

LATE QUATERNARY VEGETATION AND GLACIAL HISTORY IN THE ST. LAWRENCE LOWLANDS, CANADA

BY

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ABSTRACT

This paper presents data of various kinds concerning the Quaternary geology of the St. Lawrence Lowlands: pollen diagrams, C¹⁴ dates, and diatom floras. These data show that the highest parts of the St. Lawrence Lowlands were already deglaciated more than 12,000 years ago, as appears from the existence of glacial lakes around some of the Monteregian Hills.

The collected evidence seems to confirm the data concerning the age of the Champlain Sea: it lasted from approximately 11,400 years B.P. to somewhat before 9,500 years B.P.

The data supply also evidence for a lowering of sea level during the Champlain Sea episode, related to the St. Narcisse readvance, followed by a sea level rise (indicated by deeper water) after the retreat of the St. Narcisse ice.

As to the pollen diagrams presented here, they show that the New England pollen zonation can be applied to the lacustrine pollen sequence of the St. Lawrence Lowlands, and strongly suggest (together with C¹⁴ dates) that a correlation exists between the Younger Dryas of northwestern Europe, the St. Narcisse readvance, and the first part of the pollen zone A4 from New England as described by Davis and other workers.

The diatom data of Lake Hertel appear to confirm the present elevation of the maximum marine limit (level) in the Montreal area as being approximately 570 feet or 171 meters. Finally the diatom floras supply information on the paleo-ecological conditions of the lakes studied.

RÉSUMÉ

Le présent travail rassemble des données de plusieurs sortes sur la géologie quaternaire des basses terres du St. Laurent: des diagrammes polliniques, des mesures d'âge au C¹⁴ et des flores de diatomées fossiles.

On peut en conclure d'abord que la déglaciation des points les plus élevés des basses terres du St. Laurent eut lieu 12,000 ans avant aujourd'hui.

L'âge de l'épisode marin désigné sous le nom de „Mer Champlain” semble être confirmé: il s'étendrait de 11,400 jusqu'à un peu avant 9500 ans avant aujourd'hui. Les faits semblent aussi démontrer qu'un abaissement relatif du niveau de la mer s'est produit pendant cette période, suivie d'une remontée relative du niveau des eaux marines. Cet événement semble être relié à l'avancée glaciaire de St. Narcisse, suivie de son retrait.

Les diagrammes polliniques semblent démontrer que la séquence des zones polliniques de la Nouvelle Angleterre peut être appliquée aux séquences polliniques des dépôts lacustres des basses terres du St. Laurent.

Ces diagrammes donnent de fortes indications (en considérant aussi les mesures d'âge au C¹⁴) que le Dryas supérieur de l'Europe septentrionale de l'ouest, la réavancée de St. Narcisse et la zone pollinique A4 (Davis, 1958) sont corrélatifs.

Les diatomées fossiles du Lac Hertel (dans la partie tout à fait inférieure de la section) semblent confirmer l'altitude actuelle du niveau maximum de la dernière invasion marine (Mer Champlain) dans la région de Montréal: environ 570 pieds ou 172 m au-dessus du présent niveau moyen de la mer.

Enfin les flores de diatomées fossiles ont permis de tirer des conclusions concernant les conditions paléo-écologiques des lacs étudiés.

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CHAPTER I

INTRODUCTION

The interest of the author for the Pleistocene geology of the St. Lawrence Lowlands and the Montreal area developed in the course of the mapping of the surficial sediments of the Beloeil map area during the field season of 1960 (Lasalle and Elson, 1962).

In the successive years, many more excursions were made by the author alone or with other people to collect material. During the fall of 1963 the author visited all the depressions that appeared on the aerial photograph of the St. Hilaire mountain in the hope of discovering some late-glacial sediments or at least sediments older than the bogs lying on the Champlain Sea deposits (Terasmae, 1960). The St. Hilaire bog was finally located, and it was thought that with the 9.5 meters of sediments collected it would be possible to define late-glacial pollen zones in the St. Lawrence Lowlands.

Pollen analysis of the core of St. Hilaire bog as well as the core of Lake Hertel and St. Bruno bog has indeed revealed an interesting sequence.

1. PURPOSE OF THE INVESTIGATION

The purpose of the present work is to define the late-glacial pollen zones in the St. Lawrence Lowlands and attempt correlation with other pollen zones defined in the North-eastern United States, and with geological events in the area (Champlain Sea, moraines etc.).

