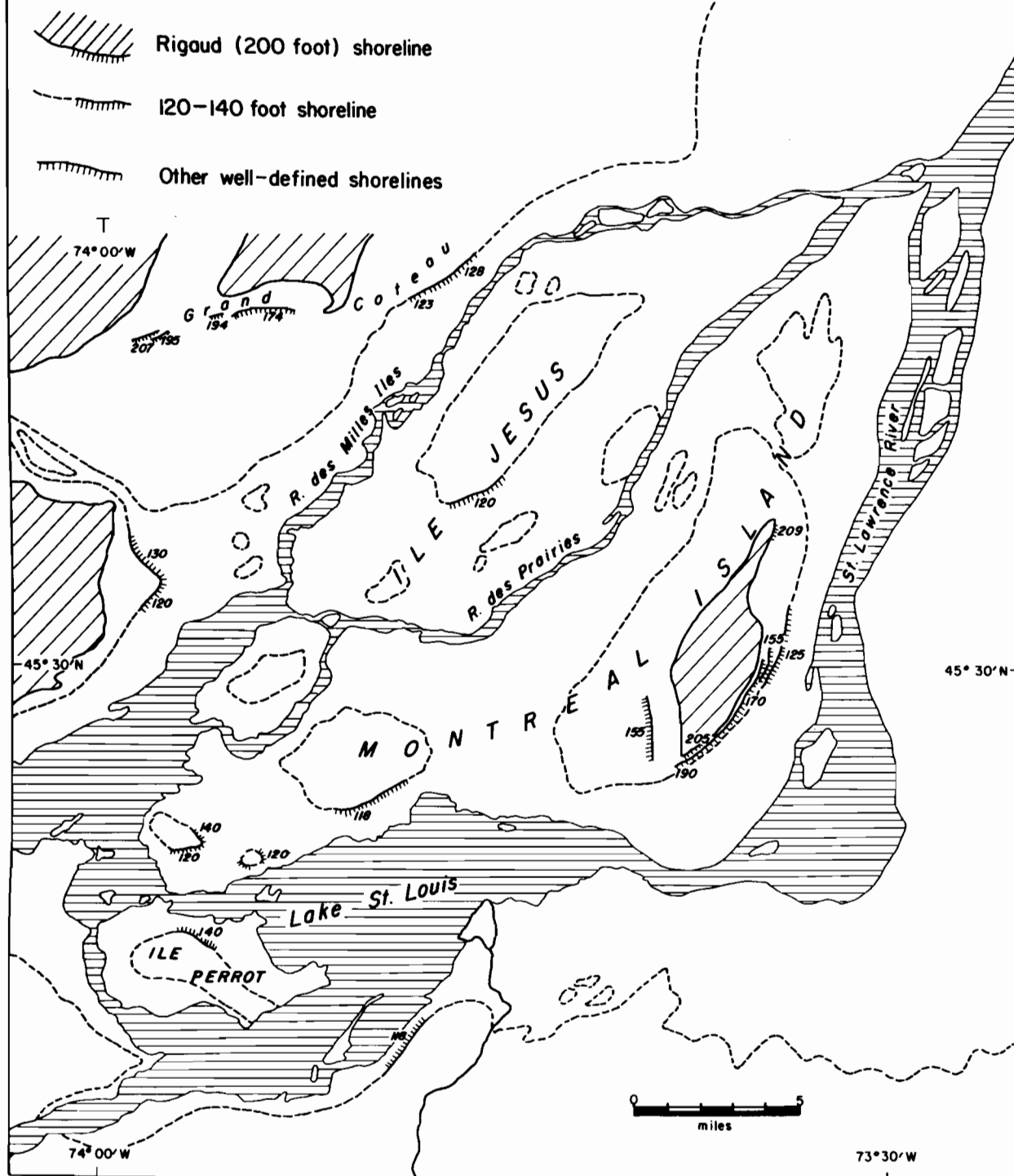
The limestone spine of Montreal Island, extending northeast from Mount Royal, and rising to more than 150 feet above sea level, is a high point on the bedrock surface (Figure 4). Equivalent elevations in bedrock are found to the northwest only on Ile Jésus, and close to the margin of the Shield, while to the east the surface of the younger and less resistant shales along the structural axis of the lowland has been eroded to much lower elevations. Indeed, with the exception of the residual masses of the Monteregian Hills, it is only at Logan's Line that the bedrock surface rises to greater heights. It is probable, therefore, that the Montreal archipelago received thinner deposits of marine bottom sediments than the basins to either side. Marine deposits were, however, undoubtedly more extensive than the present limited outcrops; there are, for example, isolated plateaux of marine sediments, surrounded by erosional bluffs, at the western end of Montreal Island. It may be suggested that as the spine of the island began to emerge, it was scoured of its veneer of loose sediments by wave action, and that both wave action and estuarine currents were effective agents of erosion as the emergence progressed. The suggestion of Lajoie and Baril (1954) that the absence of marine clay over much of the archipelago can be attributed to erosive action by the early Ottawa and St. Lawrence rivers cannot be supported: truly fluvial conditions were not established until the separation of the Lake of the Two Mountains from the estuary at a relatively late stage in the emergence.

b. Stages in the emergence

The stripped surfaces of till and bedrock which cover the greater part of the islands have not been amenable to the formation of bluffs, so that well-defined and continuous shorelines occur principally within the limited areas where marine clay still remains, especially on the eastern slopes of Mount Royal. Stansfield (1915) and Byers (1933) have listed beaches and terraces throughout the possible range of elevation; not all their sites can be identified, and reference to the 10-foot contours of the 1:25,000 map and to the 5-foot contours of the 1:18,000 map suggests that the elevations they give are only approximate. Goldthwait (1933) was more particularly concerned with the evidence of 210-foot and 110-foot stages, mentioning specific sites whose elevations can be more or less confirmed from the published topographic surveys.

The evidence of Goldthwait's 210-foot stage occurs only locally. He found a beach at Rosemont Boulevard and Mont St. Michel Boulevard, northeast of Mount Royal, at an elevation of 209-216 feet, and another at Sherbrooke St. and Walkley Road, at 214 feet (from the map, about 205 feet) above sea level. The latter beach is associated with a distinct flattening of the tail of drift projecting southwestward from Mount Royal (Figure 42); elsewhere at the 200-foot level bedrock is close to the surface and wave action could have had little effect. Above the 200-foot flat on the drift tail, flats backed by bluffs occur at about 220, 240, and 260 feet above sea level. At lower elevations in the same area there are flats at about 190 and 170 feet, and a well-marked west-facing bluff has its foot at 155-160 feet above sea level. Reference to Figure 11 suggests that the features at about 200 feet above sea level are to be correlated with the Rigaud shoreline at the same elevation in the basin of the

**FIG.42 THE MONTREAL ARCHIPELAGO:
SHORELINES ABOVE THE MONTREAL PLANE**



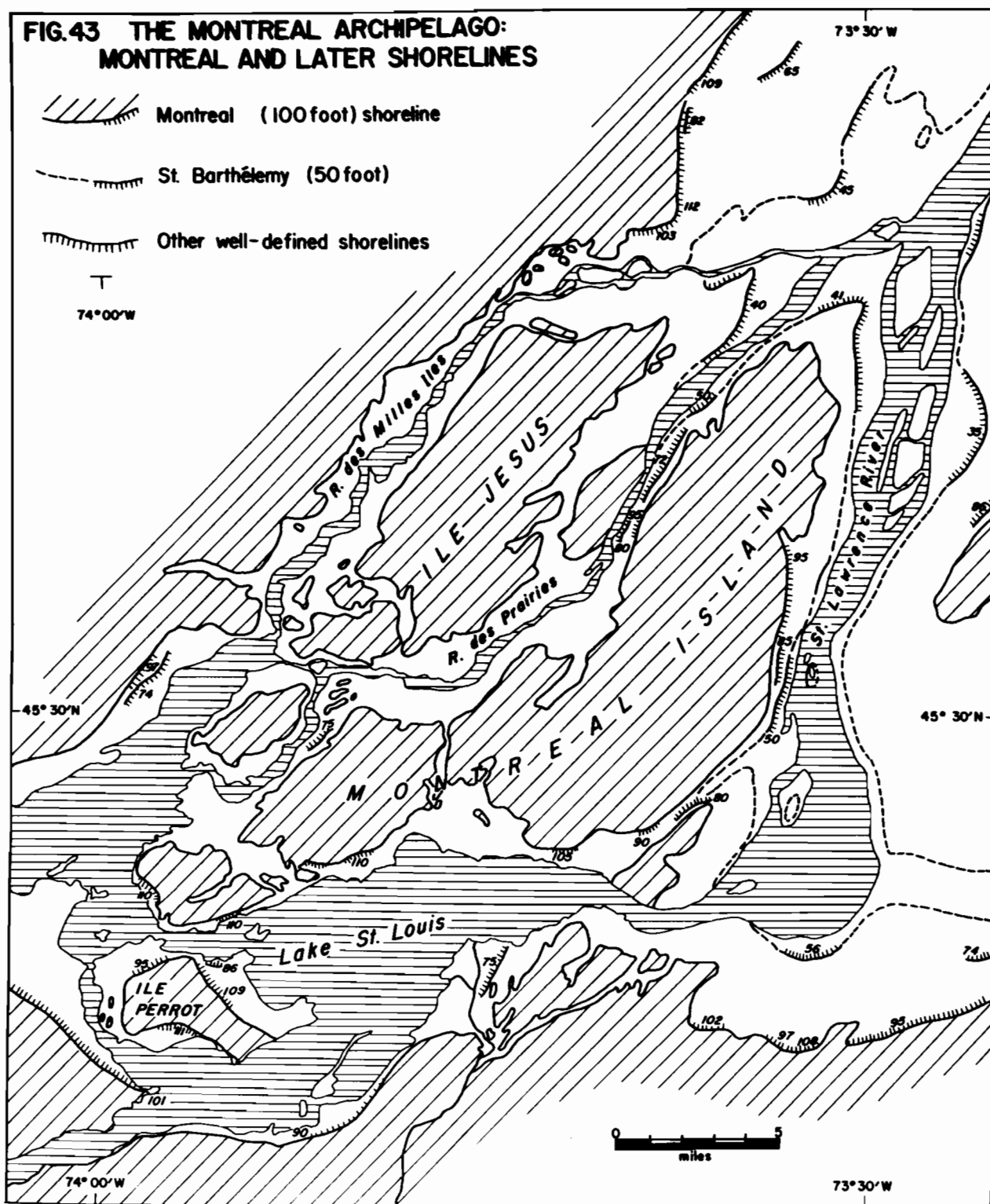
Lake of the Two Mountains, and with features at about 220 feet in the Terrebonne sand plain.

The stages which intervene on Montreal Island between the Rigaud and Montreal (100-foot) levels may be correlated with similar stages in the lower Ottawa valley. The flat at 170 feet southwest of Mount Royal merges to the northeast with what appears to be a depositional surface below the steep slope of the mountain, well developed, for example, in the vicinity of Côte des Neiges and Sherbrooke Street; it probably represents the same stage as the 175-foot bluff in the basin of the Lake of the Two Mountains. The 155-160 foot bluff reappears below St. Catherine Street west of Atwater Avenue and may be traced northeastward as an erosional feature until it merges with the slope of the mountain behind the campus of McGill University. The surface on which the campus lies continues northeastward as a shelf, largely developed in marine clay, flanking the spine of the island. Sherbrooke Street follows its outer edge as far as Molson's Creek. Below Sherbrooke Street there is a drop to another shoreline at about 125 feet above sea level. This shoreline is well developed near the McGill campus, but to the northeast it is represented only by a narrow shelf in the bluff which descends to the 100-foot shoreline. At the west end of Montreal Island, also, shorelines at between 120 and 130 feet above sea level have been preserved, for example around the plateaux of marine sediments at Senneville and Baie d'Urfé. The 125-foot shoreline is to be correlated with that at a similar elevation around the Lake of the Two Mountains. It is probable that the 155-160 foot shoreline is the correlative of the 165-foot shoreline in the St. Hermas basin.

When the sea stood at the 200-foot level, the Montreal archipelago was represented by only one island. As the emergence continued summits

much lower than Mount Royal broke the surface, and at the 100-foot stage the archipelago consisted of numerous islands of various sizes (Figure 43). The number of islands decreased again after the 100-foot stage, as the straits between them became dry. There is little direct evidence of the shorelines of these former straits; wave propagation was hindered by the closely spaced islands, and wave action, which appears to have stripped the marine sediments from the crests of the islands during their emergence, had little effect upon the underlying till. With few exceptions it is the slopes leading down to present channels which provide evidence of relative stands of water level. Although it does not appear profitable to describe in detail the development of the archipelago at each stage in the emergence from the 200-foot level, the evidence of the 100-foot or Montreal stage is so widespread in the lowland that it will be given some consideration.

At the Montreal stage the archipelago had begun to assume its present outlines. The channels through which Ottawa water now drains from the Lake of the Two Mountains lay as straits between islands or groups of islands. Those on either side of Ile Perrot had shores which were bluffed in part, and the trend of the bluffs on Ile Perrot itself is significant. They bound a low plateau of marine sediments which extends southeastward from a higher till and bedrock area in the west central part of the island. The preservation of the marine sediments in this location indicates that the higher more resistant area may have protected them from erosion by currents sweeping through the straits, and suggests that until this stage the discharge of the Ottawa River was greater than that of the St. Lawrence River. Following the 100-foot stage the shoreline withdrew from the bluffs, except near Fortier Point at the southern end of the island, while on the side facing the St. Lawrence channel the marine sediments were truncated



by a bluff which descends to the present water level. A reversal of the relative power of the Ottawa and St. Lawrence is thus indicated following the 100-foot stage. It is possible that Lake Barlow-Ojibway still contributed to the discharge of the Ottawa River at the 100-foot stage, 7,500 B.P. (Chapter III); it was not until about 3,200 B.P. that the St. Lawrence River began to carry the drainage of all the Great Lakes (Farrand, 1962).

As the present shores of Lake St. Louis extend from the foot of Cedars Rapids and close in toward the Lachine Rapids, so did the shoreline of the Montreal stage, and bluffs around the lake lie at measured elevations of between 90 and 111 feet. East of the later site of the Lachine Rapids the water body opened out, and its southern shoreline lay along the Laprairie-Chambly bluff, to be discussed in Chapter V. The valley of the Rivière St. Pierre functioned as a strait at this time, leading northeastward from above the site of the Lachine Rapids. Its northern shoreline continues as the well-developed bluff below Sherbrooke Street in the eastern part of the City of Montreal.

At the Montreal stage the Rivière des Prairies was represented by a strait leading from the expanse of water in the lower Ottawa valley to the open estuary northeast of the archipelago. Ile Bizard lay across the entrance to the strait while in its central section an island, now part of Ile Jésus, lay between the sites of Pont Viau and St. Vincent de Paul.

The shores of the strait which was to develop into the Rivière des Milles Iles were very irregular, a characteristic which persists to the present. Many small morainic hills projected as promontories or formed islands. North of the belt of morainic country there rose the Grand Coteau, the bluff bounding the Terrebonne sand plain. At the 100-foot stage the bluff merged with the shore of the strait at its eastern end, diverging

from it to the west where the elevation of the bluff foot lay at higher elevations.

The Montreal stage was followed by a stage at 85 feet, evidence of which is found where the Grand C[^]oteau swings northward to truncate the eastern end of the Terrebonne sand plain; near the Riviere Mascouche the bluff foot descends to an elevation of 82 feet. Evidence of the same stage is found south of Lake St. Louis and also on the Montreal archipelago, for example in a bluff at about 85 feet above sea level which extends north-eastward from the intersection of Bleury Street and Dorchester Boulevard. Traces of a 75-foot stage also occur, and may be found as far to the west as the slopes of Oka Mountain. Later 65-foot, 55-foot and 40-45 foot stages are also represented on the archipelago by discontinuous bluffs.

As the shoreline withdrew from the 85-foot level the Pont Viau-St. Vincent de Paul channel on Ile J[^]esus was abandoned. The St. Pierre channel on Montreal Island remained in operation, for the sill which separates it from Lake St. Louis lies at 73 feet above sea level, four feet above the present level of the lake (Figure 44). It is possible that the channel continued to discharge St. Lawrence water even after the 75-foot stage; if Lake St. Louis were held at the 75-foot level as the sea withdrew, its outflow would have been carried by both the Lachine Rapids and the St. Pierre channel for a time. This would explain the removal of much unconsolidated material from the channel and the erosion of its floor to an elevation of below 50 feet at little more than three miles from the sill. Bluffs descend to an elevation of 60 feet in the channel, and it may be that the last of the St. Lawrence water to pass through the channel entered an estuary at this level. Bedrock geology provides an explanation of the suggested capture of the whole of the flow of the river by the

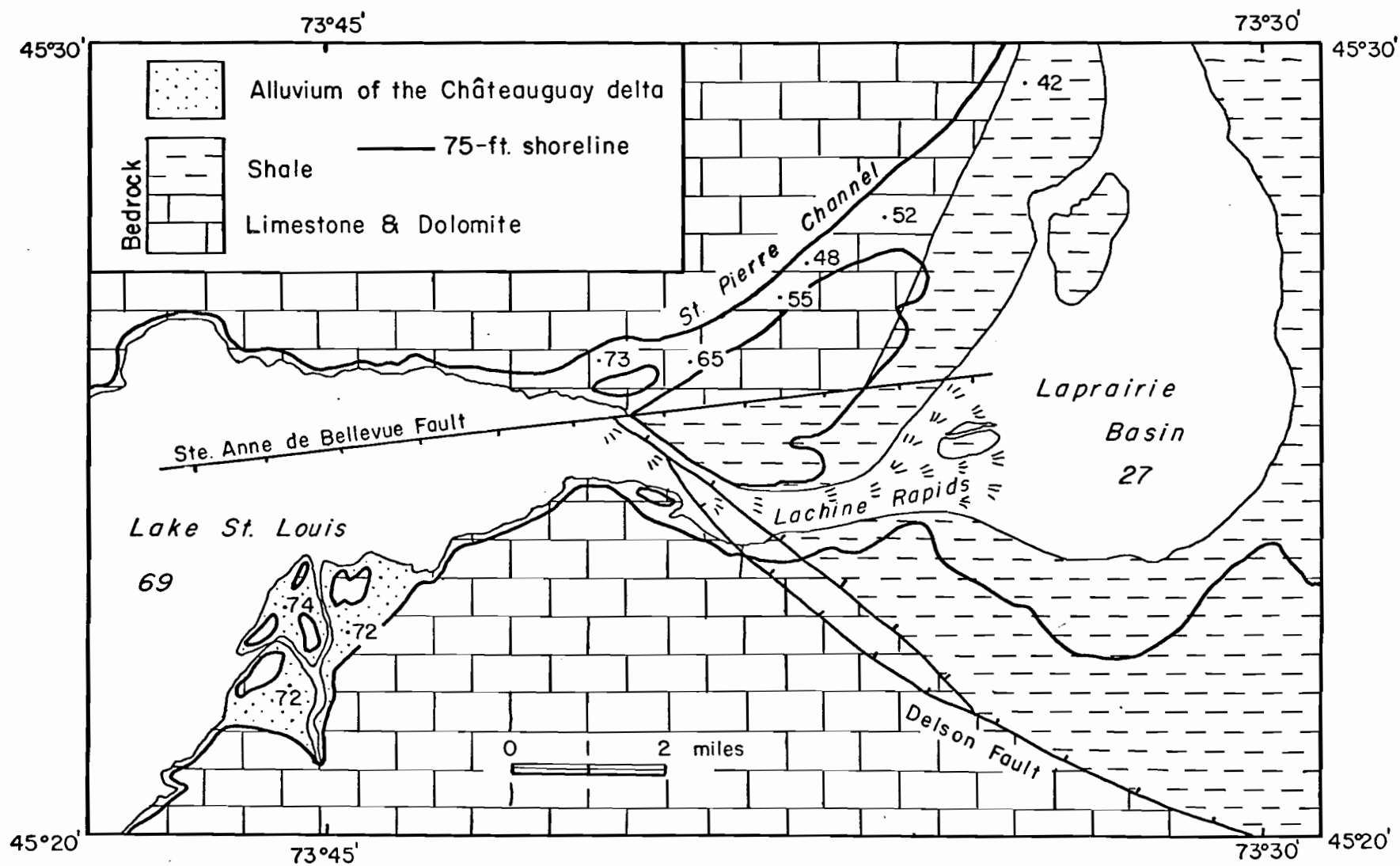


Figure 44. The relationship of the St. Pierre channel and the Lachine Rapids

Lachine Rapids, for the St. Pierre channel is underlain by relatively resistant Trenton limestone, whereas the lower section of the rapids is cut in Utica shale which would have facilitated downcutting.

This hypothesis carries with it two interesting corollaries. The Chateauguay River enters Lake St. Louis through a delta whose surface is about 75 feet above sea level. If Lake St. Louis were held in by bedrock sills after the sea withdrew from this level, the delta would have had for its formation not only the limited time of the 75-foot stage, but the considerably longer period during which the Lachine Rapids were being eroded, before the lake fell to its present level. Secondly, a lake at 75 feet in the basin of Lake St. Louis would have been continuous with a lake at the same elevation in the basin of the Lake of the Two Mountains. The rapids on either side of Ile Perrot would have been initiated only as the level of Lake St. Louis fell. Following this argument it may be predicted that the sequence of events will be repeated when one of the rapids at Ile Perrot lowers the sill and allows the level of the Lake of the Two Mountains to fall. The other Ile Perrot rapid will be abandoned, as will the Rivière des Milles Iles and the Rivière des Prairies; the Montreal archipelago will then become part of the mainland to the north.

CHAPTER V

The development of the drainage pattern of the eastern Montreal lowland

1. THE UPPER RICHELIEU VALLEY AND ADJACENT AREAS

a. Topography and present drainage pattern

The area to be considered in this section lies between the Châteauguay drainage basin and Logan's Line (Figure 45). Within the area structural features and depositional glacial forms combine to impose a north-south lineation upon the drainage pattern. The Richelieu River is the axis of the pattern, but it fulfils only a limited function as a drainage artery of the area, receiving only two significant tributaries, the left-bank Rivière Lacolle and the right-bank South River, between the international boundary and the St. Jean Rapids. The drainage of the remainder of the area is carried northward by a number of streams leading into the lower Richelieu River, the Yamaska River, or directly into the St. Lawrence River, while the Pike River flows southward into Missisquoi Bay, the Canadian arm of Lake Champlain (Figure 46).

The Richelieu River carries the outflow from Lake Champlain. Above the St. Jean Rapids it is, in fact, itself an arm of the lake, having a scarcely perceptible gradient (Profile of Rivière Richelieu, 1928). Below St. Jean it descends 70 feet in a series of rapids to Chambly Basin, crossing the shoreline of the Montreal stage and entering the lower section of its valley. The head of the rapids occurs where the river crosses the Delson Fault (Clark, 1955), a feature which exerts considerable influence in the present landscape. North of the fault river-bank exposures reveal weak Utica and Lorraine shales, while to the south occur the relatively

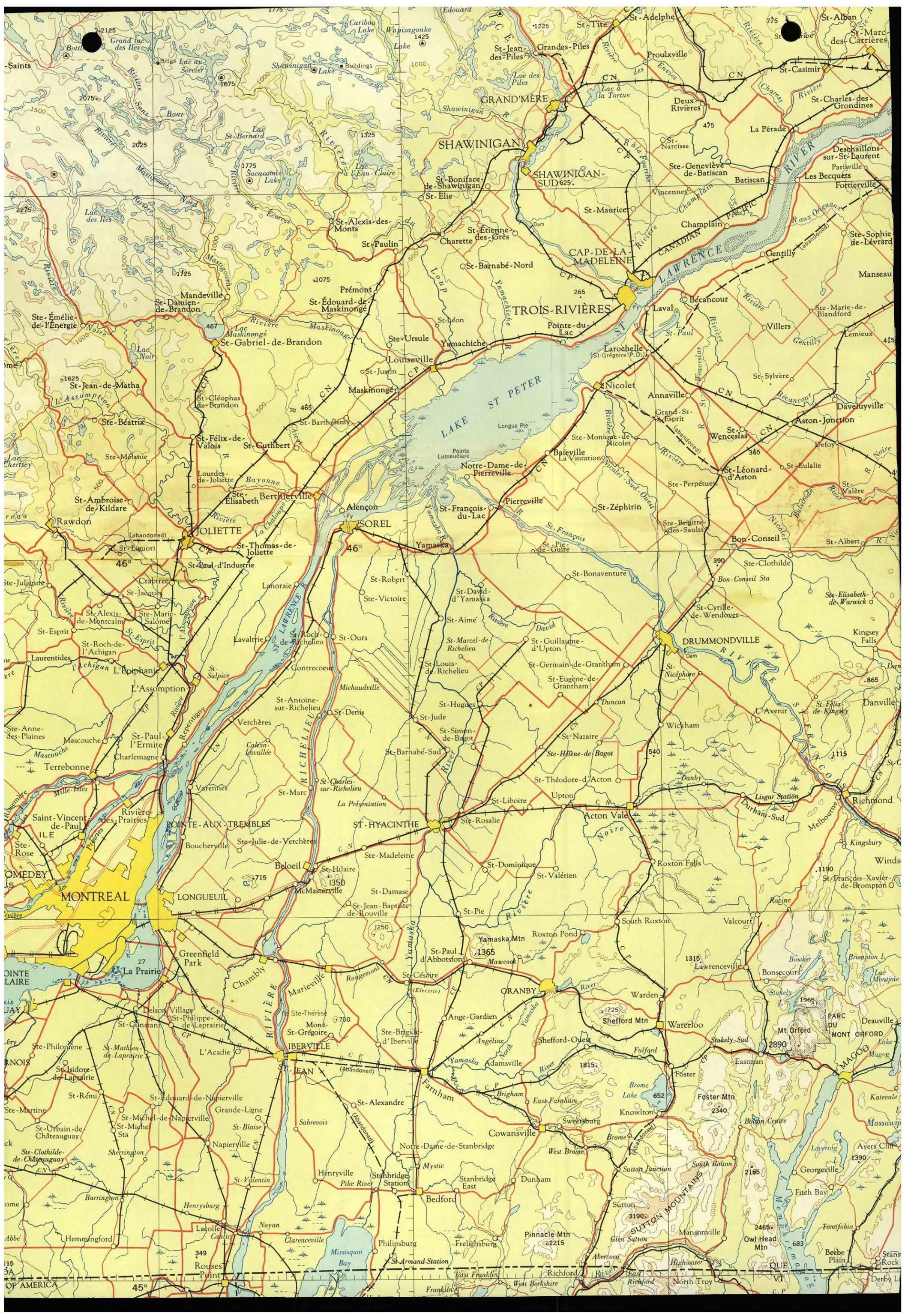
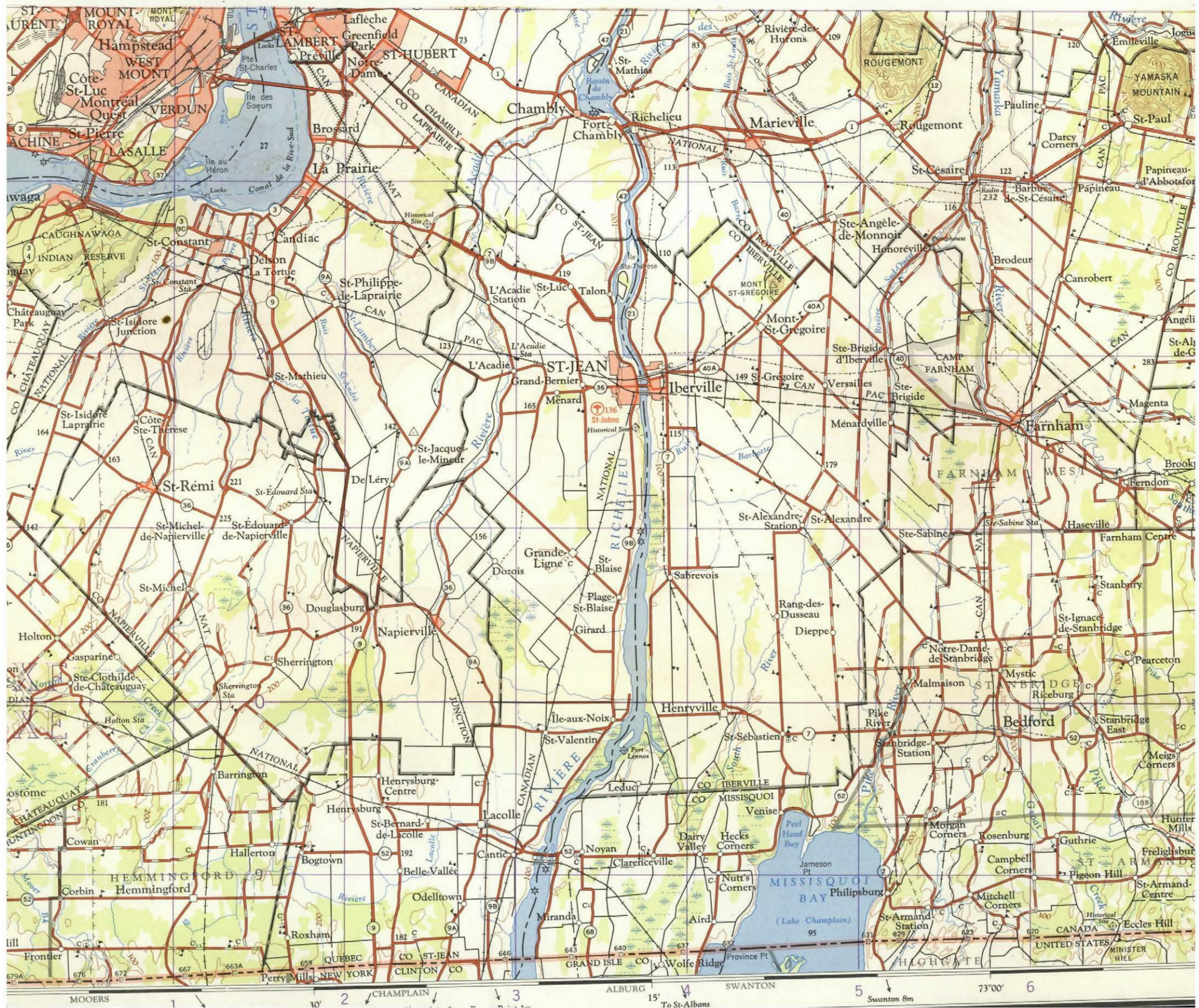


Figure 46. General map of the upper Richelieu valley (from N.T.S. 1:250,000 map, Sheet 31 H)



resistant older sedimentary rocks of the lowland. The surface of the resistant rocks lies at a higher elevation than that of the weaker rocks north of the fault, and provides a higher base for the overlying glacial deposits. Ground moraine which rests upon the bedrock forms much of the surface south of the fault, and descends with the bedrock north of the fault where it is overlain by marine sediments.

The Delson Fault forms the northern limit of the structural trough in which Lake Champlain lies, cutting off the south-southwest trending Tracy Brook Fault which forms the western margin of the trough (Figure 2). The course of the Richelieu River lies close to the line of the Tracy Brook Fault, and the bedrock contours (Freeze, 1964) indicate that it probably follows the structurally controlled trend of a preglacial stream (Figure 4). The eastern limit of the trough is Logan's Line, beyond which lies the Appalachian piedmont. Within the trough the bedrock has been thrown into a series of minor folds, which locally control the detail of the drainage pattern, for example in the area west of Missisquoi Bay. However, the high points within the trough, as in the area to the west, generally occur on masses of till.

The surface on both sides of the Richelieu valley consists of broad, subdued till ridges with a thin cover of marine sediment, diversified by narrow gravel ridges, the origin of which has already been discussed (Chapter II). The depth of the marine sediments is greater in the depressions between the ridges, but is insufficient to fill the depressions completely; there were no large rivers bringing sediment into the Champlain Sea in this vicinity. After emergence lakes occupying some of the depressions were partially filled with sediment brought in by streams of local origin, and were finally eliminated by the process of paludification.

Four major bogs, with surface elevations of between 170 and 200 feet above sea level, occur in such depressions west of the Richelieu River (Figure 46). Two of these lie south of a bedrock-cored, till-capped plateau near St. Remi. The Holton bog drains westward into the Châteauguay system, and the drainage of the smaller Sherrington bog is carried northward to the St. Lawrence River by the Rivière la Tortue. A gravel ridge separates the basin of the Sherrington bog from that of the Napierville bog, which drains northward by the Rivière l'Acadie to the lower Richelieu River. A bog east of the town of Napierville lies in a depression separated from the Richelieu valley by the Grande Ligne gravel ridge, and drains directly to the Richelieu River.

East of the Richelieu River there is one major bog, near Farnham, with a surface elevation of 170-180 feet. The irregular depression in which it lies is a col, draining northward into the Yamaska River, and southward into the Pike River and Missisquoi Bay. The col is bounded to the east by the higher ground of the Appalachian piedmont and to the west by a low till plateau near St. Alexandre.

Numerous streams drain from the till plateau. The southward drainage is carried by the Pike and South rivers, which flow in depressions floored with marine sediments and separated from each other and from the Richelieu River by low till ridges. The lower course of the South River follows a swampy channel, an abandoned marine or lacustrine strait which formerly linked Missisquoi Bay with the Richelieu River channel. The South River channel transects a bedrock ridge and swings through an angle of more than 90° to enter the Richelieu valley from the southeast.

The Pike River rises in the Appalachians, and before entering the lowland flows generally toward the northwest. Within the lowland it swings

to the south to flow into Missisquoi Bay. The same pattern is repeated to the north by the Ruisseau aux Morpions, a tributary of the Pike River. The northwesterly trend of the lowest Appalachian reaches of these streams suggests that they were tributary to a north-flowing stream in the lowland, of which the Yamaska River is the successor. The depression in which the Farnham bog occurs may lie over the buried valley of this stream.

Northward drainage from the St. Alexandre till plateau is carried to the Yamaska and Richelieu systems by the Rivière Sud-Ouest and the Ruisseau St. Louis respectively. The divide between these two streams lies in a belt of sandy soil, which forms a thin veneer over bedrock and extends between Mount Johnson and Rougemont. The St. Louis-Richelieu divide lies along an almost buried till ridge, a northward extension of the till plateau. The Ruisseau Barbotte drains westward from the till area directly to the Richelieu River; the lower course of the stream is controlled by a north-south trending gravel ridge (Figure 47). The ridge is parallel to the Grande Ligne ridge west of the Richelieu River, and both function as local base levels or as dams for the weaker deposits held behind them. Thus they are insignificant features of the landscape when looking toward the Richelieu River, but appear as bluffs bounding the valley when seen from the river.

b. Stages in the emergence

While in many places the clay slopes bordering the Richelieu River roll over smoothly, or decline very gently to the water level, a bluff, its foot at measured elevations of from 99 to 107 feet, is locally conspicuous, especially immediately to the north of the international boundary. Traces of a bluff at the same elevation are also found along the river



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Figure 47. Control of the Ruisseau Barbotte by a partially-buried gravel ridge

north of the sill at the head of the St. Jean Rapids, and it may well be that these watermarks were all formed at the shoreline of the 100-foot or Montreal water body. On the other hand, the bluff south of the rock sill may have been formed at the shoreline of Lake Champlain after the first emergence of the sill. The present elevation of the sill is a little over 90 feet above sea level, but it is likely that it has been reduced by fluvial erosion since its emergence. Indeed, downcutting of the Lake St. Francis sill in the St. Lawrence valley, of the order of 5-10 feet, was postulated in Chapter IV. Thus the low bluff on the upper Richelieu valley may be of lacustrine origin.

This bluff should provide evidence of the Port Henry stage of Lake Champlain (Chapman, 1937). Chapman referred a drowned valley at the south end of the lake to this low water stage; continuing differential uplift of the rock sill caused the re-submergence of land to the south. The Port Henry shoreline should rise northward at the rate of about 0.5 feet per mile, to emerge above the water level at the St. Jean Rapids, assuming no downcutting of the sill, or 10 miles south of St. Jean, assuming downcutting of 5 feet. Thus the bluff should appear at about the international boundary, rising to an elevation of about 100 feet at St. Jean. The low bluff that exists does not lie at the required elevation, but the differences are slight. More important, it does not appear to be tilted in the required manner. Thus the physiographic evidence in this area does not support the existence of the Port Henry stage.

The palynological evidence is not conclusive. In the bedrock-controlled area west of Missisquoi Bay there are a number of linear depressions which would have formed arms of the lake when the water level stood at about 110 feet. One such depression, the site of the Venise bog,

where its floor is at about 95 feet above sea level, leads northward from Peel Head Bay into the valley of the South River and thence into the Richelieu valley. The clay floor of the Venise bog lies at almost the same elevation as that of the water level of Lake Champlain. The difficulty arising from differing interpretations of the pollen profile has already been discussed (Chapter III). The author interprets the pollen profile as indicating that peat began to accumulate during pollen zone III, but Dr. Terasmae (personal communication) suggests that the basal peat may be referable to pollen zone IV. If the author is correct, then the boundary between pollen zones III and IV lies above the elevation of the bog, and retains in this southern area the horizontality it possesses in the more northerly parts of the lowland. If, on the other hand, Dr. Terasmae's view is correct, then the pollen zone boundary must decline beneath the level of Lake Champlain, and differential uplift had not ceased at the 100-foot or Montreal stage. This conclusion would lend support for the Port Henry stage of Chapman.

The argument for placing the boundary between pollen zones IV and V at an elevation of 170 feet near the north end of Lake Champlain has already been given (Chapter III). This boundary lies at an elevation of 220 feet over the Lake of the Two Mountains. Hence the features which were formed during pollen zone IV occur over an altitudinal range of more than 100 feet in the lower Ottawa valley but are here compressed into a range considerably less. The materials upon which the waves had to work at the higher elevations in the Richelieu valley were, moreover, till or gravel, which were much less amenable to bluff formation than the clays and sands of the Ottawa valley. Thus it is that the watermarks in the Richelieu valley area are generally crude terraces, often spaced at vertical

intervals of 10 feet or less. The emergence was not accompanied in this area by any spectacular changes of drainage; rather there was a gradual concentration of drainage into those parts of the Champlain Sea floor which were of lowest elevation. It does not, therefore, appear to be a profitable exercise to attempt a complete correlation of stages in the emergence of this area with those, for example, in the lower Ottawa valley.

Chapman (1937) recorded a number of beaches in this area, which he related to stages of Lake Champlain. It has not been possible to identify with certainty any of the features he lists, but it seems probable that his "beaches" are, in fact, the wave-washed crests of gravel ridges. For example, he records a beach at Sherrington at an elevation of 220 feet, which is that of the crest of the Sherrington ridge.

This ridge does, however, provide evidence of stages in the emergence which are of local importance. Northeast of the village of Sherrington a steep bluff drops from 207 to 197 feet, and a bench at the lower elevation occurs at the north end of the ridge. Features at corresponding elevations occur on the steep northern slopes of the St. Rémi plateau, to the northwest. St. Rémi village is built on a flat at an elevation of 199 feet; immediately to the east there is a terrace at 207 feet. Four miles east-northeast of the village a small embayment preserves clear evidence of wave action: a belt of boulders marks the former shoreline, at an elevation of about 205 feet, and the fines which were removed from the till during the formation of the boulder concentrate are found on the sandy floor of the cove, some ten feet lower. On the eastern slope of the plateau flats have been measured at elevations of 205 and 197 feet. Thus there appear to be two well-defined stages at about 205 and 195 feet. It may be that shoreline features at these elevations are

conspicuous mainly as a result of their greater exposure to wave action than those at lower elevations. Nevertheless, it should be possible to correlate them with features in the lower Ottawa valley. However, it appears that they are not to be correlated with the major Rigaud stage of that area, for the tilt of that water plane, calculated both from physiographic and from palynological evidence, is too great. The calculated tilt suggests that they may be the correlatives of a terrace at about 240 feet in the North River valley near Lachute.

2. THE LOWER RICHELIEU VALLEY AND THE ST. LAWRENCE-RICHELIEU INTERFLUVE

a. Topography and present drainage pattern

It was shown in the previous section that the drainage pattern of the upper Richelieu valley evolved by a simple convergence of drainage into the lowest parts of the area, and that the disposition of glacial depositional features was the principal factor determining the form of the drainage network. In its descent to Chambly Basin the Richelieu River crosses the shoreline of the Montreal stage of the Champlain Sea and enters the lower section of the valley, an area which offers many contrasts with the upper valley. The drainage pattern of the lower valley, together with areas lying to the east and west, evolved through a sequence of changes, in contrast to the simple development in the upper valley. A number of factors, of which the distribution of features of glacial deposition is only a minor one, must be invoked to account for the greater complexity of development in the lower valley.

While the relief of the bedrock surface in the lower valley is greater, rising to 1,363 feet in Mont St. Hilaire and descending possibly to 200 feet below sea level near Contrecoeur (Lasalle, 1963), its general

elevation is less than that of the upper valley, since it lies closer to the axis of the lowland and is cut in generally less resistant strata. Greater depths of marine sediment therefore accumulated during the Champlain Sea submergence; the thickness of marine clay is locally more than 100 feet (Lasalle and Elson, 1962). During the emergence marine currents were concentrated in the straits between the islands formed by the Monteregian hills; at later stages estuarine channels were eroded in the floors of the former straits. Estuarine conditions may be considered to have begun with the Montreal stage, by which time the emergence of the upper valley was almost complete. Some areas of marine sediment in the lower valley were converted into island terraces, such as Vercheres Wood, north of Mont St. Bruno. The bluffs bounding such island terraces, and other steep slopes in marine sediments, bear the evidence of successive stages in the emergence in the form of flights of minor bluffs and flats.

The landscape of the lower Richelieu valley differs from that of the upper valley not only in the greater influence of marine deposition and erosion, but also in the very considerable influence of estuarine deposition. The marine clay of Vercheres Wood, and of the low plateau extending north from Mont St. Hilaire, is capped with "high terrace sand" (Lasalle and Elson, 1962), but it is the sand of the Lanoraie delta downstream which exerts a greater influence upon the drainage pattern. The evolution of the delta will be discussed in Chapter VI. The St. Lawrence and Richelieu rivers follow major channels between the sandy island terraces of which the delta is composed. Other channels, now drained only by minor streams, trend diagonally across the St. Lawrence-Richelieu interfluvium and may be traced beyond the Richelieu River. Thus the right-bank tributaries of both the St. Lawrence and Richelieu rivers make barbed

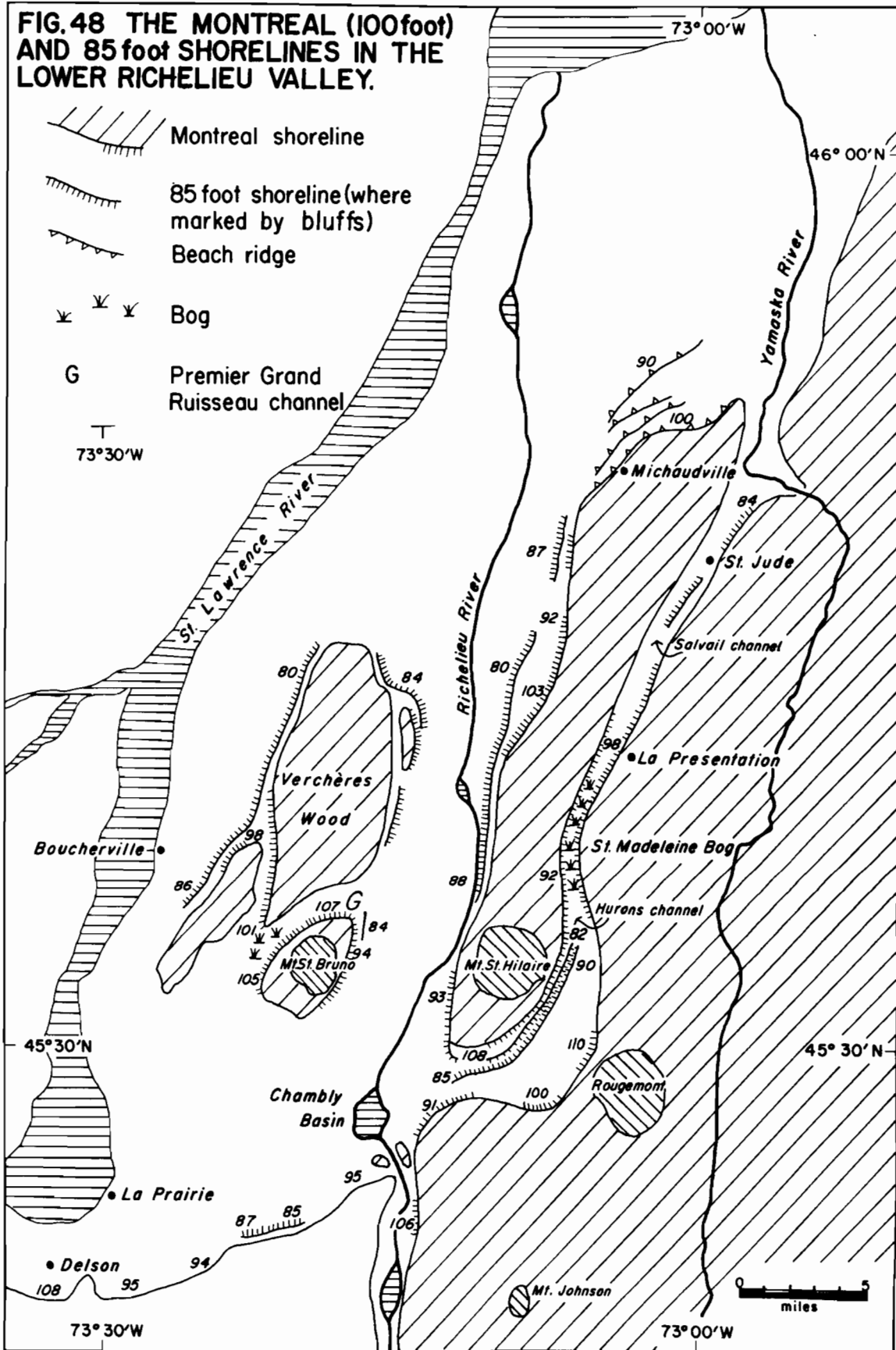
junctions with the main streams, while the left-bank tributaries of the Richelieu River make normal junctions. The shoreline of the Montreal stage in the Richelieu valley is therefore a significant geomorphological boundary, separating an area which emerged but little modified from the Champlain Sea from one which was profoundly modified during the emergence.

b. The Laprairie-Chambly bluff

The Montreal shoreline trends in an east-northeasterly direction from south of Laprairie to south of Chambly Basin (Figure 48), at the southern margin of the Laprairie-Chambly depression (Chapter II). The Laprairie-Chambly bluff bears traces not only of the Montreal stage, but of later stages.