On the basis of the new radiocarbon dates obtained from these cores, it appeared also pertinent to discuss some of the hypotheses concerning the glacial lakes that preceded the Champlain Sea in the St. Lawrence Lowlands, and to attempt a correlation of the moraines that have already been outlined.

Finally an abundant diatom flora has been discovered

in the cores analysed and special diatom data are presented in a qualitative way. Some ecological conclusions are finally drawn and an attempt is made to relate the diatom data with the geological history of the area.

2. METHODS AND EQUIPMENT

The core of the St. Hilaire bog was collected by the author with a Hiller borer. As the St. Hilaire bog is completely filled now, and its surface forested, it has been possible to make a reconnaissance survey to find the maximum depth to refusal before collecting the core for pollen analysis. Dr. Terasmae kindly collected the sample for C¹⁴ dating with a Livingstone borer.

The Lake Hertel core was obtained with a Livingstone sampler operated by the party of Dr. Terasmae and the author. The sample for C¹⁴ dating was obtained from the same core.

The core of the St. Bruno bog was collected by the author, with a Hiller borer.

The boring was made on the side of the partially filled lake.

The core of the Champlain Sea sediments was obtained from the Ecole Polytechnique, University of Montreal, through courtesy of Dr. Jean Bérard.

Preparations for pollen analysis of the St. Hilaire bog were first made in the Palynology Laboratory of the Geological Survey of Canada, in Ottawa. The samples were prepared again in the Palynology Laboratory of the University of Leiden, The Netherlands, in the following manner: they were first boiled in KOH 10 % for a few minutes, and then cooled and left in the ultra-sound apparatus at moderate intensity for

5 minutes; mineral matter was removed in the more silty ones by using either bromoform or hydrofluoric acid; acetolysis was performed on all of them. They were mounted in glycerine jelly. The same method was followed for the St. Bruno bog samples.

For the Lake Hertel samples, bromoform was not used to remove the mineral matter; only hydrofluoric acid was employed for the lowermost samples; they were mounted in liquid glycerine to allow the movement of the grains under the microscope.

The numbers of grains counted per slide range between 200 and 250; sometimes a larger number was counted.

The slides for diatom analysis were prepared by boiling the material with dilute peroxide. To accelerate the process of oxydation, drops of dilute permanganate of potassium were added. The mounting medium is Gurr's Clearax.

Identifications of the pollen grains and their counting were made with a Leitz Dialux using mostly a magnification of 500 times. The critical identifications were made at 1250 times.

Most of the photographs were made at the Geologische Dienst Nederland in Haarlem with a Leitz microscope automatic camera; Agfa AGEPE FF Dokumentenfilm was used (12Din). A small number of the diatom photographs have also been made in Uppsala, with a Wild microscope equipped with a photo-tube; the same type of film was used. Finally, the enlargements of the fossils have been calculated individually for each print as it revealed difficult to get a uniform enlargement from the photographic shop.

3. ACKNOWLEDGMENTS

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He would like also to thank specially Dr. Th. van der Hammen under whose direction the present research was done. Dr. van der Hammen has been most encouraging during all phases of the work, and without his help and support, the present paper could not have come to completion.

The author is also grateful to Dr. J. Terasmae of the Geological Survey of Canada, who has collected the material for the C^{14} dating of the St. Hilaire bog and also the core of Lake Hertel. His collaboration is gratefully acknowledged.

The author has been introduced into the study of diatoms by Mr. A. du Saar and Mr. A. van der Werff of the Geologische Dienst Nederland. He also spent two weeks at the Institute of Quarternary Geology and Paleontology of the University of Uppsala working with Docent Maj-Britt Florin. The help of these persons with the identification of diatoms or confirmation of identification is gratefully acknowledged. But the author bears all responsibility for omission, misidentification, or any conclusion drawn from the diatom data.

He would like to thank also the following persons for valuable discussions: Dr. S. Jelgersma, Dr. W. H. Zagwijn, Mr. A. van der Werff and Mr. A. du Saar of the Geologische Dienst Nederland, and Dr. J. C. Vogel, of the University of Groningen.

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Dr. J. A. Elson, of McGill University, who has allowed the author to quote some of his C^{14} data.

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CHAPTER II

HISTORICAL GEOLOGY AND GEOMORPHOLOGY

1. GLACIAL SEDIMENTS AND STRATIGRAPHY IN THE ST. LAWRENCE LOWLANDS

The basic scheme of the glacial stratigraphy of the St. Lawrence Lowlands is mainly the result of recent studies (Gadd, 1955, 1960; Terasmae, 1955, 1958; Gadd and Karrow, 1959). Mac Clintock and Stewart (1965, p. 11 to 24) have ably resumed the literature dealing with the Pleistocene studies in the St. Lawrence Lowlands for the last one hundred years, or so.