Two phases of the Montreal stage may be recognized, as they may in the lower Ottawa valley. Evidence of the upper level is preserved only in the vicinity of Delson, where a bluff foot has been measured at 102, 103 and 108 feet above sea level. To the east the upper shoreline has been destroyed during the formation of lower bluffs. The lower Montreal shoreline may be traced eastward from the Rivière St. Lambert at an elevation of close to 95 feet to an outcrop of till which interrupts the continuity of the bluff west of the Rivière l'Acadie. Eastward again evidence of this water level has in its turn been destroyed. However, it reappears in a terrace at about 95 feet above sea level which lies between the upper surface of the plain and the floor of the Richelieu valley south of Chambly Basin.

The bluff may be traced east of the Richelieu River into the valley of the Rivière des Hurons. Both Montreal phases are represented here, together with a lower bluff at about 85 feet above sea level.



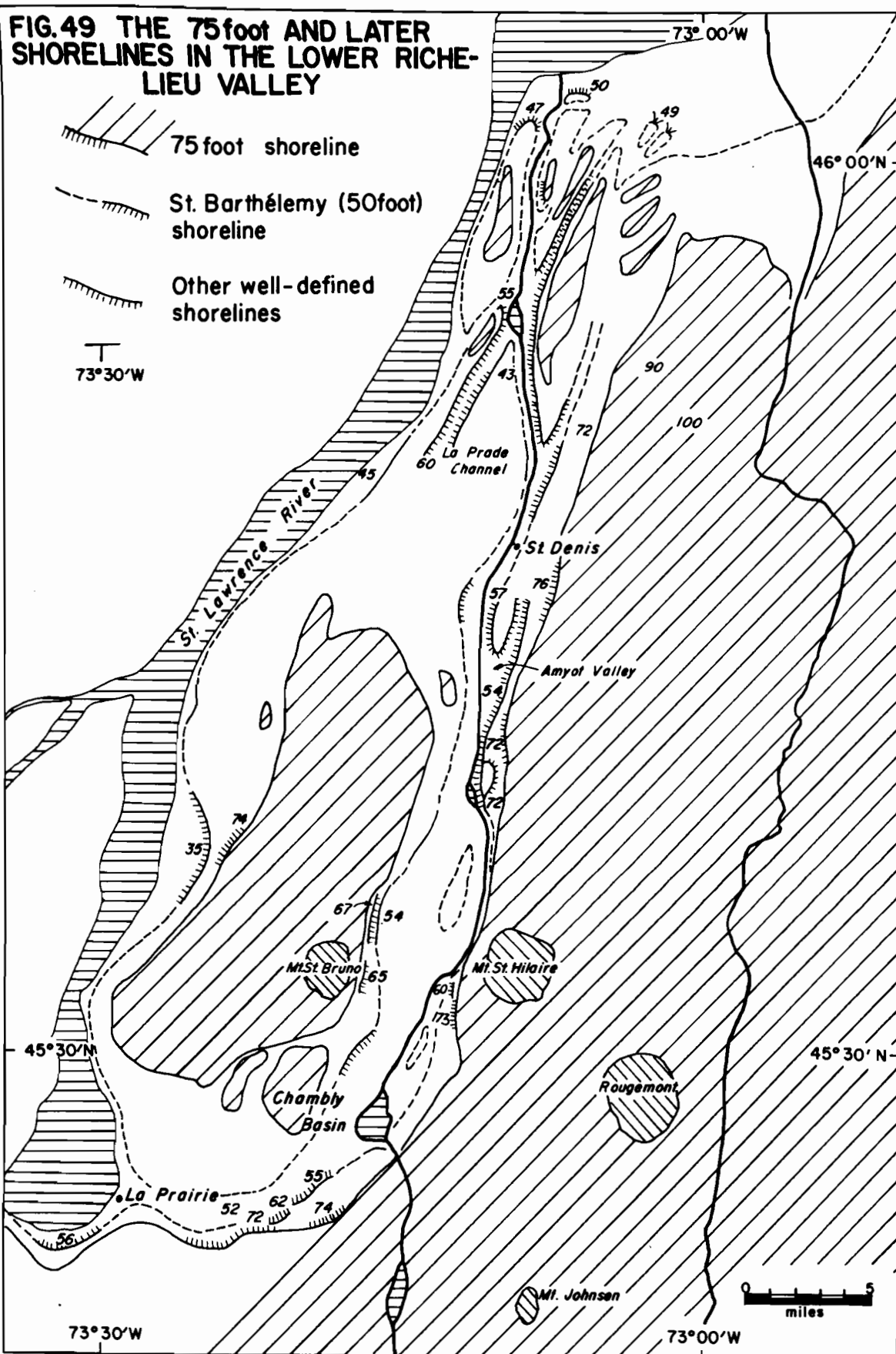
Traces of the 85-foot shoreline on the Laprairie-Chambly bluff are wanting, except near the Rivière l'Acadie, where the bluff foot lies at a little above 80 feet. However, the 95-foot terrace south of Chambly Basin is dissected by a number of channels about 10 feet deep, which lead northward from the Richelieu valley, and which evidently carried Richelieu water into the 85-foot stage of the water body to the north.

Evidence of the succeeding 75-foot stage is seen in a low but well-defined bluff at between 70 and 75 feet above sea level, which may be traced eastward from Laprairie to merge with the main bluff east of the Rivière l'Acadie (Figure 49). The 75-foot stage was followed by the cutting of a faint shoreline at an elevation of a little above 60 feet, visible near the Rivière l'Acadie, and of a more well-developed bluff at a slightly lower elevation. The most westerly indication of this, the lowest shoreline represented on the Laprairie-Chambly bluff, is a minor erosional feature which crosses the Rivière la Tortue near its mouth. Further evidence is found south of Chambly where a terrace at an elevation of 50-55 feet lies at the foot of the main bluff.

Watermarks at scattered elevations occur north of the bluff; an attempt to correlate them will be postponed until the evidence afforded by the Hurons-Salvail channel has been examined.

c. The Hurons-Salvail Channel

A shallow trench, defined approximately by the 100-foot contour, extends north-northeastward for thirty miles from Chambly Basin in the Richelieu valley, to the Yamaska River, passing between Mont St. Hilaire and Rougemont (Figures 45 and 48). Where it skirts Mont St. Hilaire a series of sand and gravel terraces rises above the channel, while its



northern section traverses one of the most monotonously flat areas of the lowland, whose almost undissected surface declines in elevation from 120 feet near the two Monteregian hills to 100 feet near the Yamaska River. The channel drains northward by the Rivière Salvail, a tributary of the Yamaska River, and southward by the Rivière des Hurons, which flows into Chambly Basin. Both streams rise in the Ste. Madeleine bog at the midpoint of the channel (Figure 50). The surface elevation of the bog is 96 feet, and its base is at least 10 feet lower.

Where the Rivière des Hurons flows from its source in the bog the channel is bounded by single bluffs, which rise to 120 feet on the west, where the marine clay in which the channel is cut is capped with sand, and to 110 feet on the east, where no sand overlies the clay. To the south, near Mont St. Hilaire, the difference in elevation between the land on either side of the channel becomes more pronounced. Terraces, which appear to be almost horizontal, lie at between 105 and 110 feet and at about 95 feet on the west side, while the crest of the bluff to the east lies between 90 and 95 feet. The surface above the eastern bluff appears to correspond with the 95-foot terrace to the west, and its back lies on the slope of Rougemont, where a low bluff in till has its foot close to 110 feet. The terraces diminish the width of the channel floor, whose elevation is here close to 80 feet.

The mouth of the Rivière des Hurons, at Chambly Basin, is at 21 feet above sea level. Incision of the river into the floor of the channel has proceeded upstream as far as Mont St. Hilaire, where the river has encountered bedrock. Here artificial deepening of the bedrock channel has been undertaken to improve the drainage. Below this point the bounding bluffs open out into the Richelieu valley, and the river has created a



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Figure 50. The Ste. Madeleine bog in the Hurons-Salvail channel

Elevations in feet. H is the site of the boring for the pollen profile of the bog. The bounding bluffs are emphasized.

narrow flood plain within the channel floor.

The valley of the Rivière Salvail contrasts strongly with that of the Rivière des Hurons. The river's total length and fall are comparable with those of the southward-flowing stream, but no bedrock outcrops have impeded downcutting, and incision into the marine deposits has proceeded to within a few miles of the source. Near its mouth the river flows in a narrow valley some 70 feet below the level of the plain, and this incision has resulted in the destruction of much of the channel floor. In its original form the channel appears to have been poorly defined, as the bounding bluffs decrease in height northward. However, there appear to be terrace remnants below St. Jude at about 85 feet. Such a terrace at St. Jude village either has never existed or has been destroyed by erosion. Enough remains of the original floor of the channel, however, to suggest that both the floor itself and the feet of the bounding bluffs may have risen northward. From an elevation of 79 feet in the valley of the Rivière des Hurons east of Mont St. Hilaire the floor rises to 85 feet north of La Présentation. The bluff foot similarly rises from 82 feet east of Mont St. Hilaire to 98 feet at La Présentation. Thus, although the Rivière Salvail flows with the slope of the plain, it flows against the slope of the original channel floor.

The form of the channel is similar to others which have been described, and it must have been shaped by a single broad stream. The summits of Mont St. Hilaire and Rougemont rose as islands above the Champlain Sea at its maximum elevation, which was here close to 600 feet. During the emergence the body of water between the mountains diminished in width until, when sea level lay at about 120 feet, it formed a strait, the lowest point of whose floor lay closer to Mont St. Hilaire than to

Rougemont. This assymetry probably resulted from the presence of a till ridge which today forms the divide between the Richelieu River and the Ruisseau St. Louis, and which would have confined any currents in the strait to its northwestern side. At this stage of the emergence the flat divides between the present valleys of the Richelieu, Salvail and Yamaska rivers would have been just awash, and it is possible to envisage that a depression continued the line of the strait seaward, to determine the future course of the channel. It is noteworthy in this respect that the channel lies, throughout its length, within a mile of the axis of the Chambly-Fortierville syncline, as mapped by Clark (1955). It may be that the syncline was followed by a preglacial stream, whose valley was never completely obliterated by the deposition of glacial and marine sediments, providing an easy route for the developing channel.

When sea level fell to the upper Montreal level of about 110 feet, a bluff was formed below the 120-foot surface flanking Mont St. Hilaire, dying away northward where the water lay against the gently shelving shore of the Richelieu-Hurons divide. No traces of the corresponding shoreline are visible on the clay plain of the Salvail-Yamaska divide; the only evidence of this stage east of the channel is a low bluff northwest of Rougemont, the foot of which lies at about 110 feet above sea level. Subsequently the water level fell to 95 feet, the lower Montreal level, with the formation locally of a second bluff on the slopes of Mont St. Hilaire. Again, to the east of the channel no bluffs were formed at the shelving shoreline, except where the Ruisseau St. Louis appears to have flowed into a small embayment south of Mont St. Hilaire.

It was only with a fall in water level to about 85 feet that the channel became bounded by bluffs on either side. This seems to have been

related to a change in the function of the channel, from that of a marine strait with slight currents to that of a more confined water course with a considerable current. It has already been emphasized that no erosional shorelines are visible on the very gentle clay slopes flanking the northern part of the channel at higher elevations. Where erosional bluffs exist at these elevations they are related to steeper initial slopes. The appearance of bluffs within the gently shelving floor of the original marine strait must imply a change in the process of bluff formation. Despite the present southward gradient of the channel floor, it seems probable that the current responsible for producing the bluffs flowed northward, and that it was part of the discharge of the 85-foot water body, which was extensive in the Montreal area. This conclusion is reinforced by the northward slope of the interfluves east and west of the channel, a slope which causes the tributaries of the Rivière des Hurons to make barbed junctions with the southward-flowing main stream.

What, then, was the cause of the reversal of the Rivière des Hurons? Has its direction been reversed by differential uplift? There is little evidence from the floor of the south end of the channel, or from the bounding terraces, to suggest that this may be so. The terraces appear to have no longitudinal gradient; it is not to be concluded that originally sloping terraces have been tilted into a horizontal attitude, for they are shoreline, rather than fluvial terraces. It is only when the channel is considered as a whole that the northward rise of its floor becomes apparent. Then it becomes evident that the low points on the channel floor coincide with the constricted section adjacent to Mont St. Hilaire; where the channel widens northward it could carry the same discharge with a smaller depth, and the elevation of the floor rises. While this evidence

does not eliminate the possibility of differential uplift, it does not favour it.

Palynological evidence is similarly inconclusive. The problem of determining the differential uplift, if any, of the boundary surface between pollen zones III and IV has already been discussed (Chapter III). The surface lies above the Ste. Madeleine bog at the centre of the channel, of which the basal peat, with a pollen assemblage of pollen zone III, rests upon clay at an elevation of 85 feet. Were the pollen boundary surface tilted, a somewhat smaller degree of tilting of the lower, 85-foot water plane, as represented by the floor of the channel, might be expected.

Since it is not possible to prove differential uplift, an alternative explanation of the southward course of the Rivière des Hurons must be sought, based upon an assumption of uniform uplift. The first part of the floor of the channel to emerge would have been the shallower northern section now drained by the Rivière Salvail. An arm of water would have extended from the Richelieu valley at Chambly Basin to the site of the Ste. Madeleine bog. The basal peat in the bog is silty, indicating that in its early stages the bog experienced periodic inundation.

From this stage in the emergence the southward development of the Rivière des Hurons over the emerging bed of the channel requires little explanation. It is, rather, the northward direction of the Rivière Salvail which must be examined. This river must have developed as the result of headward erosion by a stream at the northern end of the channel, flowing into the arm of water occupying the present Yamaska valley. The gradient of the river, once established, would have been increased both by the general lowering of base level and by the upward growth of the Ste. Madeleine bog. Terraces within its valley show its response to the falling

base level.

d. Stages in the emergence

Since no conclusive evidence of differential uplift is obtainable from the northward-trending Hurons-Salvail channel, correlations of water-marks in the lower Richelieu valley are made on the basis of uniform uplift. Despite a considerable scatter of elevations, which reflects both original variations and instrumental errors, it is possible to recognize distinct stages in the lower Richelieu valley and the adjacent areas.

i. The Montreal stage. The two phases of the Montreal stage are represented by a scatter of water marks which may not readily be separated except where one occurs above the other in the same locality. The southern shoreline of both phases of the Montreal water body was formed by the Laprairie-Chambly bluff (Figure 48). The water at the upper phase washed against only the western slopes of Rougemont, but surrounded St. Hilaire and St. Bruno mountains. Verchères Wood, and a bedrock-cored till ridge to the west of Mont St. Bruno near Boucherville also emerged as islands.

The upper Montreal shoreline may be traced at elevations of between 104 and 107 feet on the west and north sides of Mont St. Bruno, leading into the channel which separates the mountain and its adjacent terraces from Verchères Wood. The channel is drained eastward by the Premier Grand Ruisseau, which rises in the St. Bruno bog at the western intake of the channel to flow into the Richelieu River. The clay floor of the bog at the site of the pollen profile (Chapter III) is at an elevation of 95 feet, while the elevation of the truncated eastern end of the channel is about 80 feet. A considerable eastward gradient is indicated, but this is not reflected in the elevations of the feet of the bounding bluffs, which lie

between 101 and 110 feet. The clay flat west of the intake of the channel lies at an elevation of about 90 feet, so that the waters of the lower Montreal phase would scarcely have washed over it. It therefore appears unlikely that any considerable current passed through the channel at that time. The deepening of the eastern end of the channel must have occurred as the result of the concentration of current action in the narrow strait during the earlier, upper Montreal phase. Erosion at the shoreline of the late 65-foot water body in the Richelieu valley has truncated the eastern floor of this channel.

Elsewhere on the St. Lawrence-Richelieu interfluvial traces of the upper Montreal shoreline have not been found, and the shoreline of the lower phase is preserved only locally. A well-marked bluff occurs east of Mont St. Bruno, its foot at elevations between 95 and 100 feet. The bluff rises above the level at which traces of the upper shoreline would be expected and was probably cut during the whole of the Montreal stage.

Wave-worked ridges at elevations of between 88 and 100 feet occur on the northwestern slope of the Boucherville till ridge, and the foot of the bluff bounding Verchères Wood north of the intake of the Premier Grand Ruisseau channel is at a little above 100 feet. To the north the bluff descends to lower elevations, and traces of the Montreal shorelines have not been found on the wooded slope. However, a northward-trending channel, its floor at an elevation of 100 feet, occurs close to the northeastern margin of the island terrace, and may be related to the Montreal stage. The eastern side of the channel has been breached by a small tributary of the Richelieu River, and only at its southern end is it followed by a present day stream.

East of the Richelieu River terraces and bluffs occur throughout a

wide range of elevation on the slopes of Mont St. Hilaire, and include evidence of the lower Montreal phase in a bluff whose foot lies at 93 feet southwest of the mountain. The terrace above the bluff is at an elevation of about 120 feet; thus evidence of the upper phase has been removed. North of Mont St. Hilaire this bluff forms the eastern boundary of the Richelieu valley for several miles although the bluff foot has been cut down to the 85-foot level in many places. The Montreal shoreline may be traced northward into the Amyot valley at elevations of between 92 and 100 feet.

To the northeast, on the Richelieu-Salvail interfluvium near Michaudville, the shoreline is represented by a sequence of low, sandy beach ridges at elevations of between 90 and 100 feet.

ii. The 85-foot stage. Emergence after the lower Montreal phase reduced the width of the channel between Mont St. Bruno and the Laprairie-Chambly bluff, but the gentle slopes of the till area south of the mountain were not favourable for the formation of well-marked shorelines. The steeper northwestern slopes of the Boucherville till ridge, however, preserve evidence of the 85-foot shoreline in a low bluff, its foot between 80 and 85 feet, which may be traced from the ridge northward across the clay plain to merge with the bluff bounding Verchères Wood (Figure 48). At the northern margin of Verchères Wood the bluff foot lies at measured elevations of 80 and 84 feet.

The 85-foot stage east of the Richelieu River is represented by a terrace which occurs at an elevation of 88 feet northwest of Mont St. Hilaire, and by a bluff at 80-85 feet which cuts off the lower Montreal shoreline terrace in the Amyot valley.

iii. The 75-foot stage. In the Amyot valley, a low bluff, the foot of

which lies at 72 feet above sea level, occurs below the 80-85 foot bluff, and is ascribed to the following stage in the emergence (Figure 49).

Traces of the 75-foot shoreline are to be found elsewhere east of the Richelieu River, in the form of narrow terraces which lie at measured elevations of 72 and 73 feet.

West of the Richelieu River the 75-foot shoreline is represented by a bluff at 74 feet on the Boucherville till ridge, and traces of the shoreline are found along the Laprairie-Chambly bluff.

iv. The 65-foot stage. The 65-foot stage marked a great change in conditions in the lower Richelieu valley. Areas in which sedimentation had occurred were emerging, as were low till ridges, resulting in a drastic reduction in water area and a corresponding reduction in wave activity. Erosional shoreline features therefore occur infrequently. However, mention has already been made of the low bluff which was cut at this elevation when the shoreline withdrew from the Laprairie-Chambly bluff. In addition, a bluff foot has been measured at elevations of 65 and 67 feet east of Mont St. Bruno, where the bluff truncates the floor of the Premier Grand Ruisseau channel. A corresponding flat at an elevation of 60 feet occurs on the slope of Mont St. Hilaire, east of the Richelieu River.

Deltaic conditions had extended as far upstream as St. Denis in the Richelieu valley, with the emergence of the island terrace which forms the Richelieu-Amyot interfluve. The crests of the island terraces in the main part of the Lanoraie delta were emerging. As a result currents were confined to narrow channels whose floors were deepened. The elevations of the channel floors may therefore not be used to establish stages in the emergence. The channel drained by the Ruisseau la Prade provides an example (Figure 49). The stream rises on the clay plain of the St. Lawrence-

Richelieu interfluve at an elevation of about 70 feet. It flows north into a channel bounded by straight bluffs, the floor of which slopes from about 60 feet at the intake to close to 40 feet at the confluence of the stream with the Richelieu River. This slope cannot be attributed to drainage from a higher water body to a lower; it must therefore be of submarine origin, like the eastward slope of the Premier Grand Ruisseau channel between Mont St. Bruno and Verchères Wood.

v. The 55-foot and later stages. The 55-foot stage was the last at which water extended across the St. Lawrence-Richelieu interfluve south of Mont St. Bruno. At this stage only a shallow channel remained, overlying a bed-rock depression whose origin has already been discussed (Chapter II). Today the western end of the channel drains into the St. Lawrence River by the Rivière St. Lambert, while the drainage of the eastern end is carried into the Richelieu River by the lower Rivière l'Acadie. The present divide lies on an outcrop of till at an elevation of 52 feet (Figure 49). A bluff and terrace at the required elevation occur frequently east of the Richelieu River, but on the west side of the valley the emergence of low till-cored ridges hindered terrace cutting. One such ridge, north of Beloeil, formed an island at this stage. To the north the Amyot valley, together with the valleys of smaller streams, still functioned as deltaic channels, linking the water body in the Richelieu valley with the estuary to the northeast.