It is not our intention here to take up again that re-

view. The interested reader is referred to the work of Gadd (1960) and Mac Clintock and Stewart (1965) for a complete historical background.

According to recent studies, two till sheets have been recognized in the Bécancour area, located approximately half-way between Montreal and Quebec City. The lower till sheet is called the Bécancour, and is separated from the upper one, the Gentilly till, by the St. Pierre sediments. The latter are sands and peat of fresh water origin indicating a climate cooler than

the present (Gadd, 1960, p. 12). As material from these sediments has yielded ages possibly of the order of 60,000 years B. P. (Gadd, 1960, p. 24), the deposit has been assigned stratigraphically to the early Wisconsin (Flint, 1963, p. 403).

In adjacent areas of New England and New York State, Mac Clintock and Terasmae (1960) and Mac Clintock and Stewart (1965) have also reported two tills: The Malone till deposited by an ice sheet moving from the northeast, and the Fort Covington till deposited by an ice sheet moving from the northwest. Mac Clintock and Stewart (1965) have suggested the Fort-Covington is of Port-Huron (Mankato) age and that the Malone till is of Cary age. This is based in part on C^{14} dating, but mainly on the fact that the „rearrangement” of the ice that permitted two readvances from so divergent directions is of a magnitude that deserves a substage status (Mac Clintock and Stewart, 1965, p. 41). The correlation of the Malone and Fort Covington tills with the Bécancour and Gently tills respectively, though probable (because of closeness of their type areas), does not yet rest on firm ground.

The glacial sediments of the St. Lawrence Lowlands are overlain in places by varved clays, separating them from the marine clays above. The latter are for the greater part silty clays, fossiliferous in places. Upward in the section, they are replaced by interbedded sands and clays and then by sands, that are the estuarine shallow-water sediments of the early St. Lawrence. The latter have been in places channelled, together with the underlying clays: that river erosion was produced as the St. Lawrence River was gradually retreating to its present position. Some of these channels are occupied today by large peat bogs and underfit streams (Verchères and Sorel areas). The distribution of the peat bogs on aerial photographs depicts very well the pattern of those braided streams.

The St. Lawrence River may have retreated to its present position some 6000 (?) years ago when eustatic sea-level reached its present position or approximately so (see also Terasmae, 1960, p. 21).

The river valley itself in which the St. Lawrence River is flowing is undoubtedly a geologic feature that is of Tertiary age or even older. It has been intermittently occupied by continental glaciers during the Pleistocene and presumably filled in part by glacial and marine sediments, before becoming the major river course that it is today.

2. MORAINES IN THE ST. LAWRENCE LOWLANDS

Three moraines or systems of moraines have been reported in the St. Lawrence Lowlands. The several students who have contributed to their descriptions and definitions will be mentioned below.

The southernmost of those is Gadd's Highland Front Moraine System (Gadd, 1964). In fig. 1 this system has been generalized. It includes various gravelly deposits, and the St. Antonin moraine of Lee (1962). Gadd (1964) considers that this system is older than

11,500 yrs. B. P. on account of C^{14} dates obtained on fossil marine shells in the St. Lawrence Lowlands. Indeed, the sea could not have occupied the St. Lawrence Lowlands unless the area was deglaciated; hence the maximum age obtained on shells of the Champlain Sea would give a minimum age for its deglaciation.

On the other hand, a maximum age has been assigned to the St. Antonin moraine (GSC-102, 12,770 \pm 170 yrs. B. P.; Dyck and Fyles, 1963, p. 18). This date has been performed on marine shells that were „part of a marine-deltaic-outwash deposit formed when wastage of the ice sheet permitted the sea to penetrate into this part of the St. Lawrence basin” (Dyck and Fyles, 1963, p. 18). This date is then more likely to be related to an improvement of the climate, since the deltaic material has been deposited during a „wastage” of the ice sheet. The sea waters at that time appear to have occupied only a re-entrant in the ice. Later, the ice that deposited the St. Antonin moraine overrode the outwash deposit. The correlation problem of this moraine with other areas will be taken up later in this section. But is it important to remember that the south-western part of the Highland Front Moraine System may be younger than the north-eastern part as it may have been deposited during a retreat of the ice from a more advanced southern position. Indeed, the nature of the deposits suggests that they were deposited during a wastage of the ice sheet.