Emergence following the formation of the 55-foot shoreline reduced the water body in the Richelieu valley to a comparatively narrow estuary. Bluffs at elevations of between 40 and 45 feet may be correlated with the bluff at the same elevation which borders the St. Lawrence River. At Boucherville the St. Lawrence bluff swings inland, and the terrace at its

foot appears to have originated as a low island, crossed by distributary channels.

The 45-foot bluffs in the Richelieu valley lead into the northeastward-trending deltaic channels, and indicate the continued braiding of the channels across the Lanoraie delta. The floor of the Amyot channel had, however, emerged by this time.

e. The development of the drainage pattern

The bluffs which have been described are attributed to wave and current action at the shoreline of a diminishing water body, and not to fluvial action. Bluffs attributable to lateral fluvial erosion occur locally at lower elevations. For example, the lower course of the Riviere des Hurons flows through a narrow flood plain incised within the channel floor of the 85-foot stage. The streams which flow in the channels across the Lanoraie delta have created similar inner trenches.

The drainage pattern seems to have developed by the seaward extension of the course of the Richelieu River across the emerging sea floor, and by the development of smaller streams in the depressions which existed between low till ridges and island terraces. The final development of the drainage pattern in the lowest part of the Richelieu valley poses two questions, however. The first concerns the course of the Richelieu River itself. Where the original deltaic channels bifurcate the river flows, with only one minor exception, in the western branch. This phenomenon first occurs at the confluence with the Rivière des Hurons. It may be that the westerly channels, lying closer to the mid-line of the preglacial St. Lawrence valley, were being cut in unconsolidated marine sediments rather than encountering more resistant till; till is known to occur at a

low elevation in the intake of the Amyot channel. Certainly differential uplift cannot be invoked to account for the systematic abandonment of the eastern channels, for the uplift, if any, was to the west of north, and would thus have favoured the eastern channels at the expense of the western ones. Nor can downcutting in response to the lowering of the level of the St. Lawrence River be appealed to, since the Richelieu River developed by downstream extension, rather than by headward erosion.

The second question concerns the reversal of drainage at the southern ends of the abandoned channels: the Riviere Amyot and three streams in channels to the north all drain southward. Three possible explanations may be suggested. The reversal of drainage may be due in part to initial irregularities of the channel floors, as has been suggested in the case of the Riviere des Hurons, although its systematic occurrence suggests that this was not the principal cause. Differential uplift, too small to be demonstrated instrumentally, may also have had some effect, but this appears unlikely. In the case of the more northerly streams, however, it is possible to suggest that the principal cause of the reversal has been headward erosion by small streams at the southern ends of the channels, eroding actively in response to the lowering of the local base level, the Richelieu River, the new base level being closer to the upper end of the former channel than to the lower end.

3. THE YAMASKA VALLEY

The Yamaska River descends across Logan's Line at Farnham to enter the lowland, swinging from a westerly to a northerly direction as if diverted by the St. Alexandre till mass lying between Farnham and the Richelieu River. The general northward or north-northeastward course of

the river is continued for 35 miles, when it turns abruptly to the west-northwest for 5 miles. At the confluence with the Rivière Salvail the river resumes its former direction, continuing the line of the Hurons-Salvail channel. Its deltaic mouth lies at the head of Lake St. Peter.

The river's steep descent from the Appalachian piedmont is continued below Farnham, to the confluence of the Rivière Sud-Ouest (Figure 46), at which point it enters the marine plain which it traverses for the remainder of its course. The Rivière Sud-Ouest drains from the Farnham bog and skirts a belt of thinly drift-covered bedrock extending south from Rougemont. Below the confluence the gradient of the main stream flattens abruptly; water is ponded back to this point by a dam less than 15 feet high at St. Hyacinthe, 18 miles downstream (Profile of Rivière Yamaska, 1934). The surface of the weak rocks of the Lorraine group which underlie this reach of the river is obscured beneath many feet of unconsolidated surficial material.

The river flows between Rougemont and Yamaska Mountain, receiving tributaries which rise on their slopes. However, the major tributary of this section of the Yamaska River is the Black River; the confluence is 6 miles south of St. Hyacinthe (Figure 45). The Black River flows southward in a structurally controlled depression along Logan's Line, between the St. Dominique fault slice and the Appalachian piedmont proper (Figure 2). North of Yamaska Mountain the Black River swings westward across the southern part of the fault slice to enter the lowland. Below the confluence with the Black River the Yamaska River receives numerous tributaries draining from the subdued, drift-mantled, west-facing fault scarp of the St. Dominique slice.

Below St. Hyacinthe, where the river leaves the area underlain by

rocks of the Lorraine group, its gradient increases, and outcrops of bed-rock occur in its bed. Its course closely parallels the line of the St. Barnabé Fault (Figure 2). If the river is structurally guided, the influence of the fault must have been inherited from the preglacial drainage pattern, since its outcrop is buried beneath surficial deposits. It was, perhaps, rather the existence of a low swell on the emerging sea floor, extending north from Rougemont, which determined the course of the present river. The relief of the Yamaska-Salvail interfluvium is no more than 10 feet; the crest of this swell lies closer to the Yamaska River than to the Rivière Salvail, so that only a few minor tributaries enter this section of the river, and the greater part of the drainage of the interfluvium is carried into the Rivière Salvail.

Although at the confluence with the Rivière Salvail the Yamaska River is still 20 miles from its mouth, its water level is that of Lake St. Peter. No rock outcrops occur in the river bed below the confluence, and incision to base level has taken place unhindered through the unconsolidated marine deposits. The last major tributary is the Rivière David, whose headwaters rise in a belt of morainic country (the Drummondville "moraine") at the eastern margin of the lowland, south of the St. Francis River.

Between the confluences of the Rivière Sud-Ouest and the Rivière Salvail with the Yamaska River the general level of the plain descends from 125 feet to 100 feet, a slope of less than one foot per mile. Since the river falls 70 feet over the same distance, its incision below the surface of the plain increases downstream. Below the Salvail confluence, however, the slope of the plain increases to an average of 3 feet per mile, and the height of the river banks therefore decreases. The banks are at their

highest in the vicinity of the Salvail confluence, where numerous landslips have occurred.

The evolution of the drainage pattern of the Yamaska River and its tributaries poses few problems. The two elbows at and above the Salvail confluence are not indicative of capture as there is no abandoned channel leading northward from the first elbow. The general form of the surface of the plain is that of the emerging sea floor. Examination of the contour pattern indicates that at the time of the emergence of the floor of the Yamaska valley above the first elbow, an arm of water still occupied the Hurons-Salvail channel and the lower Yamaska valley. The Yamaska River made its way into this arm of water along the shortest available route, at the northern end of the swell which forms the Salvail-Yamaska divide. This is a further example of the process which occurred so frequently in the lower Richelieu valley, whereby drainage was attracted westward by the greater gradient toward the centre of the lowland.

The even surface of the plain adjacent to the Yamaska River was not favourable for the formation of bluffs at the retreating margin of the Champlain Sea. Shoreline features, low sandy ridges at elevations of between 90 and 100 feet, which occur west of the river near the Salvail confluence, have already been mentioned, but these afford the only evidence of a stage in the emergence. The beach lines are ascribed to the Montreal stage of the Champlain Sea and occur where the northward slope of the plain increases.

East of the river, however, where the slope increases toward the Appalachian piedmont, traces of wave action are abundant. The till which mantles the slopes of the St. Dominique slice has been fashioned into crude terraces which extend into the valley of the Black River. At least twelve

terraces occur between measured elevations of 265 and 135 feet. Some of the terraces appear to have a certain persistence when traced along the slope, but their close vertical spacing makes correlation with other areas hazardous.

The part of the plain drained by the Rivière David and its tributaries has a northwestward gradient of the order of 8 feet per mile, and carries watermarks at several elevations. The clay surface is traversed by narrow belts of sand and gravel running along the contour, which have been mapped by Gadd (1960c) as high terrace sand and described by him as "terrace, beach and bar deposits". In the field these belts are seen to rise a few feet above the general level, and frequently the drop to the west is greater than that to the east, a characteristic which is shared by the partially buried gravel ridges in the upper Richelieu valley. In fact, both sets of features have much in common, and the belts of sand in this area are similarly, wave-washed crests of till or gravel ridges partially buried in marine sediment (Figure 7). On the soils map of Yamaska County (Laplanche et Choinière, 1954) some of the ridges are mapped as the Grande Ligne series, indicating their pedological affinity with the ridge near the village of that name in the Richelieu valley. The elevation of the crest of such a ridge is of little significance, but where the core of the ridge has been exposed to, and has resisted, wave action, the elevation of the eroded clay surface to the west is an indication of a level of the sea. The most continuous of the ridges extends for close to 20 miles, with an expansion northwest of St. Guillaume d'Upton, where the Rivière David cuts through it, which could be mistaken for a delta of the river. Elevations of the flat west of the ridge range from 120 to 125 feet, and seem to represent a distinct stage in the

emergence. Similar, but less well-marked, features occur at about 130 and 115 feet.

At lower elevations the mapped belts of sand take on the appearance of true terraces, probably related to water levels of about 80 and 55 feet. It is probable that these lower stages are represented by breaks of slope on the valley sides bordering the Yamaska River; the flat at the northern end of the Salvail valley at an elevation of 85 feet has already been mentioned.

Below the 50-foot contour the land falls away gently to the deltaic flats bordering Lake St. Peter. Sedimentation, rather than erosion, has been the rule in the areas between the mouths of the Richelieu, Yamaska and St. Francis rivers, and erosional shoreline features are generally absent.

A minor feature of the drainage pattern remains to be mentioned. In the lower part of the Salvail valley and the adjacent parts of the Yamaska valley minor tributaries frequently follow courses parallel with the main stream, flowing either in the same or in the opposite direction. Although this phenomenon coincides with the area liable to landslips, the two do not appear to be related, for similar tributaries occur in the Richelieu valley, which is not subject to slipping. The tributaries have probably incised themselves within channels which were occupied by branches of the main streams when they were flowing at higher elevations. Thus the area between such a tributary and the main stream was formerly a fluvial island.

4. THE ST. FRANCIS VALLEY AND THE AREA TO THE NORTHEAST

a. The present and preglacial drainage patterns

The delta of the St. Francis River at the head of Lake St. Peter is almost confluent with that of the Yamaska River. The courses of these rivers, however, lie almost at right angles to each other. The St. Francis River is the first of a series of northwestward trending right-bank tributaries of the St. Lawrence River. The major streams of this series, the St. Francis River itself, the Rivière Nicolet, its tributary, the Rivière Nicolet Sud-Ouest or Pontgravé, and the Rivière Bécancour rise within the Appalachians, where they flow in preglacial valleys; the drainage basins of the smaller streams, such as the Rivière Gentilly, lie wholly, or to a very large extent, within the lowland.

Southwest of the St. Francis River Logan's Line is etched out by the valley of the Rivière St. Germain (Figure 8), but to the northeast the geological boundary between the lowland and the Appalachians is obscured with drift and has no topographic expression. The outcrop of the thrust plane is offset between the St. Francis and Bécancour rivers by a number of cross faults, but its general trend is crudely parallel both to the axis of the Chambly-Fortierville syncline and to the course of the St. Lawrence River, which follows the outcrop of the weak rocks of the Lorraine group at the northern limb of the syncline (Figure 2). With the convergence of the outcrops toward the northeastern nose of the syncline the St. Lawrence River approaches closer to Logan's Line; beyond the limits of the area under discussion, indeed, it crosses in turn both the synclinal axis and the thrust fault.

Blanchard's detailed study (1947) of the form of the bedrock surface in this area established it as a type area of the Quebec platform.

He concluded that the platform had been formed preglacially by fluvial action, and that tilting downstream had resulted in the incision of the preglacial drainage. One result of the fluvial incision was the formation of a bluff cut in bedrock which occurs along the St. Lawrence River at and downstream of the mouth of the Rivière Bécancour. Glacial erosion later gave to the platform its concave form; this erosion was most active in the excavation of the basin of Lake St. Peter.

Gadd (1960a) gives less weight to the occurrence of bedrock exposures in the bluff at the mouth of the Rivière Bécancour, and implies that the bluff was cut by the erosive action of the present St. Lawrence River. Indeed, it is difficult to reconcile Blanchard's hypothesis of a preglacial origin of the feature with intense glacial erosion upstream in the basin of Lake St. Peter.

It is difficult to reach more than limited conclusions regarding the preglacial drainage pattern. The St. Lawrence River clearly inherited its course from a preglacial ancestor, but a geological section given by Karrow (1959) indicates that in the Grondines map area the present river diverges northward of the course of the preglacial stream, which evidently followed more closely the outcrop of the Lorraine shales (Figure 6). The divergence is, however, slight; the deposition of more than 200 feet of glacial, lacustrine, marine and fluvial sediments was inadequate to obliterate completely the broad depression in which the river flowed.

Choinière and Laplante (1948) suggest that the Bécancour and Nicolet rivers are of preglacial origin, citing as evidence the gentle gradient of their lowland courses. These courses are not, however, free from rapids. The Rivière Bécancour, it is true, has an almost ideal "graded" profile from its entry into the lowland to a point 10 miles from

its mouth. In the next five miles, however, it descends 70 feet in a series of rapids (Figure 5b). This steepening of gradient appears to be related to overdeepening along the channel of the St. Lawrence River. The overdeepening would appear to be the result, as Blanchard suggested, of fluvial and glacial processes, but it is not necessary to follow him in invoking tilting to account for the fluvial incision. In this area, as in the area west of Montreal, the streams could well have been entrenching themselves below the surface of the Quebec platform in response to an early Wisconsin, or even earlier, low sea level. It may well be, then, that the Bécancour and Nicolet rivers are re-excavating the valleys of preglacial streams.

It is less likely that the St. Francis River follows a preglacial valley in its course across the lowland. The gradient of most of the lowland course of the river is both steep and irregular, although that of the lowest 10 miles is very slight (Profile of Rivière St. François, 1917). In plan, the lowland course of the river is almost rectilinear, yet it diverges from the general trend of the course within the Appalachians. The Appalachian section is, in fact, in better alignment with the Shield course of the St. Maurice River than with its own downstream course, a fact which may have some relevance in any discussion of the early evolution of the drainage pattern of the region as a whole.

b. Surface deposits

The glacial history of the area has been discussed by Gadd (1955, 1960a) and Karrow (1957, 1959), and a summary has already been given (Chapter II). In discussing the evolution of the drainage pattern of this area the actual surface distribution of deposits is of more importance

than their sequence. The surficial geology of the greater part of the area has been mapped on the one-inch scale, and a broad zoning of deposits is apparent. The outcrops of till at the margin of the lowland are succeeded to the northwest by a belt of beach sands and gravels washed from the till. These give way at lower elevations to the clay of the Champlain Sea floor, which near the St. Lawrence River is overlain by "high terrace sands". Recent alluvium, "low terrace sands", lies close to Lake St. Peter and the St. Lawrence River.

None of these belts of surficial material is without variety. The gently rolling topography of the till area is diversified by depressions floored with marine clay, often overlain by peat, and by beach sands, locally worked subsequently into dunes. Low hills of till project through the later deposits at lower elevations, and the belt of marine clay is crossed by belts of sand beside the valleys of the larger streams, which are deeply incised below the general surface.

Choinière and Laplante (1948, 1954) note that in Nicolet and Yamaska counties the crests of the river banks are frequently a few feet higher than the adjacent land, so that drainage is away from, rather than toward, the major streams. This is particularly evident in the case of the St. Francis River, which receives but one significant tributary in its lowland course. This situation results from deltaic deposition at the mouths of the rivers as they extended their courses across the emerging sea floor. It is locally possible even from the published topographic map on a scale of 1:50,000 and with a contour interval of 25 feet to distinguish between raised deltas of differing type: those which were typified by submerged levees, comparable with the present deltas of the Yamaska and St. Francis rivers, and those of the arcuate type, like the present delta of

the Rivière Nicolet.

c. The development of the drainage pattern during the Champlain Sea regression

The earliest deltas were constructed at the mouths of the Appalachian valleys, from redeposited material of fluvio-glacial origin. With continuing uplift this material was constantly re-excavated and re-deposited downstream. Confined within their own deposits, and becoming increasingly incised with the lowering of base level, the courses of the major streams were not always extended over the lowest part of the sea floor. Hence the linear course of the lower St. Francis River may well have been determined by an outcrop of till eight miles northeast of Drummondville. Once the river had been deflected at the southern margin of this outcrop, its new direction was self-perpetuating.

With the emergence of the belt of till smaller streams were initiated, to join together and extend northwestward in the re-entrants between the deltas of the major rivers. The unconsolidated beach sands and gravels at the margins of till outcrops provided material for the formation of deltas at the temporary mouths of these lesser streams. As the shoreline retreated toward the northwest, belts of "high terrace sand", subsequently truncated in places by bluffs, were spread laterally between the river mouths. Springs emerging from the sand give rise to minor streams draining directly to the St. Lawrence River across the belt of recent alluvium, the "low terrace sands".

Between the mouths of the Rivers Nicolet and Bécancour the continuity of the belt of "low terrace sands" is interrupted by an outcrop of till, which was an island when part of the St. Lawrence water passed

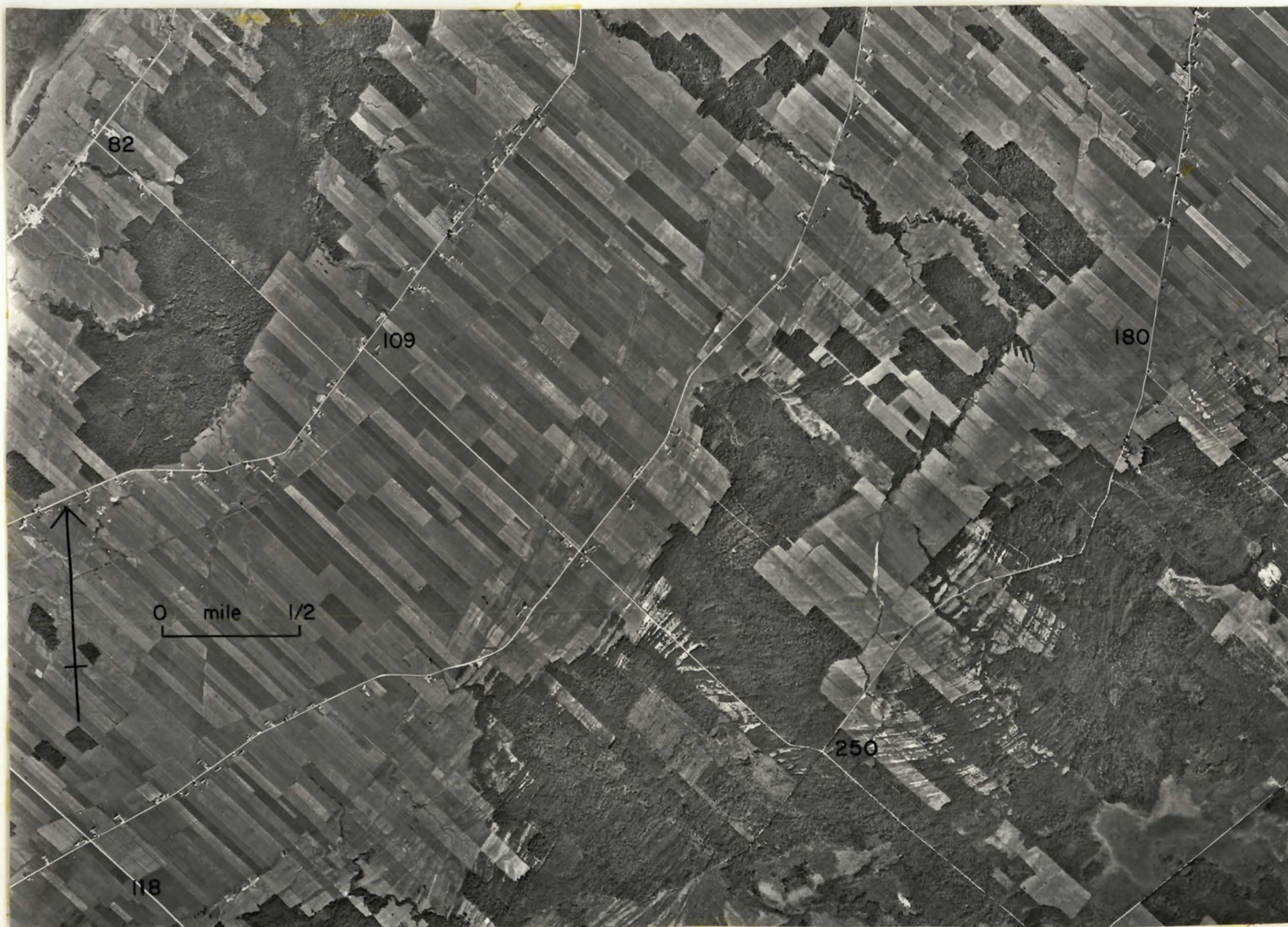
through the channel now occupied by Lake St. Paul. Northeast of the mouth of the Rivière Bécancour the belt of alluvium is pinched out between the river and the shore-cliff, which rises northward to a height of 100 feet, exposing a sequence of deposits including those of the pro-glacial Lake Deschaillons (Karrow, 1959).

It is not only in the character of the belt adjacent to the St. Lawrence River that the section of the lowland northeast of the Rivière Bécancour differs from that already described, between the St. Francis and Bécancour rivers. In this northeastern area the belt of till which overlaps Logan's Line lies closer to the St. Lawrence River, with the result that the slope toward the river is steeper. The slope is not an even one, but is composed of a complex of flats of varying widths and bluffs of varying heights (Figure 51). Gadd describes the topography of the area of the Bécancour map sheet thus:

A thick wedge of sand deposits flanks the northwestern limit of the morainic belt. A major compound escarpment is cut in these sands.... It extends northeastward through Ste. Gertrude, reaches its maximum 3 miles southeast of Gentilly, and then divides into a number of scarps.... The main scarp is complex, comprising numerous narrow terraces and minor scarps ranging in height from a few feet to about 50 feet; the minor scarps truncate one another in a very complex pattern of multiple-swing cusps.

Northwest of the major scarp, in a belt about 6 miles wide crossing diagonally across the centre of the area (and in the vertical zone between 150 and 100 feet elevation), terraces are broad, (up to about a mile wide), and are limited by low sandy beach ridges. Terraces are separated by small vertical intervals, and scarps are not always readily visible on the ground. (Gadd, 1960a, pp. 2-3)

The implications of Gadd's description of the pattern of scarps (or bluffs) as that of multiple-swing cusps is questionable. At the time when they were being cut the St. Lawrence River was a body of water of estuarine proportions, and it seems more probable that the bluffs were cut by wave



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Figure 51. Shoreline features east of the Rivière Bécancour (elevations in feet)
Gadd's "major compound escarpment" occupies the southeastern part of the area.

action at the shore of the estuary, than that they were eroded by the lateral erosion of the river. Indeed, when Gadd describes beach ridges at lower elevations, he implies a return to estuarine conditions as the width of the river diminished. It is more probable that the erosive action of fluvial currents was not felt at the river bank until it was constricted into a channel little wider than the present.