The Drummondville moraine (fig. 1) occupies a position subparallel to the Highland Front Moraine System. It consists of an elongated ridge and is interpreted (Gadd, 1960, 1964) as a „halt” of the ice as it retreated across the St. Lawrence valley. A minimum age has been assigned to this moraine because the basal layer of a bog resting on it has yielded ages of ca. 9500 yrs. B. P. (L-441-C, 9,550 \pm 600 years; Terasmae, 1960, p. 16). However, the moraine, because of its position with respect to the only plausible entrance for the marine waters (Quebec narrows) in the St. Lawrence Lowlands, is most probably a few hundred years older, than this minimum reported age (above), if we take into account the maximum ages reported on fossil marine shells in the St. Lawrence Lowlands. In fact, the Drummondville moraine may be as old as the maximum reported age of the marine shells, or even slightly older, as no indication of calving into the sea waters has been reported.

The shells that were found more or less incorporated into it are attributed to reworking by waves (Gadd, 1960, p. 16). Presumably, the ice front may have been standing in the waters of proglacial Lake Frontenac, just prior to the opening of the Quebec narrows to the sea waters. This would make the moraine slightly older than 11,400 yrs. B. P.

The northernmost known moraine, i.e. the St. Narcisse moraine was first reported by Osborne (1950). However the first segment of it had been reported by Mawdsley, (fig. 1) in his memoir of 1927, dealing with the bedrock geology of the St. Urbain area, Quebec. We quote the following paragraph from Mawdsley's paper (p. 39): „Two well defined terminal moraines are known

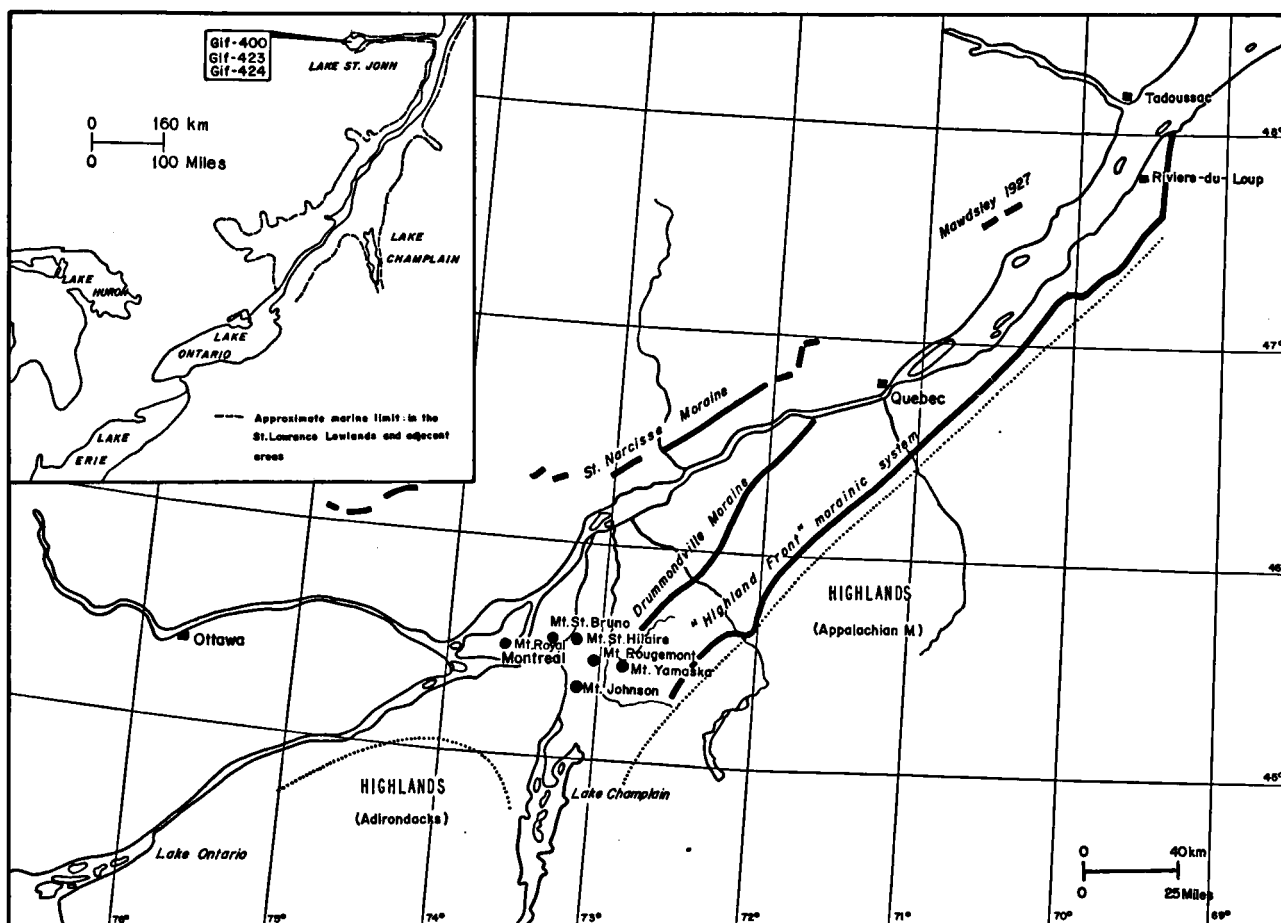


Fig. 1. Moraines in the St. Lawrence Lowlands

within the area. One dams the outlet of Four valley, out of which flows the brook which feeds lake Cygnes, and the other dams the outlet of the valley through which the upper part of Mouche river flows". In the last few years several workers have found extensions of this moraine: Laverdière and Courtemanche (1959), Elson and Karrow (reported in Lasalle, 1965), Gadd and Karrow (1959). The concensus of geologists having worked in the area of the St. Lawrence is that the stratigraphic position of this moraine is equivalent to the Valdres readvance of the Mid-continent. However, only a minumum age had been available so far, the same as for the Drummondville moraine (Terasmae, 1960, p. 20), and of the order of 9,500 yrs. B. P.

C^{14} assays performed on marine shells collected at the marine limit along the Saguenay River and in the Lake St. John area (see fig. 1) and located behind the inferred position of the ice front (Lasalle, 1965), have yielded ages from 9,400 to 10,250 approximately (cf. appendix, table 3: GrN-4811, Gif-423, and Gif-424; see also Lasalle, 1966).

The time of the St. Narcisse readvance (and also the Drummondville „halt") is then older than the above dates by the amount of time needed for the ice to retreat from the St. Narcisse moraine to the position of the

collecting sites of the shells. This distance is of the order of 200 kilometers. Hence the real age of the St. Narcisse readvance must be in the 10,500 years B. P. range.

The oscillation of the St. Narcisse readvance appears to fit the low *Quercus* and strong herb zone (A4a) of the St. Hilaire bog pollen diagram. The low *Quercus* is very prominent in most late-glacial diagrams of New England and the several dates obtained on zone A4 (low *Quercus*) range from approximately 10,800 to 10,400 years B.P. (see Davis, 1965, p. 389). These dates suggest very strongly that the St. Narcisse readvance is contemporaneous with the Younger Dryas of European stratigraphers. That readvance is certainly also contemporaneous with some phase of the Champlain Sea. Indeed, in the Trois-Rivières area, it has been demonstrated (Gadd and Karrow, 1959) that the ice overrode the marine clays at the time of the deposition of the St. Narcisse moraine.

Furthermore, in the Verchères area (Lasalle, 1964), a clay layer containing marine fossils (exact location: 46°46' latitude, 73°16' longitude, in an excavation for a gravel pit) has been found overlying a granule gravel and coarse sand layer containing a mixed fossil fauna of fresh water and marine mollusks.