Evidence of the estuarine rather than fluvial origin of the bluffs is provided by certain consistent elevations. The foot of the major scarp described by Gadd lies at a measured elevation of 187 feet west of the Rivière Bécancour, of 185 feet at Ste. Gertrude and of 181 feet at Ste. Sophie de Levrard; at an intermediate point, southeast of Gentilly, there is a well-marked flat at an elevation of 183 feet. Fragmentary water marks occur at lower elevations. Of these, the 125-130 foot level appears to be significant, and is marked by flats and by the feet of bluffs. The continuity of this feature is broken southwest of the Rivière Bécancour, but a water level between 130 and 135 feet occurs in the lower valley of the Yamaska River. Since the trend of the 180-foot and 130-foot shorelines is crudely parallel with the isobases on the V-IV pollen boundary plane (Figure 11) measurable differential uplift is not to be expected.

Numerous shoreline traces occur above the 180-foot level, but no significant stages have been recognized between this elevation and delta surfaces at between 350 and 360 feet in the valleys of the St. Francis and Nicolet rivers. At elevations below the 130-foot level the correlation of watermarks becomes more feasible. A possible 120-foot level intervenes locally between the 130-foot shoreline and the more widespread and continuous shoreline of the Montreal stage, which occurs in this area at elevations of between 95 and 108 feet. The Montreal shoreline may be traced

as an erosional feature between the valleys of the major streams, merging with the constructional deltaic surfaces adjacent to the valleys (Figure 52).

Below the Montreal shoreline the surface descends to the low terrace sands, in a compound erosional bluff between the tributary valleys, and in a smooth slope in areas of deltaic deposition. Traces may be found of stages at approximate elevations of 75, 55, 40-45, 35 and 25 feet. Since the Montreal shoreline is undeformed, it may be expected that the 75-foot, 55-foot and 40-45 foot stages correspond with those at the same elevations in the lower Richelieu valley. Direct evidence of the continuity of these shorelines is lost in the Lanoraie delta, the raised area of early deposition at the head of Lake St. Peter.

In sum, differential uplift has had little influence upon the evolution of the drainage pattern of the area northeast of the St. Francis River. Its effect has been to reduce the gradient of the slope leading down to the St. Lawrence River, and hence of the streams draining it. However, as the main trend of the drainage pattern is at right angles to the isobases, there are no diversions of drainage which may be attributed to differential uplift.

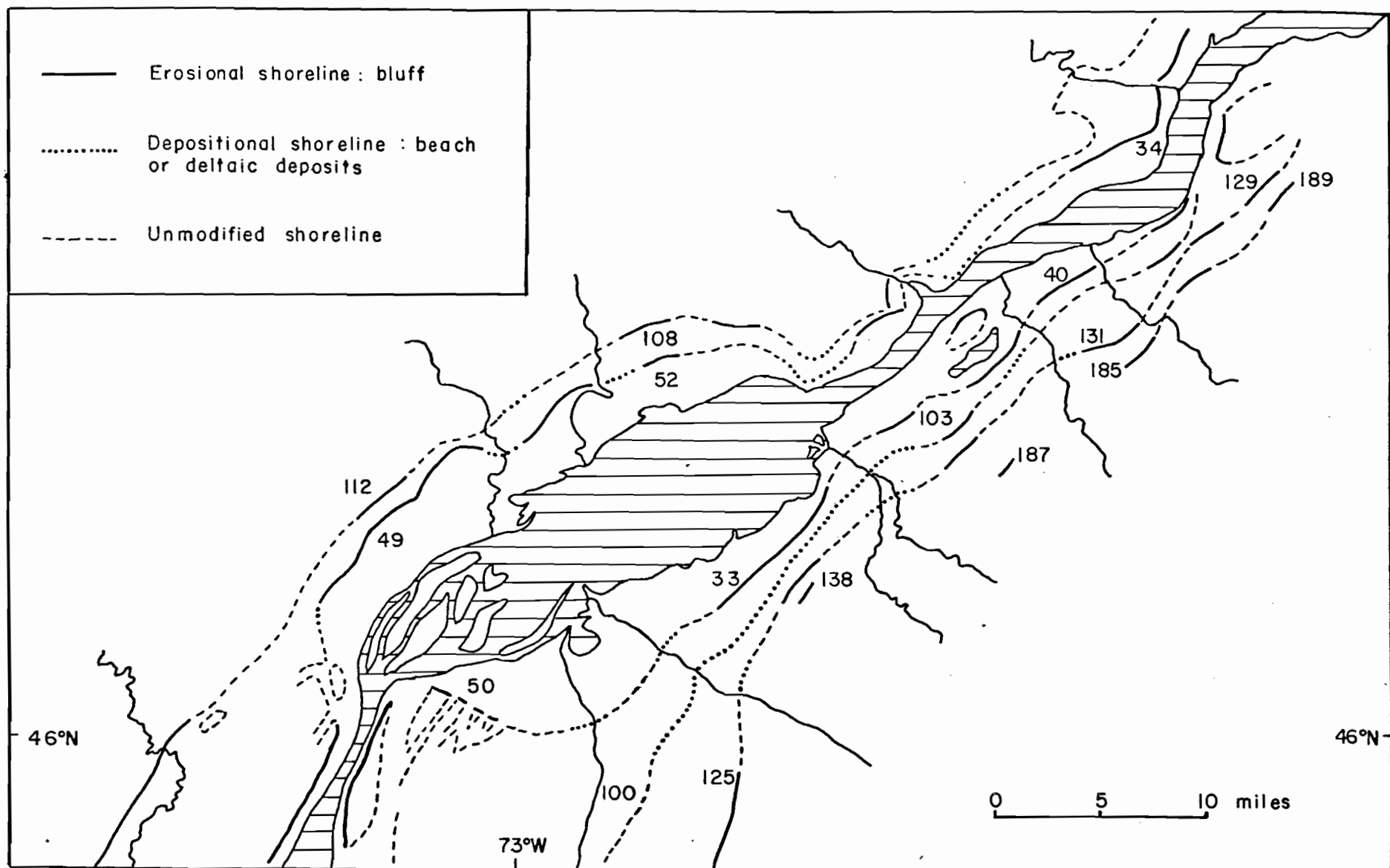


Figure 52. Significant shorelines in the northeastern Montreal lowland

CHAPTER VI

The development of the drainage pattern of the northern Montreal lowland

1. THE ASSOMPTION EMBAYMENT

East of the Oka-Beauharnois axis blunt upland salients and shallow lowland embayments alternate along the margin of the Shield. The drainage of the first of the embayments is collected by the Rivière l'Assomption, which enters the apex of the embayment through a hilly transition zone and flows, with many tortuous meanders, in a generally southerly direction through its own dissected delta (Figure 53). Below Joliette it crosses the 100-foot shoreline of the Montreal stage and swings to the south-southwest to gather the drainage of its major tributaries. These streams descend the scarped western margin of the embayment and follow roughly parallel easterly or east-southeasterly courses across the lowland. The south-southwest trend of the lower course of the Rivière l'Assomption is opposite to that of the St. Lawrence River, and it uses channels which appear formerly to have carried drainage to the northeast.

The Rivière l'Assomption presents three problems: the almost complete lack of tributaries in the upper part of its lowland course, and, indeed, of any significant left-bank tributaries; its tortuously meandering habit, unusual among the rivers of the lowland and, finally, the apparent reversal of its lowest reaches.

The lack of tributaries in the section above the Montreal shoreline results from the existence of the deep and extensive delta built by the river into high levels of the Champlain Sea. As the delta emerged the



Shield scarp



Upper Assumption and
Ouareau deltas

0 5 miles

from N.T.S. 1:250,000 map, Sheets 31 H,I

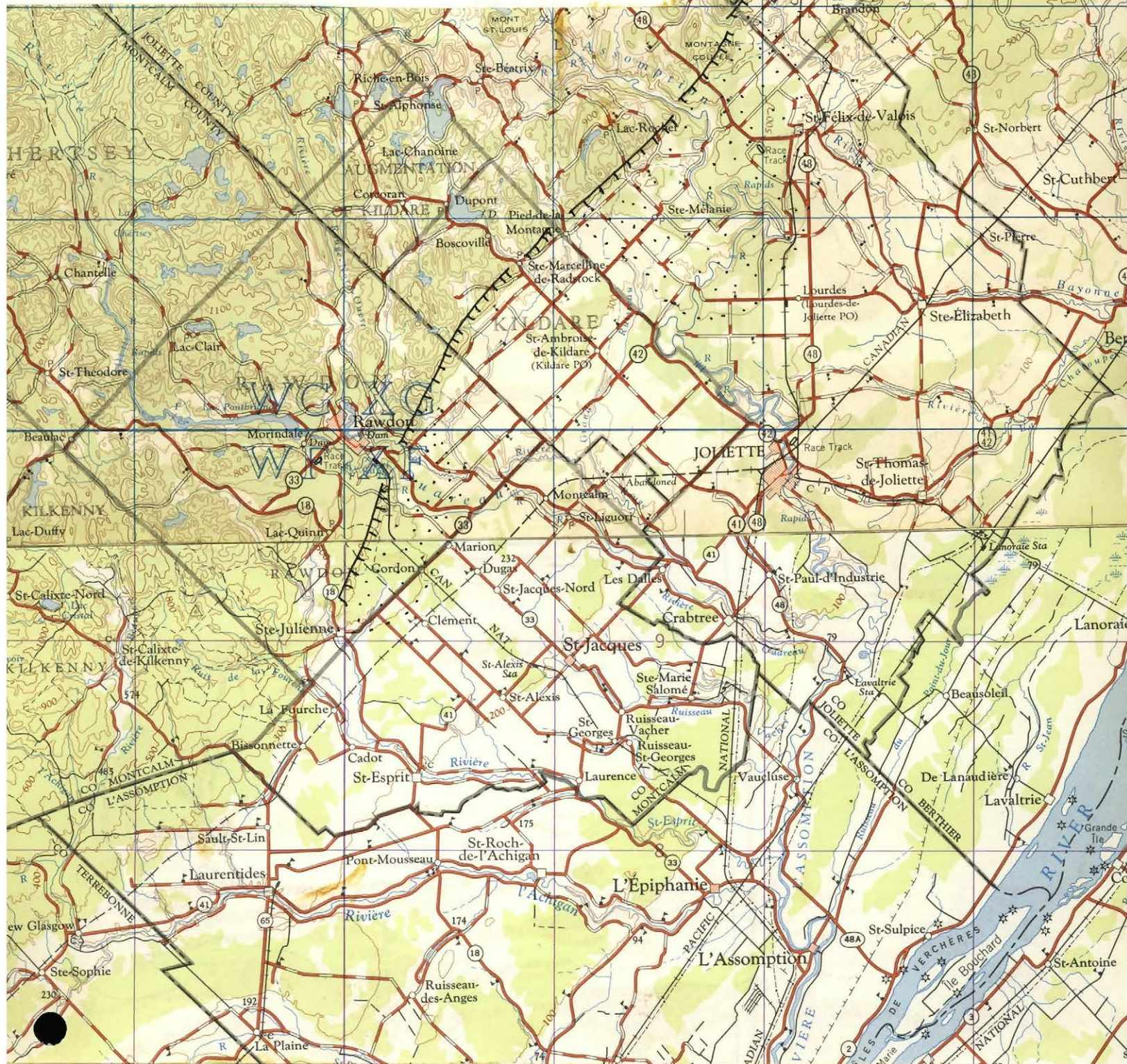
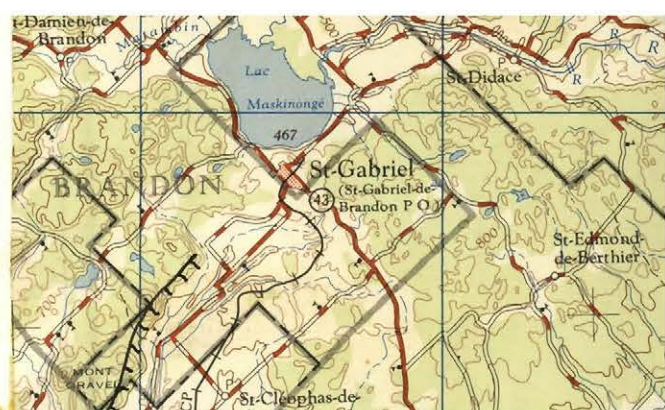


Figure 53. General map of the Assumption embayment

river became incised and minor drainage was thrown outward down the frontal slopes. The delta, in addition, has obstructed the possible entry of tributaries. Its eastern slopes extend almost across the mouth of the valley to the east, forcing the Rivière Bayonne toward the eastern valley wall. Similarly, to the west, the Grand Ruisseau is confined to a depression between the delta and a low outcrop of crystalline rock near St. Ambroise de Kildare.

The delta heads near the St. Faustin-St. Narcisse moraine near Ste. Béatrix, within the Shield, at an elevation of about 650 feet (Parry and Macpherson, in press). The section of the delta within the Shield is confined by the valley walls, but within the lowland it expands laterally and its upper surface slopes gently southward to an elevation of about 500 feet. The composition of the delta, as revealed in exposures in the valley side west of St. Félix de Valois, is given in Table 7.

Table 7

<u>Deposits of the Assomption delta</u>		
<u>Deposit</u>	<u>Elevation (feet)</u> (aneroid)	<u>Thickness (feet)</u>
6. Gravelly sand	537-531	6
5. Clay, laminar at base and grading downward to sand.	531-475	56
4. Sand	475-384	91
3. Massive silty clay, with pockets of silty sand.		
junction obscure	384-358	26
2. Bedded sand, overlain by bouldery material (downwash?) (this may be a later fluvial terrace deposit).		
1. Stony clay (till?) Flood plain	358-332	26+

The uppermost sand is the topset bed of the delta, deposited immediately before its emergence. Its contact with the underlying clay (5) is sharp, indicating that the two beds were deposited under different conditions, of shallow and deep water respectively. There is, by contrast, an upward gradation from bed 4 (sand) to bed 5 (clay), indicating either a deepening of water during their deposition, or a reduction in the amount and calibre of the load of the river, or both. It may be that the sand (4) is outwash from the St. Narcisse ice, and that the gradation to clay occurred as the ice front withdrew northward and the sea level rose. The lower clay bed (3) would thus have been deposited before the St. Narcisse readvance.

As the delta finally emerged the meandering course of the river was incised into the upper surface, while the outer slopes were worn back into bluffs or worked into beach ridges. Rapid fluvial erosion has created at the head of the delta an irregular lowland, diversified by abandoned meander scars and cores and terraces at many elevations (Figure 54). No attempt will be made to correlate these features. On the outer slopes of the delta, where the features are attributable to wave action, bluffs, beach-ribbed slopes, and smooth slopes all occur within the same range of elevation, making correlation impossible. The conspicuous bluff bounding the western part of the delta at Ste. Mélanie, its foot close to 370 feet above sea level might, for example, be expected to have a counterpart east of the river, but none exists. Within the delta the features were developed by fluvial action. The present river, with its swinging meanders and considerable gradient, although held locally upon bedrock where rapids occur, appears to be of essentially similar character to its earlier stages (Profile of Rivière l'Assomption, 1933), and it is not to be



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Figure 54. The upper Assomption delta
 Elevations in feet. Significant bluffs on the outer slopes of the delta are emphasized.

expected that the features would provide any clear evidence of stands of base level. All that can be said is that the delta appears to have emerged rapidly, and that the bluffs which were cut in its outer slopes do not represent relative stands of sea level but, rather, local conditions of erosion during a period of emergence.

The meandering character of the river, the second of the problems listed above, may be related to the relative cohesiveness of the laminated clay (bed 5) which the river encountered beneath the shallow top-set sand (Schumm, 1963). Once established, the meandering habit is likely to be maintained (Leopold, Wolman and Miller, 1964). This is not a wholly adequate explanation, however, for the major tributaries of the Rivière l'Assomption, the rivers Ouareau and l'Achigan, flowing as they do across the clay plain of the emerged sea floor, do not display meanders of comparable tortuosity. Several factors may account for the differences: the smaller gradient of the delta surface compared with that of the sea floor; the great depth of unconsolidated deposits in the delta, which permitted the river to swing widely before its course was fixed on bedrock, and differences in the calibre and quantity of the load carried by the rivers. Until the factors causing meandering are fully understood it is possible only to point to the Rivière l'Assomption and its tributaries as an interesting example.

The tributaries are confined not only in the vertical sense, by the relative shallowness of the superficial deposits into which they have become entrenched, but also in plan, by outcrops of rock and till which rise through the marine sediments, particularly near the Shield margin. These had their effect as the sea floor emerged, confining drainage to the intervening depressions. Mention has already been made of the rock outcrop

at St. Ambroise de Kildare. The clay-floored depression which surrounds it has developed a miniature text-book example of an annular drainage pattern. The two tranverse limestone ridges which lie across the course of the Rivière l'Assomption at and below Joliette, however, have had no effect upon the drainage in plan, although the river descends over the upper ridge in a considerable fall, providing the power site on which Joliette is based.

In plan, the tributaries of the Rivière l'Assomption appear to be part of the same series as those which flow across the Terrebonne sand plain, but their history has been very different. Their valleys have experienced neither the extensive deltaic deposition nor the powerful scouring which shaped the channels of the sand plain, nor have the streams suffered the same many-fold diminution of flow. The valleys are in many ways similar to that of the Yamaska River in the upper part of its lowland course: incised within the clay plain, widened to some extent by meandering and landslips, and with rapids where the river is held upon bed-rock.

The character of the valleys changes abruptly, however, where the rivers cross the shoreline of the Montreal stage of the Champlain Sea. This feature, which, as the Grand C[^]ôteau, truncates the Terrebonne sand plain, continues to the northeast as a conspicuous bluff, with its foot generally at elevations of between 100 and 110 feet. The crest of the bluff decreases in elevation northward, and the feature diminishes in height, until, where it is crossed by the Rivière l'Assomption, it is but one low bluff in a series. Below the bluff the valleys open out and the streams are little incised into the floor of the former water body. The surface of this low plain is diversified by the island terraces of the Lanoraie delta,

by accumulations of peat in depressions, and by low mounds of material which is mapped as "till-like material from floating ice" (Soil map, l'Assomption-Montcalm counties, 1962). The trend of all these features is northeast-southwest, a trend which is reflected in the drainage pattern.

The Rivière l'Assomption finds its way to the south-southwest between the island terraces at the head of the Lanoraie delta. After receiving the waters of its major tributaries it diverges from the Montreal shoreline to follow a channel closer to the St. Lawrence River. The northeastern part of the channel is drained by the Ruisseau du Point du Jour, its only left-bank tributary of any size. This stream enters the Rivière l'Assomption where it describes an almost circular meander at the town of l'Assomption. Below this point the course of the river is almost straight, but the trace of a meandering river crosses the interfluvium between the Rivière l'Assomption and the St. Lawrence River three miles above the confluence. This appears to be a former course of the Rivière l'Assomption. The river was probably diverted into its present course as a result of capture by a small southward-flowing stream. Such a capture would have been facilitated by the interfluvium's core of "till-like material".

The southward course of the Rivière l'Assomption below the Montreal shoreline is related to the Lanoraie delta and will be discussed in that context.

2. THE LANORAIE DELTA

The Lanoraie delta lies on either side of the St. Lawrence River above the head of Lake St. Peter. Numerous sand-capped island terraces are separated by anastomosing channels floored with clay, or partly choked with accumulations of peat (Figure 55). The channels of the St. Lawrence

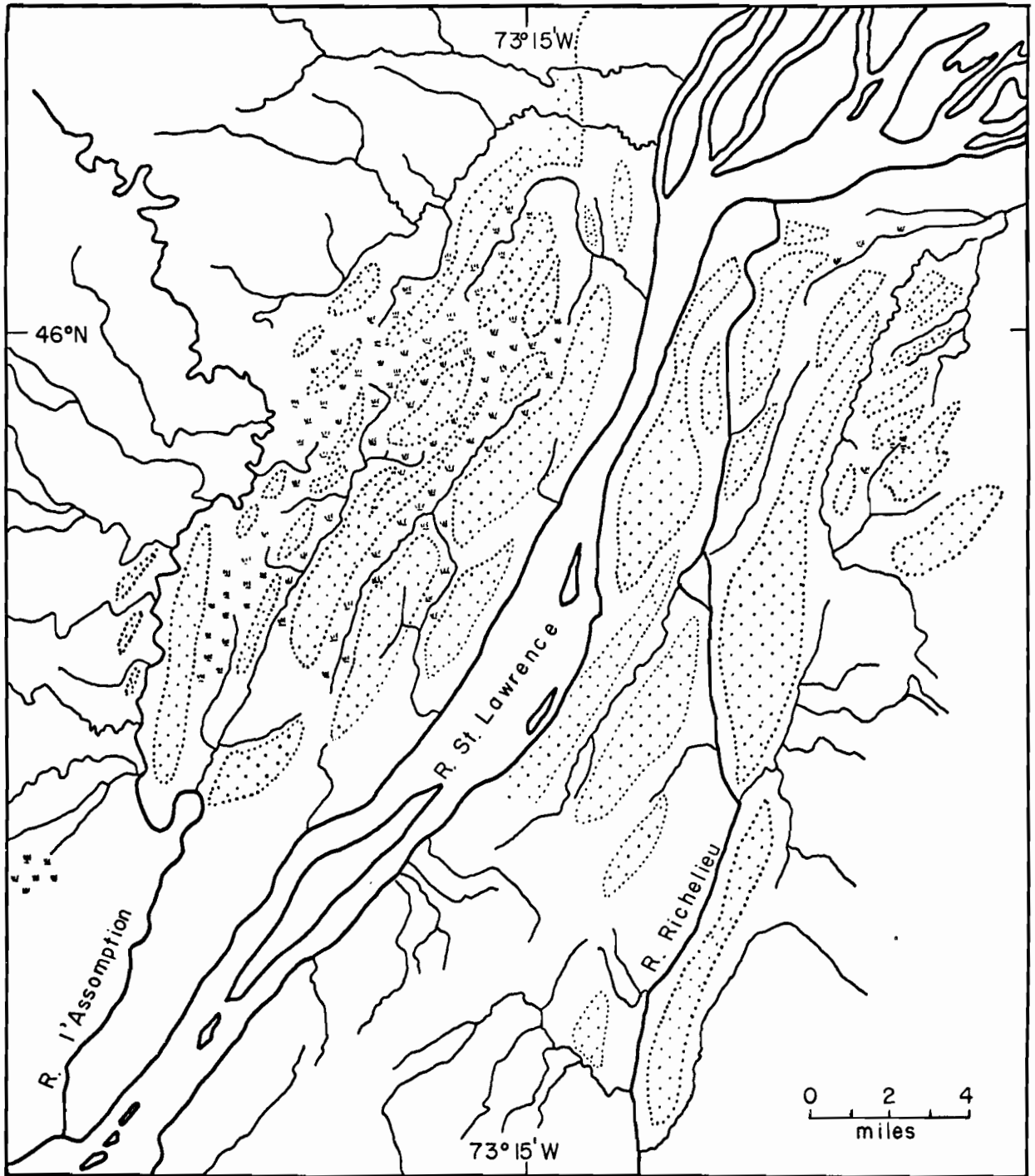


Figure 55. The island terraces of the Lanoraie delta and related drainage pattern

and Richelieu rivers have been cut to greater depths than the others, and, in general, the elevations of the channel floors increase toward the outer margins of the delta.

The delta lies within the 100-foot shoreline of the Montreal stage (Figure 56). A few of the island terraces rise almost to the 90-95 foot level of the lower Montreal phase, but summit elevations are in general somewhat lower, between 75 and 90 feet above sea level. There is some indication of the downstream extension of the delta with a relative fall in the water level, for the crests of some of the downstream terraces fail to reach 75 feet in elevation. The terraces at the lower end of the delta have been truncated by the 45-50 foot bluff surrounding Lake St. Peter.

It is not clear why deltaic deposition began in this position. Deltaic accumulations of sand at higher elevations bear some relation to former river mouths, or to higher ground, but upstream of the Lanoraie delta the surface of the lowland is lower, if by only a few feet, than the summits of the island terraces. There is no evidence to suggest that the area was reduced to its present elevation by the removal of an upstream section of the delta. Faint shoreline bluffs which cross the area between the lower Rivière l'Assomption and the Grand Côtéau trend toward the head of the delta, and suggest a gradual shallowing and channelling of the floor of the former Montreal water body, rather than any large-scale erosion.

It appears then, that the relative height of the delta is an original feature, and while it was being formed it would have lain across the estuary, dividing it into a lower section, an expanded Lake St. Peter, and an upper section, with many islands, including Montreal Island and Ile Jésus. Although tributary rivers, the Richelieu and l'Assomption,

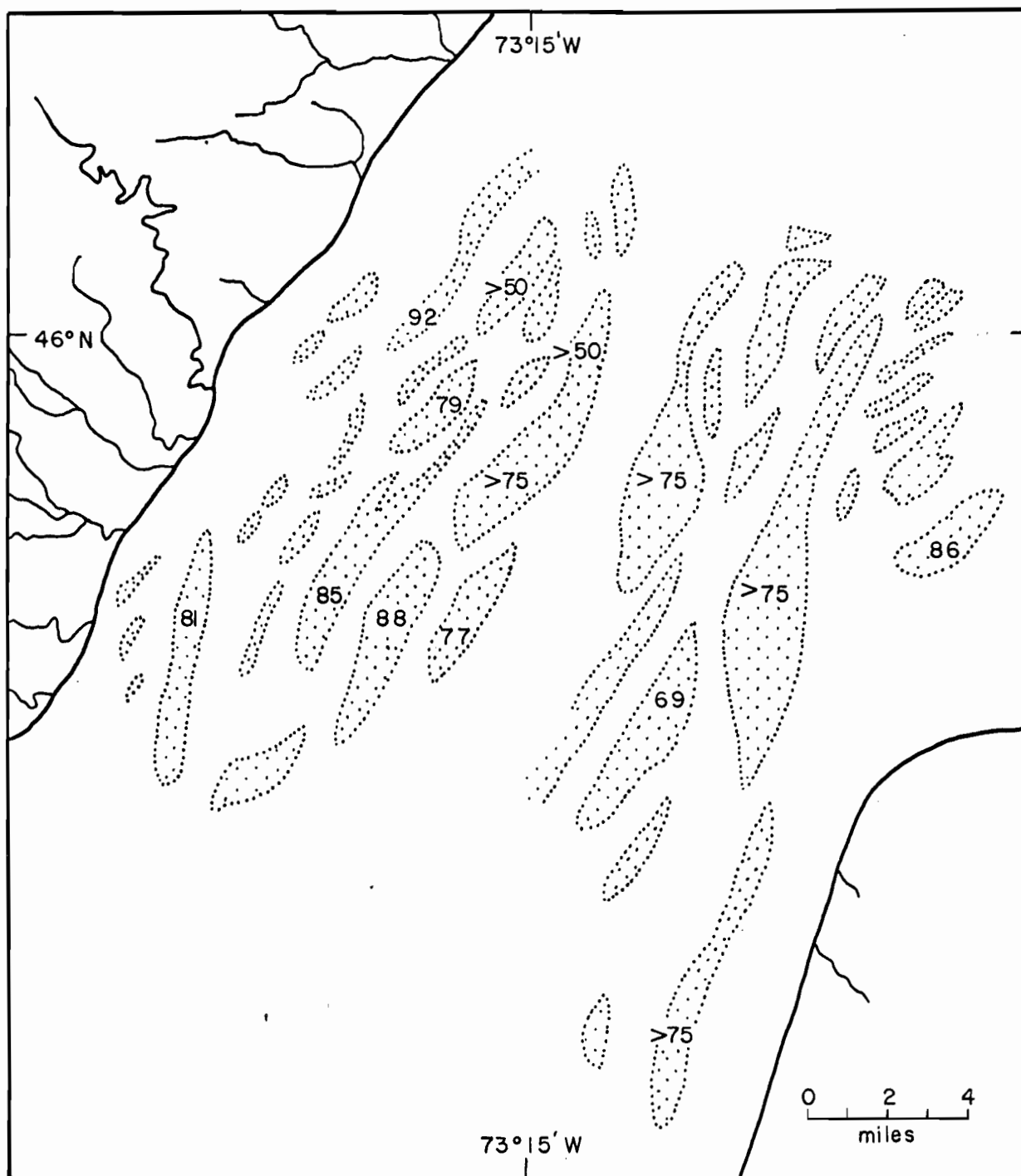


Figure 56. The submerged shoals of the Lanoraie delta at the Montreal stage
(elevations in feet above present sea level)

contributed sediment, the delta was formed by forces operating along the St. Lawrence valley. The shoaling of the floor of the water body at this point may have been due to tidal action. Robinson (1960) cites examples of sedimentation associated with ebb-flood channel systems in sandy estuaries, and Price (1963) compares the present patterns of sand-bar shoals and channels in the Chesapeake and Delaware bay estuaries with those of tidal deltas. The linear shoals described by Price strongly resemble the emerged island terraces of the Lanoraie delta.

As the crests of the linear shoals emerged, the flow was confined to the channels. The marginal channels with higher floors were the first to be abandoned (Figure 57), and with the concentration of flow into the central channels they were scoured and deepened. Those channels remote from major streams became swampy. The accumulation of peat has been much more extensive north of the St. Lawrence River, where the major tributaries skirt the delta, than to the south, where the Richelieu River and its tributaries provide outlets for the drainage of the channels. The accumulation of pollen-bearing sediment in the Lanoraie bog, north of the St. Lawrence River, began in pollen zone II, while the earliest pollen assemblage of the Ste. Victoire bog, east of the Richelieu River, is attributable to pollen zone III (Potzger, 1953). Thus the specific palynological evidence of the relative age of the delta is in agreement with the general conclusion regarding the relative age of the 100-foot shoreline (Chapter III).

It is not certain that Potzger sampled the deepest and oldest part of the Lanoraie bog, for at the sampling site the peat was 8.5 feet thick, while the maximum thickness may be as much as 10 feet (Lasalle, 1963) or even 20 feet (Scott et Thériault, 1940). Moreover the exact sampling site

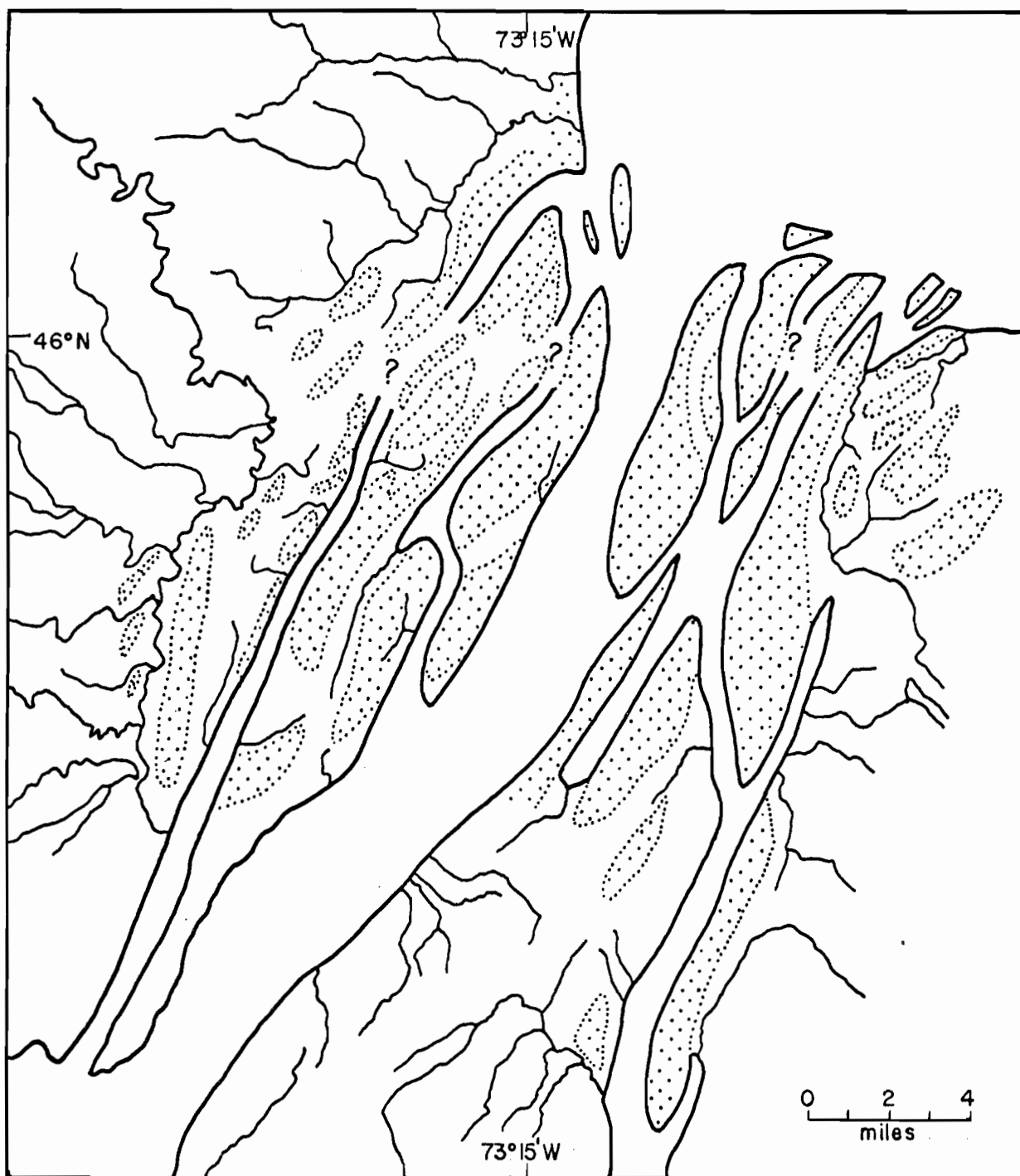


Figure 57. The 50-foot shoreline in the Lanoraie delta

is not known. In connection with the southward course of the Rivière l'Assomption it would have been convenient if data were available on the bog which occupies the channel near the northwestern margin of the delta into which the river emptied when the delta began to emerge, and which it now follows. Ritchot (1960) claimed that the river continued to flow northeastward through the channel until capture diverted it into the present southward course, citing as evidence features which he interpreted as meander scars on the flank of an island terrace south of Lanoraie Station. If his interpretation is correct, the peat on the channel floor should be younger than other bogs at the same elevation, and this is what Potzger's work suggests. However, Blanchard (1953) had previously suggested that the southward course of the Rivière l'Assomption was due, not to capture, but to a fine adjustment to the form of the emerging sea floor.

The present writer favours Blanchard's view. Fluvial erosion has played little if any part in shaping the channel northeast of the point where the Rivière l'Assomption enters it. The features which Ritchot identified as meander scars are re-entrants between cusps on the inner side of a compound spit built across the mouth of the river (Figure 58). The floor of the channel does not have an even slope. It is highest between the spit and the "mainland" where it lies at about 65 feet above sea level, and it descends northward beneath the blanket of peat. Remnants of the channel floor to the south, where it has been dissected by the river, also lie at elevations below 65 feet. Thus the first part of the channel floor to emerge lay between the spit and the former shoreline; the river could take no other path than that open to the south. The height of the channel floor near the former mouth of the river could well have resulted



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Figure 58. Island terraces of the Lanoraie delta

Bog (dark tone) occupies the floors of channels between the sandy island terraces (light tone). The irregular terrace, centre, is a cusate spit.

from deposition by the river itself.

When sea level had fallen to about 50 feet (Figure 57) the Rivière l'Assomption drained into a channel which is followed today by the Ruisseau du Point du Jour. It is not clear whether the channel was open to the northeast at this stage or whether it was already blocked by silting and possibly also by peat accumulation. If it were blocked it would be easy to explain the continuing southward course of the river below the town of l'Assomption. Otherwise it would be necessary to invoke capture, similar to that which occurred near the mouth of the river. Tilting can be invoked to account for neither of the two apparent diversions, since uplift at the Montreal and later stages was uniform.

3. THE ST. MAURICE EMBAYMENT AND ADJACENT AREAS

a. Drainage diversions associated with the St. Narcisse moraine

The upland salient between the Assomption and St. Maurice embayments is almost separated from the main part of the Shield by the former and present courses of the Rivière Maskinongé. The preglacial river led south through the depression now drained by the Rivière Bayonne. The St. Gabriel delta, part of the St. Narcisse moraine system, was built across the valley into a water body at about 700 feet above present sea level. When the ice retreated the delta dammed the southward drainage, and the lake which formed spilled eastward into the valley of another preglacial stream to initiate the present course of the Rivière Maskinongé below Lac Maskinongé (Figure 45). This valley was itself plugged with drift associated with the St. Narcisse moraine, creating the minor diversion at Ste. Ursule falls, where the river descends the scarped western margin of the St. Maurice embayment (Elson, 1962).

The St. Narcisse moraine may be traced to the northeast, along the margin of the Shield and across the lowland at the head of the St. Maurice embayment, where the ice readvanced into the Champlain Sea. The moraine is the site of a number of diversions of drainage, which will be described below.

The Rivière du Loup leaves the Shield where it is bordered by a double scarp (Figure 59). The river cuts through the outer scarp in a rocky gorge east of the village of St. Paulin. The St. Narcisse moraine crosses the valley at the head of the gorge, swings westward across the depression between the two scarps, and continues along the crest of the inner scarp above the village of Prémont. Here it is bordered by a feature which appears to be an outwash delta, at an elevation of about 700 feet. Below this level gravel terrace the scarp face is thickly blanketed with marine sediments, in which a series of conspicuous bluffs has been cut. The Prémont basin opens southward, and is drained by the headwaters of the Petite Rivière du Loup.

The village of St. Paulin lies north of the moraine, in a basin which is the continuation of the depression between the two scarps. Like the Prémont depression it has been filled with water-laid sediments, but since it has been protected from marine and fluvial erosion the level surface of the deposits is almost undissected, and forms a plain at an elevation of a little more than 500 feet, through which protrude low bedrock hills. The Rivière du Loup enters the basin through a gap in the inner scarp, and finds its way in a great curve close to the margin of the water-laid deposits, cutting through the outer scarp in the gorge below the moraine.

It is possible that the preglacial Rivière du Loup, like the



from N.T.S. 1:250,000 map, Sheet 31 I

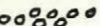
-  Shield scarp
 Preglacial stream course
 St. Narcisse moraine
 Till outcrop in lower St. Maurice delta
 400-foot contour at margin of upper St. Maurice delta
 Abandoned post-Champlain stream course
 Meander scar in lower St. Maurice delta, with elevation
- 0 5 miles

Figure 59. General map of the St. Maurice embayment

present river, cut through both inner and outer scarps in succession. It is also possible, however, to suggest courses by which the preglacial drainage of the St. Paulin basin and of the Rivière du Loup valley above the inner scarp may have been carried by separate streams into the Premont depression (Figure 59). The suggested preglacial drainage courses have not been examined in detail, and the published map of soils (Godbout, 1962) does not provide evidence adequate to prove the suggested diversions.

After the withdrawal of the Champlain Sea the Rivière du Loup appears to have spilled eastward from the St. Paulin basin through a small pre-existing valley, from which a fill of unconsolidated deposits has since been partially removed. The preglacial origin of the valley is attested by the presence of till at river level below the gorge which has been cut in the outer Shield scarp. The gorge itself is cut in rock, however, and it seems that the river was not superimposed directly over the line of the buried valley.

Beyond the Rivière du Loup the crest of the St. Narcisse moraine rises to an elevation of 550 feet in the Charette ridge. The summit of the ridge experienced intensive wave action during its emergence from the Champlain Sea and some of the fabric of the moraine was redeposited as northward-dipping beds on its inner flank. The depression north of the moraine trapped sediments brought into the sea by rivers issuing from the Shield. It is likely that in preglacial time these rivers pursued independent southward courses, but today their drainage is collected by the Rivière Yamachiche which flows eastward along the floor of the depression (Figure 60). The crest of the moraine decreases in elevation eastward as it descends the slope of the buried preglacial lower St. Maurice valley, until it is buried by water-laid sediments. Here it was possible for the



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Figure 60. Control of the Rivière Yamachiche by the St. Narcisse moraine
 Elevations in feet. A series of water marks crosses the clay plain south
 of the moraine.

Riviere Yamachiche to cross the line of the moraine and to resume its normal southward course.

The moraine reappears east of the St. Maurice valley in the Valmont ridge, and Gadd and Karrow (1960) suggest that the gap was cut by the river. However, till of the type associated with the moraine is mapped by these workers in the river banks in line with the two ridges, confirming Crosby's hypothesis (1932) that the lower St. Maurice River followed a preglacial valley, which he traced northward into the Shield from below Shawinigan Falls. Above Grand Piles he postulated that the river followed a parallel preglacial valley whose buried lower course continued to the southeast beneath Lac à la Tortue. He suggested that the section of the St. Maurice River between Grand Piles and Shawinigan was recent, and that the falls at Shawinigan marked the point where the diverted section of the river plunged into the more westerly preglacial valley. Following Crosby's hypothesis, the high section of the moraine at Valmont lies across the preglacial interfluvium, while the lower elevation of the section southeast of Lac à la Tortue indicates that the moraine crosses the more easterly of the preglacial valleys at that point.

Lac à la Tortue lies in a shallow depression in a broad plain which extends between the moraine and the hills at the apex of the St. Maurice embayment. The morainic ridge has diverted minor streams and has served to protect the plain from erosion. Along the line of the Canadian Pacific railway south of the lake the surface of the plain descends southeastward at the rate of eleven feet per mile. The slope appears to be radial from the apex of the embayment, for the 400-foot contour bounding the undissected inner portion of the plain is of arcuate form, suggesting that the feature originated as a delta (Figure 59). It is, according to

Béland (1961), composed of marine clay veneered with sand. It was deposited when the morainic ridge offshore converted the head of the embayment into a gigantic settling basin for sediment brought in by the St. Maurice River. If this hypothesis is accepted, then the diverted section of the St. Maurice River flows along a radius of the delta at the margin of the Shield upland. The corresponding position east of the delta is occupied by the small Rivière des Envies, which drains into the Rivière Batiscan.

As a result of the massive deposition of marine sediments and the burial of the preglacial topography at the head of the St. Maurice embayment, only major diversions of drainage are evident. The minor streams have developed on the surface of the unconsolidated deposits with little reference to the preglacial topography. It is significant, however, that the only streams to cross the line of the St. Narcisse moraine between the St. Maurice and Batiscan rivers are the Rivière au Lard and the Rivière la Fourche, which cross the low point of the moraine which is thought to lie over the buried valley southeast of Lac à la Tortue.

To the east the moraine traverses the upland salient between the St. Maurice and Ste. Anne embayments. Here the distinction between upland and lowland is blurred, for the low elevation of the Shield surface permitted the widespread deposition of marine sediments. Neither this deposition, however, nor intensive wave action, served to obliterate the moraine where it crosses the salient, and it has been a factor in the location of minor drainage lines, such as the Rivière des Chutes which flows along its northern flank into the Rivière Batiscan. This stream itself appears to have been diverted westward before crossing the moraine, which here lies at the crest of the low scarp bounding the Shield. A depression

in the scarp, in line with the upper, evidently preglacial, section of the Batiscan valley, may indicate the former course of the river.

b. The development of the drainage pattern during the later stages of the Champlain Sea regression

i. The lower St. Maurice delta. As the heads of the lowland embayments emerged, rivers found their way through low points in the moraine toward the retreating shoreline to the south. The St. Maurice River began to incise itself into its upper delta north of the moraine, and to develop the lower delta to the south. The lower delta heads at Shawinigan Falls and projects into Lake St. Peter. Deltaic conditions still prevail at the river's mouth, where it divides into the separate channels which give the city of Trois Rivières its name. The present river appears to follow the line of a major earlier distributary, for the delta is markedly lobate about the river mouth. The persistence of this course results from the existence upstream of a mass of till which diverted the flow into an eastern channel, the present course, and a western channel now drained by the small Rivière aux Sables. The delta lobe associated with this channel projects into Lake St. Peter at Pointe du Lac (Figure 59). The abandoned upper floor of the channel is now about 200 feet above sea level. A series of similar abandoned channels has been traced, diverging westward from the present river (Figure 61). Terasmae (1960a) showed that pollen-bearing sediment began to accumulate in the Marchand channel, at an elevation of 200 feet, in pollen zone III; in the St. Etienne channel, at 290 feet, in pollen zone IV, and in the St. Boniface bog, at 350 feet, in pollen zone V. Thus the evidence indicates the sequential abandonment of the channels. However, bog development was delayed at these sites, so that they cannot be



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Figure 61. Abandoned channels and meander scars of the lower St. Maurice delta (elevations in feet)

dated relative to other bogs in the lowland. Hence it is not possible to suggest relative dates for stages in the development of the delta.

Deltaic accumulation was not confined to the St. Maurice delta proper, but extended for some distance down the St. Lawrence valley. The low land adjacent to the St. Lawrence River is backed by a bluff which truncates a sandy terrace whose surface is a little more than 100 feet above sea level. A shallow peat-filled depression runs the length of the terrace, and appears to have carried some or all of the St. Maurice water into the St. Lawrence River at the Montreal stage.