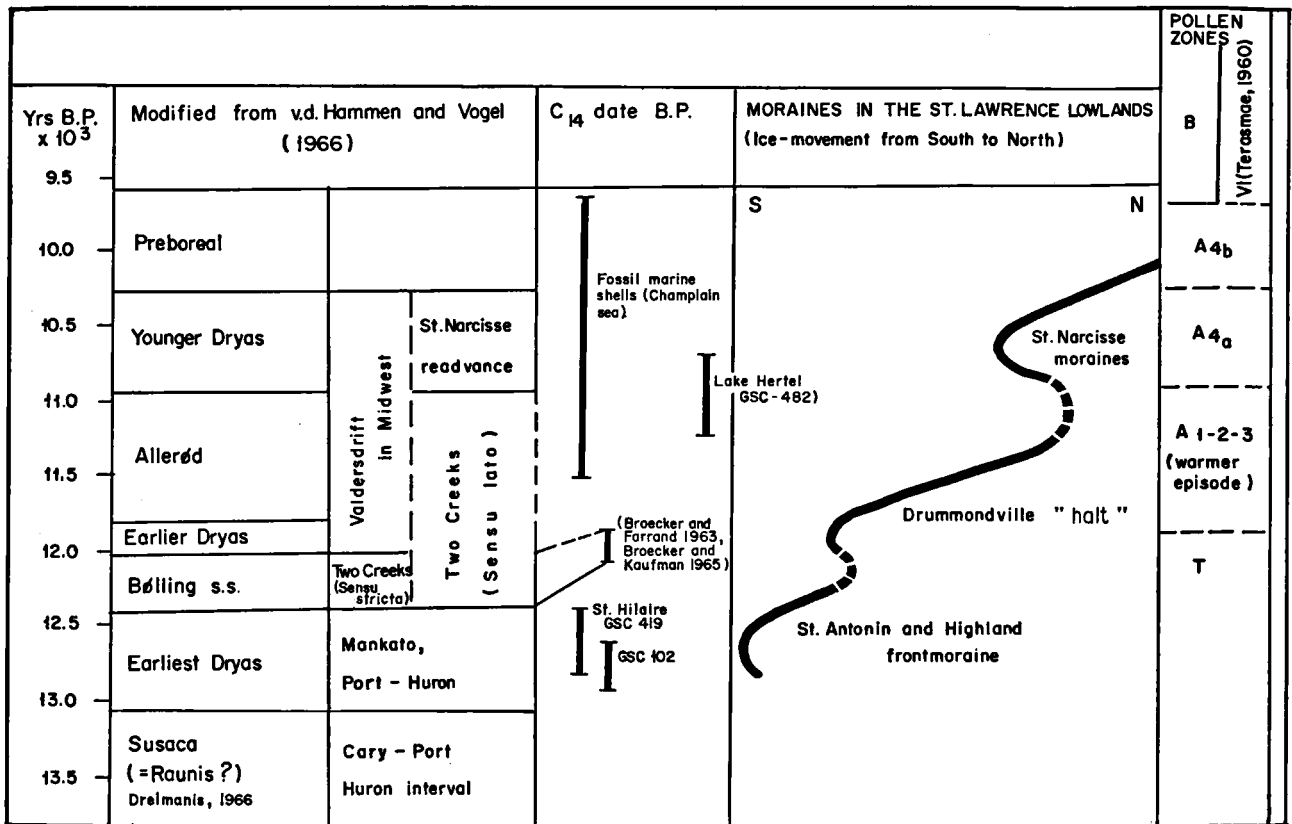


FIG. 2. PROPOSED CORRELATION BETWEEN THE MORAINES AND POLLEN ZONES.

Mollusks identified by Dr. C. O. van Regteren Altena of the Rijksmuseum van Natuurlijke Historie in Leiden are the following:

Fresh water mollusks:	Marine mollusks:
<i>Valvata</i> sp.	<i>Portlandia arctica</i> (Gray)
<i>Ammicola</i> sp.	<i>Macoma balthica</i> (L)
<i>Pleurocera</i> sp.	<i>Hiatella</i> sp.
<i>Physa</i> sp.	<i>Mya</i> sp.
<i>Lymnaea (Stagnicola)</i> sp.	
<i>Sphaerium</i> sp.	

Portlandia arctica and *Sphaerium*, the species of the latter being probably *nitidum*, which has been found elsewhere in the St. Lawrence Lowlands, are indicative of cold conditions.

As for the granule gravel, it is interpreted (together with the mixed fauna) as indicating a shoaling and freshening of the water at the time of deposition of the St. Narcisse moraine. The layer overlying the sand layer is indicative of a deepening of the water, following the deposition of the St. Narcisse moraine and retreat of the ice from the present location of the same moraine.

North of the position of the St. Narcisse moraine, only the much controversial Cochrane readvance has been reported. Recent work by Hughes (1965) appears to have shaken the status of this moraine as being a

readvance. According to Hughes, it is only of local importance (p. 564).

As for the Lake St. John area: what appears to be a gravelly moraine (Lasalle, 1966) in the Hébetville area, deserves no status at the present time as a climatic oscillation. It appears to be only a forced halt because of the depression of the Lake St. John basin. Considering the new pollen stratigraphy at St. Hilaire bog and other sites and taking the C¹⁴ dates at face value, we have proposed a tentative correlation of the moraine in the St. Lawrence Lowlands (in fig. 2).