The outer slopes of the delta lack the conspicuous erosional bluffs of the Assomption delta, reflecting the greater availability of material for deposition. While deposition continued at the delta front the river was incising its bed upstream, into the upper delta above the St. Narcisse moraine and into the upper part of the lower delta below Shawinigan Falls. Slips in the valley sides brought down additional quantities of fine sediment.

There was lateral erosion near the mouth of the main distributary, for broad meander scars are cut into the unconsolidated sediments on either side of the present river (Figures 59 and 61). The elevations of the feet of the meander bluffs are about 190 feet, 175-180 feet, 125 feet and 100 feet above sea level. The amplitude of the meanders decreases with decreasing elevation, indicating a corresponding decrease of discharge. Minor tributaries follow the depressions at the feet of the meander bluffs.

ii. The clay plain west of the St. Maurice delta. The stages indicated by the meander bluffs in the St. Maurice delta are not conspicuous in the western part of the St. Maurice embayment. This area received thick deposits of marine sediment, upon which a roughly parallel drainage pattern

has developed. The streams have become deeply incised, and landslip scars are a common feature of the landscape. The interfluves descend in a series of steps toward the St. Lawrence River (Figure 60). Shoreline bluffs may be traced from one interfluve to the next, and the best-marked have been measured at elevations of approximately 390, 300, 260, 216, 170, 108, 96 and 52 feet above sea level. None of these shorelines, nor the meander scars in the St. Maurice valley may with certainty be correlated with the conspicuous shorelines at 130 feet and 185 feet south of the St. Lawrence River, as there is insufficient evidence of the form of the boundary plane between pollen zones V and IV in the area north of Lake St. Peter.

Above the 50-foot shoreline the clay plain is continuous with that which flanks the upland salient between the St. Maurice and Assomption embayments. The upland approaches to within 6 miles of the St. Lawrence River at St. Barthélemy, and only one shoreline, at 112-116 feet above sea level, crosses the narrow upper section of the plain (Figure 52). This shoreline may be referable to the upper Montreal phase.

It appears that the water level stood at the foot of the 50-foot bluff for some time. At St. Barthélemy the bluff is cusate in plan; a bedrock outcrop inhibited retreat of the cliff at the apex of the cusp while wave action continued to cut back the marine clay on either side. Elsewhere north of Lake St. Peter several streams developed deltas where they discharged into the 50-foot water body. The shoreline not only marks a significant period of relative stability of base level, it is widespread, water marks at similar elevations being found as far upstream in the St. Lawrence and Richelieu valleys as Montreal and Chambly Basin. It is appropriate, therefore, that this stage of the Champlain Sea be accorded a

name, and it will be referred to as the St. Barthélemy stage.

A 50-foot stage around Lake St. Peter was discussed by Goldthwait (1933). He noted that the bluff foot was cut down to lower elevations in places, and claimed that the terrace below the bluff had a down-valley gradient resulting from the action of tides and currents. Karrow (1957), however, noted a terrace at 25-30 feet above sea level extending downstream for some miles below Batiscan, and it appears probable that it was formed during a stage which followed the St. Barthélemy stage. The low elevations of the bluff foot elsewhere are presumably the result of emergence also. Indeed, bluffs below 50 feet south of Lake St. Peter were accounted for in this manner in the preceding chapter.

The Rivière du Loup describes a curious westerly arcuate course below the St. Barthélemy shoreline, which appears to be related to features which developed offshore. Aerial photographs indicate a pattern of eastward-trending low bars or spits (Figure 62) and it might be expected that a river would have been deflected eastward rather than westward. However, it is possible to find features on the south shore of Lake Ontario, near Rochester, New York, which illustrate the course of the Rivière du Loup on a much smaller scale. The mouths of streams normally migrate eastward with the prevailing drift of beach material, but occasionally a stream flows westward along a beach depression to reach the lake. Figure 63 shows a stream which divides on entering a depression in the beach parallel to the shoreline; it is possible that in time the western branch will predominate. The mouths of these small streams are often marked by large meander scars; the arcuate course of the Rivière du Loup may have been inherited from a former mouth of this type. The high-level meander scars in the St. Maurice delta were formed in a similar manner.



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Figure 62. The course of the Rivière du Loup below the 50-foot shoreline
The 50-foot shoreline bluff is indicated by a broken line; dotted lines enclose spits.



A



B

- A. Stream mouth seen from the west. A branch of the stream flows westward behind the spit before cutting through the neck of the spit.
- B. The bifurcation of the stream in the depression behind the spit, seen from the east.
- C. The eastern mouth of the stream, showing meander scars.



C

Figure 63. Shoreline features, Lake Ontario

CHAPTER VII

Conclusions

1. GENERAL REMARKS

In the preceding chapters the evolution of the drainage pattern of the Montreal lowland has been examined on a regional basis. Stages in the evolution, marked by shorelines at successive elevations, were recognized in many of the regions and some attempt was made at correlation. It is appropriate, therefore, in a concluding chapter, to bring together the regional evidence and to describe the drainage pattern of the lowland as a whole at certain significant stages of its development. A review of the regional evidence also makes it possible to assess the relative importance of the factors which controlled the developing drainage pattern.

2. STAGES IN THE WITHDRAWAL OF THE CHAMPLAIN SEA AND RELATED DRAINAGE DEVELOPMENT

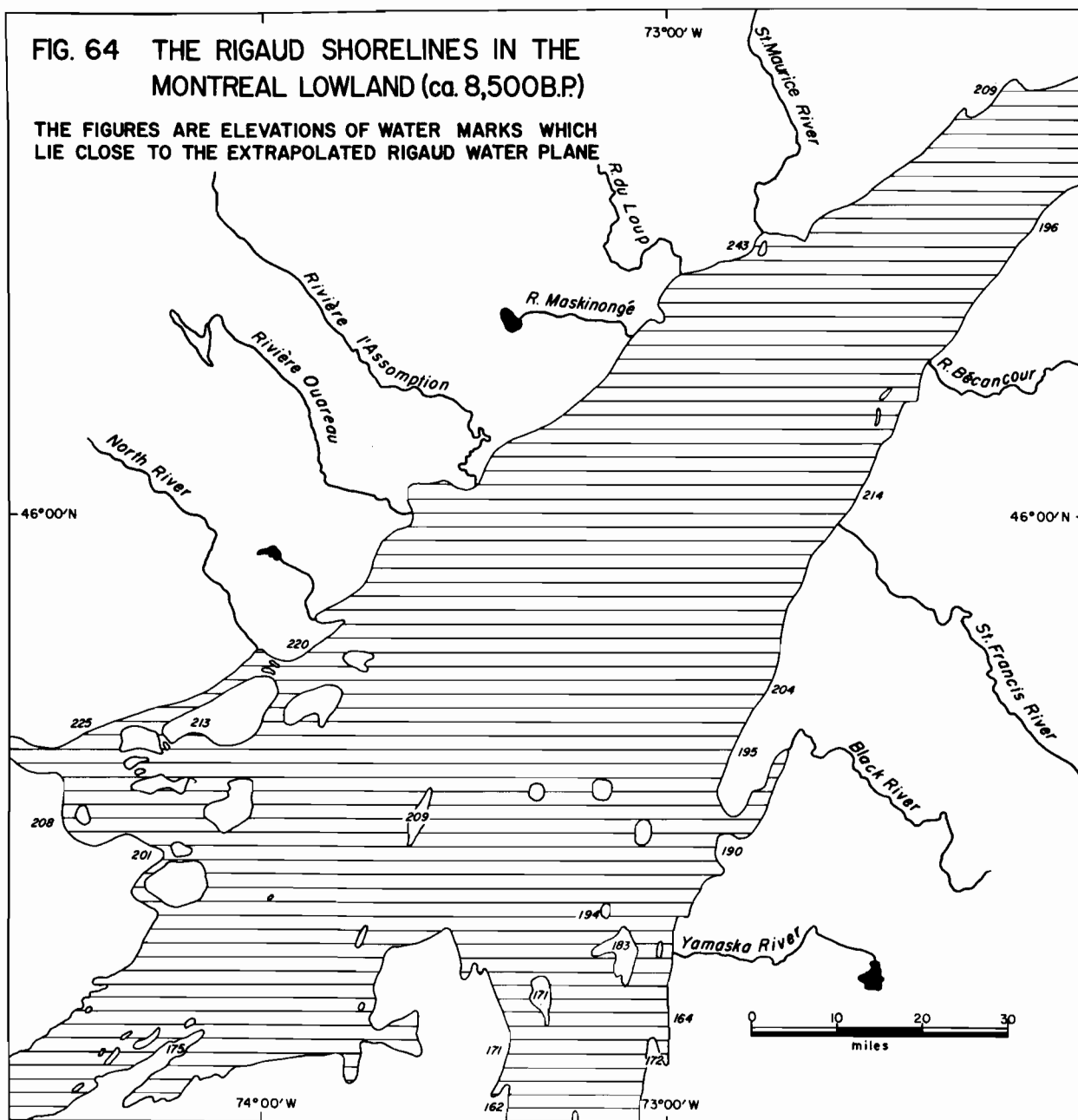
a. The Rigaud stage

The stages of the Champlain Sea which have been selected for discussion are related to the "200-foot" Rigaud shoreline, the 100-foot Montreal shoreline and the 50-foot St. Barthélemy shoreline. Goldthwait (1933) regarded these shorelines as marking significant stages of the retreating sea, and they are, indeed, conspicuous features of the landscape. It is not for that reason alone, however, that the stages that they represent have been selected.

The Rigaud stage is the earliest to be discussed, for in the preceding stages of the emergence the shoreline of the Champlain Sea lay

within or close to the margins of the bounding highlands and very little of the Montreal lowland was exposed to sub-aerial processes. Again, although some of the higher shorelines are very well-marked they are discontinuous and may not readily be correlated into successive stages, particularly as the palynological evidence at these elevations is also scanty. The Rigaud shoreline, by contrast, is fairly persistent in the type area, the lower Ottawa valley. Its tilt may be calculated from measured elevations, and when the water plane is projected into the Lake St. Francis basin it is found to coincide with one of the few better-defined shorelines there (Chapter IV). Moreover, the boundary surface between pollen zones V and IV was found to lie some 10 feet higher than the Rigaud shoreline in the lower Ottawa valley, and its tilt, calculated from independent evidence, is of the same order of magnitude (Chapter III). Since isobases on the deformed pollen boundary surface have been drawn for the greater part of the lowland it is possible to project the Rigaud water plane beyond the lower Ottawa valley, on the basis of the relationship of the two surfaces in that area.

Figure 64 shows the location of the extrapolated Rigaud shoreline throughout the lowland. It will be noted that it coincides in elevation with a number of measured water marks in widely separated localities. It may be that these water marks were in fact produced at the Rigaud shoreline but it must be remembered that there is frequently a suite of closely-spaced shoreline features at about the required elevation, and it is not surprising that one member of the suite should coincide in elevation with the hypothetical water plane (Figures 41 and 51). It should also be noted that the deformation of the water plane has been such that it now lies at an elevation of close to 200 feet above present sea level across much of the



lowland. Goldthwait (1933) attempted to correlate widely separated shoreline features at about 210 feet above sea level on the basis of elevation; this procedure was theoretically unsound as he failed to make allowance for tilting, but the evidence here put forward provides practical justification of his correlation.

The Rigaud water plane lies at an elevation of about 160 feet at the international boundary in the Champlain-Richelieu depression, and cannot be correlated with any of the stages suggested by Chapman (1937). Its tilt is comparable with that of the Plattsburg water plane, but features which Chapman ascribed to the Plattsburg stage occur at elevations greater than 200 feet.

At the Rigaud stage the head of the estuary lay in the Ottawa valley west of the area of study. Branching estuarine channels were cut in unconsolidated deposits in the lower Ottawa valley, while broad embayments occupied the basins of Lake St. Francis and Lake Champlain. At the eastern margin of the lowland the shoreline lay close to Logan's Line, while to the north the heads of the Assomption and St. Maurice embayments had emerged. The present elevation of the shoreline in the St. Maurice embayment is doubtful, as the palynological evidence was inadequate to establish the elevation of the V-IV boundary surface. The estuary decreased in width toward the narrows at Quebec.

Why is the shoreline so conspicuous only in the lower Ottawa valley and the adjacent Terrebonne sand plain? The principal reason has already been discussed: the discharge through the Ottawa valley of the outflow from Lake Barlow-Ojibway. The floors of the channels through which the current swept were soon to be raised above sea level and their bounding bluffs preserved. The erosive effects of the current would have been less

strong if the area had not previously received thick deposits of sediment carried into the sea by rivers charged with glacial melt-water. The current was dissipated in the more open parts of the estuary, so that shoreline features were less pronounced, even where there were unconsolidated sediments of a depth comparable to those of the lower Ottawa valley.

In those parts of the lowland that had emerged at the Rigaud stage the drainage pattern was little different from that of today. On the Ottawa-St. Lawrence interfluvium, west of Rigaud Mountain, a number of short streams had developed, their courses controlled by outcrops of till and by the slope of the surface of marine sediments. In a zone flanking the Adirondacks and lying west of the Richelieu valley there were again a number of small independent streams, the courses of which were determined by outcrops of bedrock and of till and glacial gravel. Despite the deep penetration by the Champlain Sea at its maximum into the Appalachian valleys, the shoreline at the Rigaud stage was little indented, the only major embayment being the valley of the Black River. The other streams had filled the floors of their valleys with deltaic deposits at higher stages of the Champlain Sea, and were by this time entrenching their courses into the deltaic sediments in response to the falling sea level.

On the northern side of the lowland a few streams drained from the crest of the Lachute-St. Jérôme morainic ridge in the lower Ottawa valley. In the Assomption embayment the Rivière l'Assomption and the streams which are now its tributaries were becoming entrenched within raised deltas, and the main stream, in particular, was continuing to extend its delta by the redeposition of material. The courses of minor streams in this area were influenced by low bedrock knobs projecting through the marine sediments. In the St. Maurice embayment, although the course of the shoreline is

uncertain, it is clear that the sea had withdrawn from the line of the St. Narcisse moraine. Thus the diversions of streams from preglacial courses, which resulted from the deposition of the moraine, were already established. The St. Maurice River was actively extending its lower delta and at least one distributary channel was operative west of the present course of the river.

b. The Montreal stage

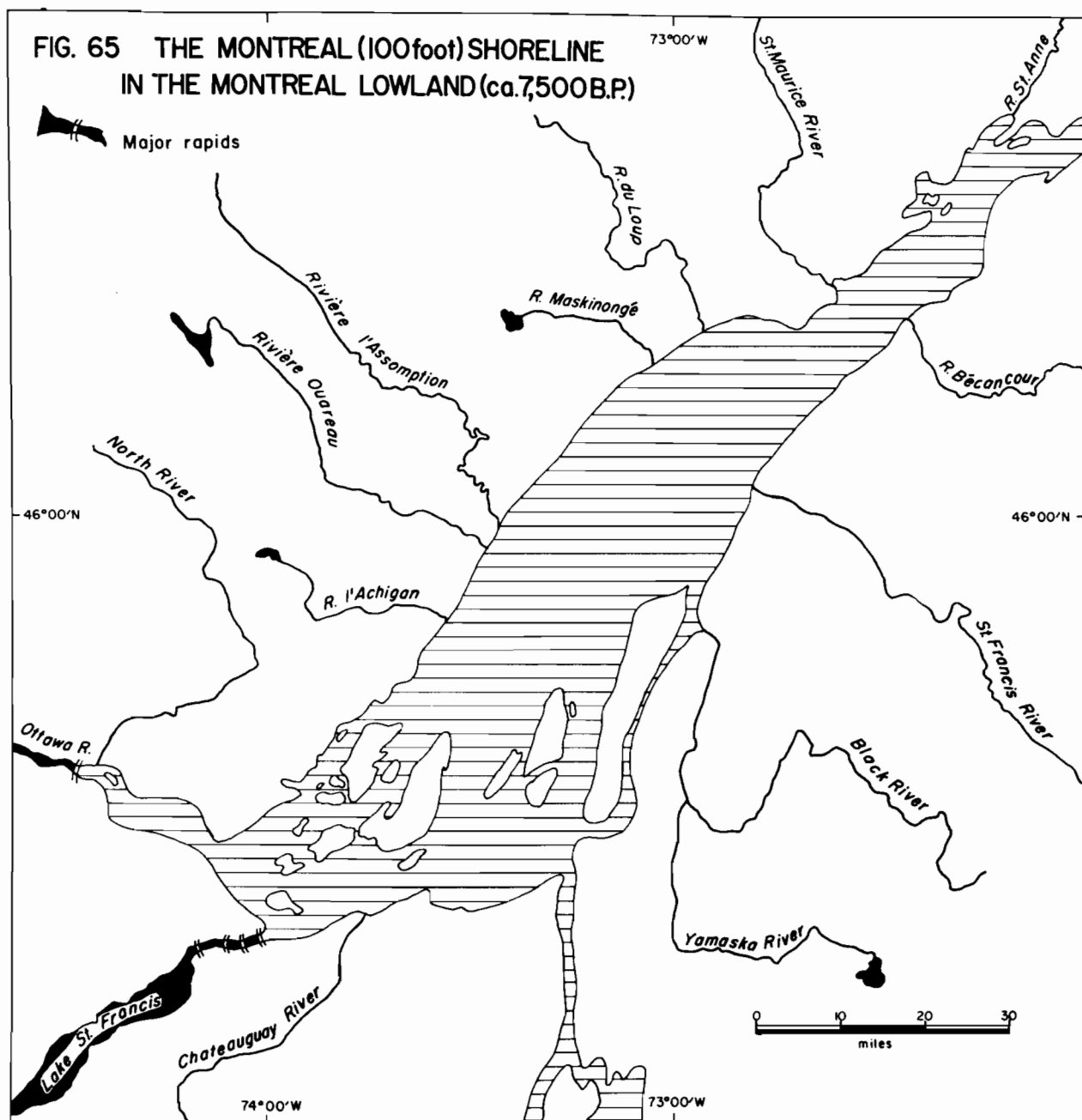
The retreat of the shoreline to about 110 feet above present sea level initiated the upper phase of the Montreal stage of the Champlain Sea; the shoreline of the lower phase lies some 10 to 15 feet lower, and it has been found convenient to refer to the Montreal stage as a whole as the 100-foot stage.

The selection of the Montreal stage as significant may be justified on several grounds. First, the shoreline may be traced with some certainty throughout the lowland, unlike any earlier water mark. Second, there is considerable evidence to suggest that the shoreline is the earliest to remain untilted. Across much of the lowland the shoreline coincides with the horizontal boundary surface between pollen zones IV and III. Unfortunately, in the area north of Lake Champlain where physiographic evidence does not exclude the possibility of tilting the palynological evidence is equally inconclusive (Chapters III and IV); it is possible that the Montreal water plane is the correlative of the tilted Port Henry stage which Chapman (1937) postulated for the Champlain basin, but the form of such a surface would be unlike any of the "hinged" shorelines of the glacial Great Lakes. The third reason for the selection of the Montreal stage is that during the Rigaud-Montreal interval considerable areas of the lowland had emerged

and had become subject to sub-aerial processes.

The head of the estuary at the Montreal stage had withdrawn down the Ottawa valley to near the foot of the Carillon Rapids (Figure 65). The volume of water carried by the Ottawa River was now much reduced compared with the Rigaud state, but was still greater than that of the St. Lawrence River (Chapter IV). The Montreal archipelago comprised many islands, and the shoreline is distinct only where cut in marine deposits. North of the archipelago the shoreline wound between the promontories and islands of the area of till which lies between the Rivière des Mille Îles and the Grand Coteau. The water washed the foot of the Grand Coteau at its eastern end, near the town of Terrebonne. The shoreline may be traced northeastward, with some gaps, mainly as a bluff cut in marine sediments, until it is lost in the salient of Shield rocks between the St. Maurice and Ste. Anne embayments.

South of the Montreal archipelago the 100-foot shoreline is usually marked by an erosional bluff. In the vicinity of the Caughnawaga Indian Reserve, however, it lay in an area of till, where its outline was irregular and its traces are few. Here an eastward-trending channel discharged some of the drainage of the Châteauguay River. The water mark of the Montreal stage may be traced along the Laprairie-Chambly bluff and into the Richelieu valley. Here, because of the inconclusive evidence for and against tilting of the Montreal water plane, it is impossible to locate the head of the marine embayment with any precision. If the plane has been affected only by simple vertical uplift and remains untilted, and if erosion at the head of the St. Jean Rapids has not been more than a few feet, the Montreal water body was continuous with that in the basin of Lake Champlain. Its extent within the basin was little greater than that



of the present lake, the surface of which is held at an elevation of 96 feet by the sill at the head of the St. Jean Rapids. If, on the other hand, the Montreal water plane has been tilted, it must pass beneath the surface of the lake and may, as Chapman (1937) suggested, intersect the lake floor in a submerged delta at Port Henry.

North of the point where the Richelieu embayment opened into the main Montreal water body the shoreline may be traced at the margins of straits between emerging islands. The strait which was to develop into the Richelieu valley lay between Monts St. Bruno and St. Hilaire; north of the two Monteregian hills former swells on the sea floor had emerged to define the course of the strait seaward. The swell extending north from Mont St. Hilaire served also to define a strait which later developed into the Hurons-Salvail channel. A bluff-bounded channel divided Mont St. Bruno from its attendant belt of marine sediments, which now forms the island terrace of Verchères Wood. The crest of the bedrock-cored Boucherville till ridge lay as an island between Mont St. Bruno and the present line of the St. Lawrence River.

To the northeast, south and east of Lake St. Peter, the shoreline lay in areas of deltaic and littoral accumulation and only rarely is it defined by an erosional bluff. It merges with the present St. Lawrence bluff near Deschaillons. In this northeastern part of the area of study the width of the Montreal water body, as of the earlier Rigaud water body, was much narrower than it was upstream in the vicinity of Montreal. It has been suggested (Chapter VI) that the shoals which were later to emerge as the island terraces of the Lanoraie delta developed as a tidal delta upstream of the narrows in the Montreal water body.

Although the Champlain Sea was still extensive between Montreal

and Trois Rivières at the Montreal stage, considerable areas of the low-land had emerged during the previous 1,000 years. This period of time, the probable duration of pollen zone IV, corresponds approximately with the Rigaud-Montreal interval. During this time the drainage patterns of the lower Ottawa valley and the Terrebonne sand plain had passed through the sequence of development discussed in detail in Chapter IV, to assume almost their present forms. In these areas the stream courses were directed principally by abandoned estuarine channels. These in their turn had been controlled in the lower Ottawa valley by the trend of outcrops of till and bedrock, and in the Terrebonne sand plain by the forms of shoal deposits of estuarine sand.