3. THE LATE-GLACIAL LAKES IN THE WESTERN PART OF THE ST. LAWRENCE LOWLANDS

Several authors have written on the late-glacial lakes in the St. Lawrence Lowlands. They cannot all be mentioned here. Most of the recent additions have been made on the basis of the framework set up by Chapman in his paper of 1937. It appears that in the light of the new C¹⁴ date (G.S.C.-419) this story can be made more precise or at least reinterpreted. Several radiocarbon dates in the New York area, south of Lake Ontario indicate now that Lake Iroquois was in existence in various phases from 12,500 to 11,500 approximately (cf. appendix, table 2). According to Rubin and Berthold (1961, comments on W-883) the Niagara escarpment was free of ice by some 12,000 years B. P., and the „Valders” ice never advanced

south of the area. Other dates quoted in the table 2 and G.S.C.-419 tend to support the idea that deglaciation was rapid in the Adirondacks and that a large body of meltwater existed in the Lake Ontario basin prior to the invasion of the St. Lawrence Lowlands by the marine waters. Glacial Lake Iroquois (as this body of water is called) was draining first via the Mohawk Valley and Hudson River south of the Adirondack Highlands. Upon retreat of the Fort Covington ice (Mac Clintock and Terasmae, 1960) Lake Iroquois drained successively at lower levels via the Covey Hill drainage way into Chapman's Lake Vermont (present elevation of shore line: 725 feet or 220 meters above sea level). Furthermore, geological evidence brought by the work of Mac Clintock and Stewart (1965) and Mac Clintock and Terasmae (1960), appears to demonstrate clearly the existence of a glacial lake in the Cornwall area of Ontario (fig. 2) prior to the marine invasion of the same area. These last two authors may well be quoted at this point: „a large body of water was confluent in the Champlain and St. Lawrence Lowlands with shore lines at present level of 725' in Covey Hill area” (Mac Clintock and Terasmae, 1960, p. 237—238). All the evidence appears to show that not only St. Hilaire Mtn. was

free of ice when the marine waters invaded the St. Lawrence Lowlands, but also a large area north of the Champlain Valley and also the St. Lawrence Valley west of Montreal (see also Elson, 1963). Indeed part of the St. Lawrence Lowlands in the west may have been deglaciated rapidly and above the sea level (Lake Ontario: Karrow et al., 1961) before the marine waters reached the area; a strong argument for this, reported also by Mac Clintock and Terasmae (1960, p. 238), is the fact that the varved clays and uppermost part of underlying till (both underlying the marine clays in places), bear evidence of sub-aerial exposure, in excavations made in the New-York part of the St. Lawrence Seaway and Power project. This would not be the first time that there is partial deglaciation of the St. Lawrence Lowlands without the presence of the marine waters in the immediate vicinity. Gadd (1960, p. 12) reports that there is „no evidence in any area studied by the writer, of marine or brackish water deposition during the St. Pierre interval”. The glacial topography existing during the St. Pierre interval after the retreat of the ice, could not have been very different from the topography emerging at the final deglaciation of the St. Lawrence Lowlands, both permitting fresh water deposition and subaerial ero-