The major event in the St. Lawrence valley during the Rigaud-Montreal interval was the separation of Lake St. Francis from the main estuary by the emergence of a bedrock sill near Valleyfield. There is some evidence that the lake was originally more extensive than it is now, its area having been reduced by downcutting at the sill. The emergence of the sill probably occurred shortly after the Rigaud stage, at a time when a well-defined shoreline at an elevation of about 175 feet was being registered in the lower Ottawa valley. The massive till ridge south of Lake St. Francis extended its function as the St. Lawrence-[^]Châteauguay interfluvium, so that at the Montreal stage the latter stream had an independent drainage basin, entering the estuary to the east of the mouth of the St. Lawrence River.

In the upper Richelieu valley only the floor of a narrow channel, probably marine but possibly lacustrine, remained to emerge at the Montreal stage. The land surface which had emerged during the Rigaud-Montreal interval was of very similar character to that which had emerged by the

Rigaud stage, and similar factors, principally the forms of till and gravel ridges, were operating to control the developing drainage pattern. South of the Laprairie-Chambly bluff, however, a clay plain had emerged and was developing a dendritic drainage pattern with streams which were becoming incised in response to the falling base-level; this area was similar to that above the Montreal bluff to the east of Rigaud Mountain.

The Rigaud-Montreal interval saw the development of the lowland course of the Yamaska River to the first of the elbows below St. Hyacinthe, where it entered the estuary. Much of this section of the river's course lies in a depression between the St. Dominique fault-slice and a sea-floor swell extending north from Rougemont. This barely perceptible ridge today forms the interfluvium between the Yamaska River and its tributary, the Rivière Salvail, the valley of which was then still a marine strait. Little of the drainage of the interfluvium entered the Yamaska River, which received, however, numerous tributaries from the slope of the fault-slice.

The St. Francis, Nicolet and Bécancour rivers, a series of north-west-flowing streams, continued to extend their deltas, into which they subsequently became incised. New generations of tributaries developed as more land was exposed, rising in some instances in belts of beach sand and gravel, and draining the depressions between the deltas of the major streams.

The main streams of the Assomption embayment at the northern margin of the lowland, the Rivière l'Assomption itself, and its present-day tributaries, the rivers Ouareau and l'Achigan, still had separate mouths at the Montreal stage. The sand of the Assomption delta extended to the shoreline. A few small sandy islands lay off shore, the flanking deposits of the Lanoraie delta most of which was still submerged and had yet to exert

its influence upon the drainage pattern.

In the western part of the St. Maurice embayment the rivers continued to extend their courses and incise their beds during the Rigaud-Montreal interval; failures of the weak banks of marine clay were common. The present mouth of the St. Maurice River had become dominant by the Montreal stage. The decreasing radius of successive meander scars on either side of the main channel bears witness to the decreasing volume of water carried by the river during the preceding 1,000 years. Despite the abandonment of the main western distributary channel deltaic accumulation still continued at its mouth; here the small Rivière aux Sables deposited material gathered in its course along the former channel floor. East of the St. Maurice delta a low ridge of marine and littoral deposits prevented the Rivière Champlain from flowing directly to the estuary, much as the course of the Yamaska River was controlled by the low ridge extending north from Rougemont. In its northeasterly course the Rivière Champlain gathered the drainage of numerous streams rising on the southern slopes of the St. Narcisse moraine. The Batiscan and Ste. Anne rivers, to the northeast, flowed into embayments of the Montreal water body and their courses had been but little extended during the Rigaud-Montreal interval.

c. The St. Barthélemy stage

A sequence of important developments of the major rivers occurred during the emergence of the lowland from the Montreal stage of the Champlain Sea to the present. It is convenient to review these developments from some intermediate point in time, and for this purpose the St. Barthélemy or 50-foot stage has been selected.

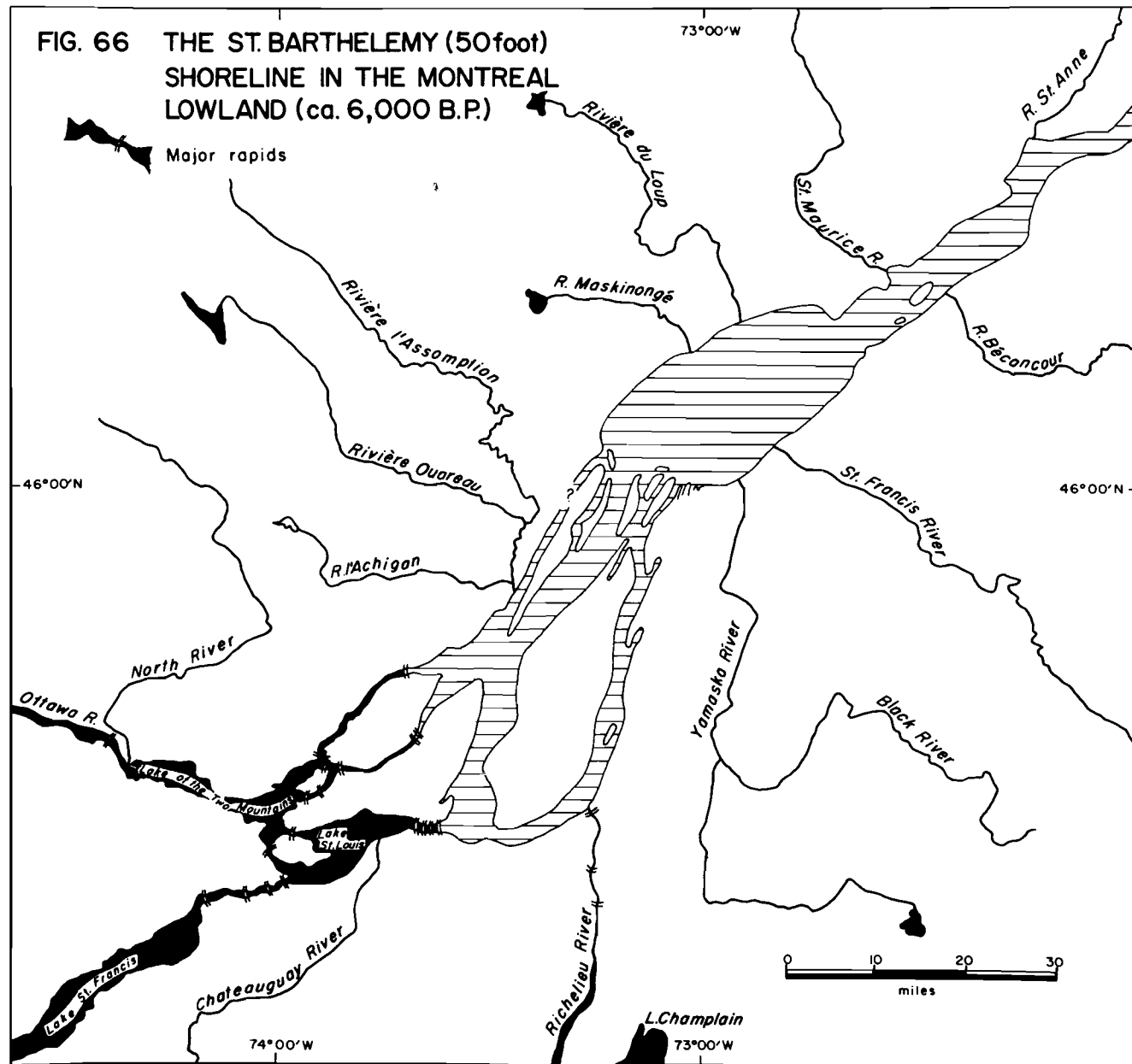
The 50-foot bluff is a conspicuous feature on either side of Lake

St. Peter, although, as Goldthwait (1933) pointed out, the bluff foot has locally been cut down to lower elevations. The head of the estuary at the St. Barthélemy stage lay at the foot of the Lachine Rapids, but there was little open water between that point and the head of Lake St. Peter (Figure 66). Instead, the upper portion of the estuary consisted of interconnecting channels, of which that which was to evolve into the St. Lawrence River was the broadest.

An estuarine channel extended eastward from the foot of the Lachine Rapids to the Richelieu valley at Chambly Basin, where the Richelieu River reached sea level at the foot of a flight of rapids. The channel continued northward along the line of the lower Richelieu valley, with embayments and branch channels where it crossed the emerging Lanoraie delta, to merge with the main estuary in the Lake St. Peter basin.

Embayments northwest of the main, or St. Lawrence, channel occupied the lower parts of the valleys of the rivers St. Pierre, des Prairies and des Milles Iles. The Rivière l'Assomption entered a branch channel through the Lanoraie delta. It cannot be determined whether this channel was still open to the northeast at the St. Barthélemy stage, as it was a short time previously, or whether the Rivière l'Assomption flowed into a residual embayment occupying the southern end of the channel.

During the Montreal-St. Barthélemy interval the Lake of the Two Mountains was separated from the estuary and the rapids on either side of Ile Perrot and at the heads of the rivers des Milles Iles and des Prairies were initiated. The local base level for the lower Ottawa valley thus became that of the present level of the lake, 73 feet above sea level. The emergence of the sills which confine the lake was shortly followed, or possibly preceded, by the emergence of the head of the Lachine Rapids and



the separation of Lake St. Louis (Chapter IV). The Châteauguay River is the largest right-bank tributary to enter the Lake St. Louis section of the St. Lawrence River. By the time of the separation of the lake the channel by which some of its water had crossed the Caughnawaga Indian Reserve at the Montreal stage had been abandoned, and the western channel was established as the mouth of the river; here a delta had begun to develop.

If the sill at the head of the St. Jean Rapids in the Richelieu valley had not emerged by the Montreal stage, it did so shortly thereafter, separating Lake Champlain from the estuary. The present elevation of the lake surface is 96 feet; thus the local base level in the upper Richelieu valley is relatively high. However, few significant tributaries enter the upper Richelieu River, which is in fact an arm of Lake Champlain.

To the east of the lower Richelieu valley the main changes which occurred during the Montreal-St. Barthélemy interval were the emergence of the floor of the Hurons-Salvail channel and the seaward extension of the Yamaska River. On the Richelieu-St. Lawrence interfluvium emerging estuarine channels provided routes for drainage of local origin. In the lowermost section of the Richelieu valley the island terraces of the Lanoraie delta had emerged, and minor streams had developed on the floors of some of the intervening channels.

It was the northern portion of the Lanoraie delta, however, which was exerting a more conspicuous influence upon the drainage pattern by the St. Barthélemy stage. The course of the Rivière l'Assomption below the Montreal shoreline was determined by channels across the delta, but the river flowed in a generally southerly direction, not, as might have been expected, toward the northeast. A channel into which the river flowed at

an intermediate stage appears to have been choked by the river's own deposits; with continuing emergence the river found no course open but that to the south (Chapter VI). In its southward course the river collected the drainage of the other major streams of the Assomption embayment, so the drainage of the greater part of the embayment was discharged through a single mouth. This was in contrast to the independent streams of the St. Maurice embayment. These, like those entering the other side of Lake St. Peter, underwent no striking developments during the Montreal-St. Barthélemy interval, which was marked only by further extension of the stream courses and incision of the stream beds.

There is no palynological evidence of the relative age of the St. Barthélemy shoreline, but an examination of Figure 26 suggests that it may have been cut at about 6,000 B.P., when the rate of eustatic rise of sea level was temporarily greater than the rate of isostatic uplift. The length of the Montreal-St. Barthélemy interval may thus have been of the order of 1,500 years, compared with the 1,000 years of the Rigaud-Montreal interval.

d. The final stages of the emergence

During the period of approximately 6,000 years that has elapsed since the St. Barthélemy shoreline was cut the Champlain Sea has been finally excluded from the Montreal lowland. Today marine influence is felt only in the tidal reach of the St. Lawrence River below Lake St. Peter.

As the land emerged the head of the estuary retreated downstream and the rivers extended their courses in a pattern which was implicit in the pattern of estuarine channels at the St. Barthélemy stage. The first

significant event was the severance of the connection between the St. Lawrence and Richelieu valleys when the floor of the Laprairie-Chambly depression was raised above sea level. The next was the separation of the Laprairie Basin from the estuary.

Gradually, as fluvial conditions extended seaward, the St. Lawrence, Richelieu and l'Assomption rivers came to occupy their present courses within the broader channels of the St. Barthélemy stage. As the shoreline withdrew from the 50-foot bluffs around Lake St. Peter the deltas of the larger streams, including the St. Lawrence River, were extended into the lake and a new generation of minor streams, rising at the former shoreline, flowed toward the lake across the "low terrace sands".

Goldthwait (1933) stated that bedrock occurs in the bed of the St. Lawrence River at Trois Rivières, below Lake St. Peter. Further emergence of this bedrock sill will complete the separation of Lake St. Peter from the head of the estuary, to extend the process which has been successively repeated in the past. Goldthwait described this process as follows:

Emergence of the lowland was not accompanied by a simple withdrawal of the sea from the far western corners of the lowland eastward to the estuary at Quebec, and the steady extension of the St. Lawrence and Ottawa rivers in that direction. Broad basin like portions of the lowland, detached from the marine waters one by one, became fresh-water lakes, through which the river pursued its new course. Rock thresholds, first to emerge as the sealevel drew down, developed rapids where the water from one basin spilled over into the next. Some of these basins and thresholds are still prominent features of the river. (Goldthwait, 1933)

3. FACTORS INFLUENCING THE DEVELOPMENT OF THE DRAINAGE PATTERN

The irregular gradients of the rivers, well described in the quotation given at the end of the previous section, indicate the youth of the drainage network of the Montreal lowland. It is a further measure

of its youth that the principal factor influencing its development has been the form of the emerging sea floor. There has been insufficient time for any significant modification of the original surface by sub-aerial action; in general, only the areas immediately adjacent to stream courses have been modified, while the form of the interfluves has been left virtually unchanged.

Only a few instances may be cited of truly fluvial, as opposed to estuarine or deltaic, adjustment to structure, using the term "structure" in the sense of the composition, morphology and distribution of surface materials. Among these are the abandonment of stream courses leading from the North River valley across an area of till to the Terrebonne sand plain (Chapter IV); the capture of the upper Châteauguay River from its course over bedrock by a tributary of its own tributary, the English River (Chapter IV), and the capture of the lowest reach of the Rivière l'Assomption by a small southward-flowing stream, where the former course of the river lay across an area of till (Chapter VI).

However, despite the lack of evidence of specific adjustments to structure, the drainage network as a whole appears in fact to be well adjusted. This has come about because the streams tend to follow ready-made depressions. High points on the bedrock surface, for example, were never buried by glacial or marine sediments, and the intervening depressions provided routes for streams. Such were a bedrock valley cut in the slopes of Rigaud Mountain, which is followed by the upper course of the Rivière Raquette (Chapters II and IV), and, on different scales, the depression between Rougemont and Yamaska Mountain which is followed by the Yamaska River (Chapter V) and the partially buried preglacial depression followed by the St. Lawrence River itself (Chapter II).

Certain deposits of till functioned similarly in directing drainage; the massive till ridge which forms the interfluve between Lake St. Francis and the Châteauguay River may be cited as an example (Chapter IV), as may the parallel till ridges north of Lake Champlain (Chapter V). The form of other till masses has been able to influence the drainage pattern only because wave action stripped away the overlying marine sediments during the emergence; such is the case in the western part of Montreal Island, where minor streams flow between low till hillocks (Chapter IV). Moraines and fluvio-glacial gravel ridges, where they rose above the original surface of the marine deposits, or where they were exposed by wave action, have also played a part; the St. Narcisse moraine diverts a series of streams from their preglacial courses (Chapter VI) and the gravel ridges in the upper Richelieu valley function as minor interfluves (Chapter V).

Surfaces of marine deposits, unmodified by offshore or shoreline processes, have influenced the development of the drainage pattern by their generally concave form; run-off was concentrated in the central depression. The precise courses followed by the Châteauguay and Yamaska rivers were determined in this way, for example. However, the course of the Yamaska River above the Salvail confluence was controlled in a more general sense by a low ridge of marine sediments extending north from Rougemont. A similar ridge related to Mont St. Hilaire forms the interfluve between the Salvail and Richelieu rivers (Chapter V); these features result from a combination of deposition seaward of the hills and current erosion in the intervening straits.

More striking examples of the influence of the surface form of marine sediments upon the drainage pattern occur in areas which evolved as

tidal or estuarine deltas. Here the sediments were deposited in shoals, which emerged as islands. The intervening channels were modified by current action and after emergence provided drainage ways. The Lanoraie delta is one such feature; channels which cross it are followed by the St. Lawrence, Richelieu and l'Assomption rivers and their tributaries (Chapter VI). The Terrebonne sand plain, which owes its existence to the Ste. Thérèse gravel ridge, is another; it forms the upper drainage basin of the Rivière Mascouche (Chapter IV).

Estuarine channels are not associated exclusively with areas of deltaic deposition. The channels which played such a significant role in the evolution of the drainage pattern of the lower Ottawa valley were in turn guided by outcrops of till and bedrock, and estuarine deposition seems to have been of very limited importance.

In considering the influence of channels of estuarine origin upon the drainage pattern it is necessary also to consider changes in the source and volume of water entering the estuary and the effect of such changes upon the trend and dimensions of the channels. The volume of water descending the Ottawa River decreased during the Rigaud-Montreal interval while the land between about 200 feet and 100 feet above present sea level emerged. Broad channels at higher elevations occur far from the present river, even crossing the Terrebonne sand plain, while those close to the elevation of the Montreal shoreline diverge to no great distance from the river and are considerably smaller. It was not until after the 50-foot shoreline of the St. Barthélemy stage had been cut that the St. Lawrence River began to carry the whole outflow of the Great Lakes (Chapter III). By this time, however, the total volume of water had diminished with the final disappearance of glacier ice from areas tributary to the lake basins;

moreover, the estuary was much reduced in extent and confined to the axis of the former sea floor. It is not surprising, therefore, that no further channels of the type found in the lower Ottawa valley were cut after the St. Barthélemy stage.

The final group of features of the emerging sea floor to be discussed are those developed by shoreline processes, among which fluvial deltas may be included. Deltas were built into the Champlain Sea by rivers issuing from the Shield and from the Appalachians. The rivers which constructed them have since cut down through the thick layers of sediment, and meander scars may indicate former river courses, as in the cases of the Assomption and St. Maurice deltas (Chapter VI). The outer slopes of deltas direct drainage away from the main streams which, as a result, have few tributaries; the St. Francis and l'Assomption rivers may be cited as examples (Chapters V and VI). The large upper delta of the St. Maurice River, which developed in an embayment behind the St. Narcisse moraine, was one of the causes of the diversion of the river into its present course below Shawinigan Falls (Chapter VI).

The influence of other, more delicate, shoreline features which developed at the mouths of streams may also be recognized in the present drainage pattern. The course of the Rivière du Loup below the 50-foot shoreline bluff is related to an eastward-trending spit, for example (Chapter VI). Streams which flowed in incised courses through shoreline bluffs frequently deposited delta fans at their mouths. Such fans, for example those below the 50-foot shoreline north of Lake St. Peter, may cause minor irregularities in the present courses of the streams. However, where the initial slope of the surface of marine sediments was considerable, as in the northwestern part of the St. Maurice embayment, the rivers

descend in roughly parallel courses, little influenced by the successive shoreline bluffs which they transect.

In summary, it may be said that the drainage pattern that exists today in the Montreal lowland has developed in response to all aspects of the emerging sea floor, and therefore reflects all the factors involved in the shaping of that surface, from the form of the bedrock to the final shaping of a shoreline during actual emergence.

However, the fine adjustment to structure, as that term was defined at the beginning of this section, is only a temporary condition. Already certain rivers, for example the St. Lawrence below Lake St. Francis, have swept their beds clear of surficial material and are becoming superimposed upon the underlying bedrock. Others are revealing deposits of till; this may lead to capture by a more favoured stream and abandonment of the stream course across the resistant material. Such a capture has already occurred in the lower valley of the Rivière l'Assomption (Chapter VI). It is evident, then, that as fluvial erosion proceeds the present state of adjustment will be destroyed and changes will occur in the drainage pattern to bring it into adjustment with the newly-revealed structure. This process will not occur widely until lateral erosion by streams becomes more common. The only significant removal of surficial material so far by this means has occurred in the Assomption and St. Maurice deltas where abandoned meander scars provide evidence of the lateral shifting of the rivers. Other streams in the lowland have meandering traces, but many of these are confined in estuarine channels and cannot swing freely.

The occurrence of bedrock in a stream bed may, but does not necessarily, inhibit lateral erosion; the Rivière l'Assomption meanders freely above and below the falls at Joliette. Such an outcrop does, however, act

as a local base level, retarding the stripping of surficial material from areas draining to the river above that point.

No mention has yet been made of differential uplift as a possible influence upon the developing drainage pattern. Tilting contributed to the form of the sea floor upon which the drainage developed, and thus may have been a factor determining the present direction of drainage in a former estuarine channel. For example, the St. Andrews River, a tributary of the North River, flows toward the former intake of the channel which it follows, and it is likely that tilting was at least a contributory cause (Chapter IV). The tendency of the Rivière Mascouche and its tributaries to flow close to the southern margins of the channels which they follow may also be due to tilting (Chapter IV).

However, it is impossible to ascribe any shifts of established stream courses to tilting. Differential uplift was at a maximum during the early stages of the emergence, when the areas which were emerging had a considerable slope toward the axis of the lowland. It increased the gradient in areas north of the axis, and decreased but failed to reverse it south of the axis. At later stages, when the newly emerging areas had a generally smaller slope, tilting had almost ceased and again failed in general to reverse the gradient of stream courses.

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Maps of the National Topographic Series

1:1,000,000:	31
1:500,000:	31 SE, 31 NE
1:250,000:	31 G, 31H, 31 I
1:63,360:	31 I/9
1:50,000:	31 G/1 E and W, 31 G/8 E and W, 31 G/9 E and W; 31 H/2 E, 31 H/3 E and W, 31 H/4 E and W, 31 H/4 E and W, 31 H/5 E and W, 31 H/6 E and W, 31 H/7 W, 31 H/9 W, 31 H/10 E and W, 31 H/11 E and W, 31 H/12 E and W, 31 H/13 E and W, 31 H/14 E and W, 31 H/15 E and W, 31 H/16 E and W; 31 I/1 E and W, 31 I/2 E and W, 31 I/3 E and W, 31 I/4 E; 31 I/6 E and W, 31 I/7 E and W, 31 I/8 E and W, 31 I/10 E and W
1:25,000	
(Provisional Map):	31 H/5-e, 31 H/5-f, 31 H/5 g, 31 H/5-h, 31 H/6-e, 31 H/11-d, 31 H/11-e, 31 H/12-a, 31 H/12-b, H/12-c, 31 H/12-d, 31 H/12-h.

Title for binding:

Post-Champlain drainage evolution, Montreal lowland. Macpherson