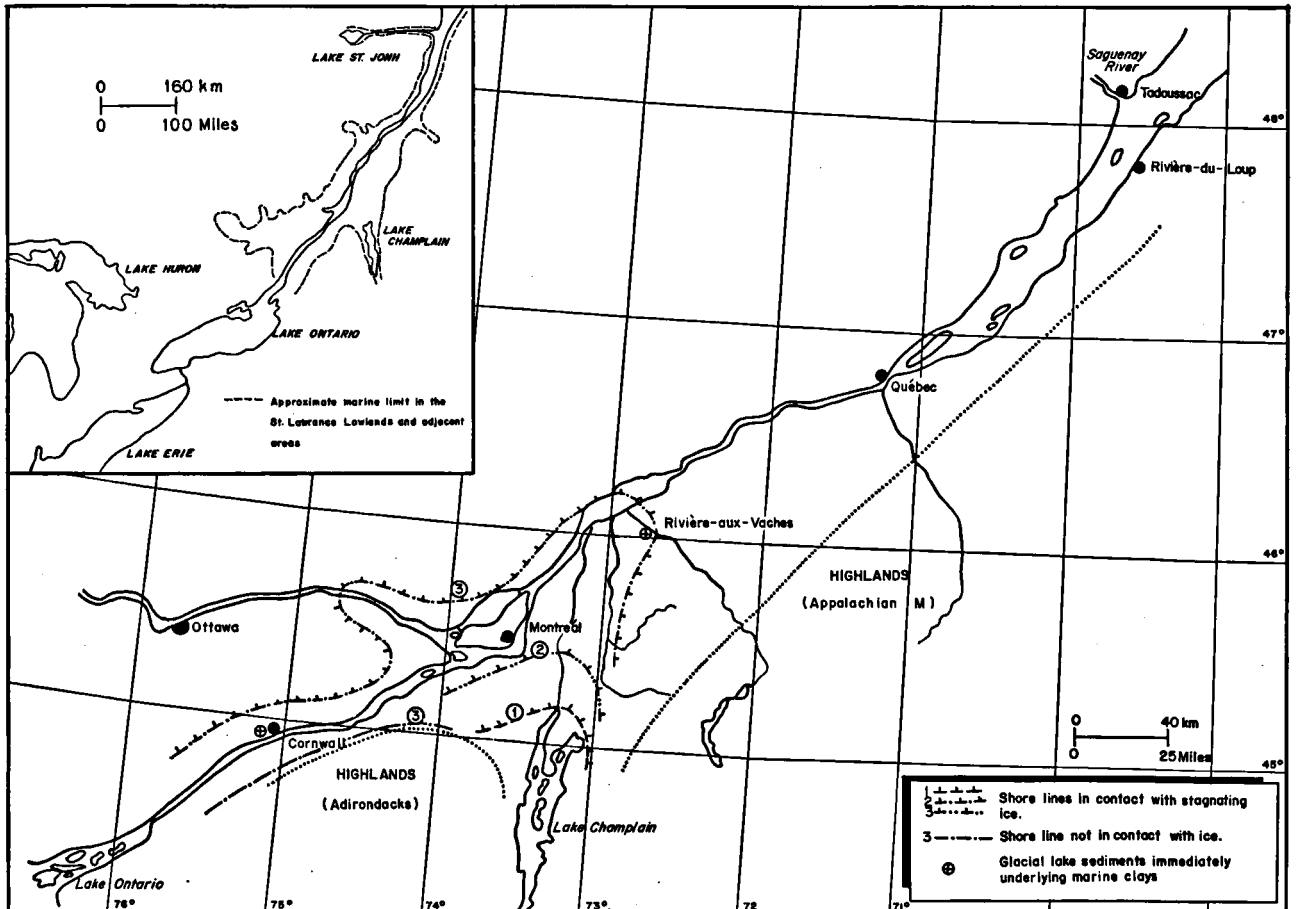


Fig. 3. Possible late-glacial lake stages in the St. Lawrence Lowlands, just prior to the marine invasion.

sion. In the second case however, the deglaciation in the eastern part was more complete allowing the marine waters to penetrate far inland.

4. THE RELATION BETWEEN THE MORAINES AND THE VARIOUS GLACIAL LAKES

It can be then accepted as a fact that the ice must have been comparatively thin in the Richelieu-Lake Champlain Valley some 12,500 years ago (G.S.C.-419). Indeed, it could not have been more than 400 meters thick (if we remove the marine sediments), otherwise the St. Hilaire bog could not have been open to organic sedimentation at that time (cf. fig. 5). As the hypothesis is set up above, and if the ice was calving in part in a re-entrant in the ice in the Champlain Valley, this would explain why we do not apparently have any trace of the Drummondville moraine west of Mount Yamaska. The area was then occupied by a glacial lake as shown on the map (fig. 3).

The various phases of the history can then be reconstructed as follows: At the time of the deposition of the Highlands Front Moraine System (Gadd, 1964) the ice was calving into a glacial lake in the Champlain Valley; if not all the time, this was at least true during the retreat of the ice from that position. Lake Iroquois was already in existence in the Lake Ontario area as suggested by Mason (1960), and as shown on the map (fig. 3), when the sea water proceeded from the east to meet the fresh water in the west; thereby a large area had already been deglaciated, including part of the Ottawa Valley. The marine waters never gained access to the Lake Ontario basin because it had already been elevated above sea level by isostatic rebound following its earlier deglaciation as dates in table 2 indicate and also probably because of the low sea level of the time (see also Karrow et al., 1961).

It can be added here that the large body of gravel and sand south of St. Hilaire (plate 3, fig. 2) may have been in part outwash deposited in a glacial lake south of the mountain (or ice-contact drift), before being re-worked by the waters of the Champlain Sea.

5. THE TWO-CREEKS, VALDERS, AND THE CHAMPLAIN SEA

The present author was tempted to name the following short and speculative discussion „The Two-Creeks problem”. However, is there a Two-Creeks problem any more than there is a Valders problem? The solution lies only in revising the correlation as the information is brought to light.

The age of the Two-Creeks forest bed appears to have been settled by Broecker and Farrand (1963), as being of the order of $11,850 \pm 100$ years B. P. (p. 796, average of several dates). A slightly older age is quoted by Broecker and Kaufman (1965, p. 556), viz. $11,900 \pm 100$ years B.P.

However the main problem that remains to us for the area that we are concerned with is the following: Is there in the eastern part of North America any equivalent of the Valders readvance that overrode

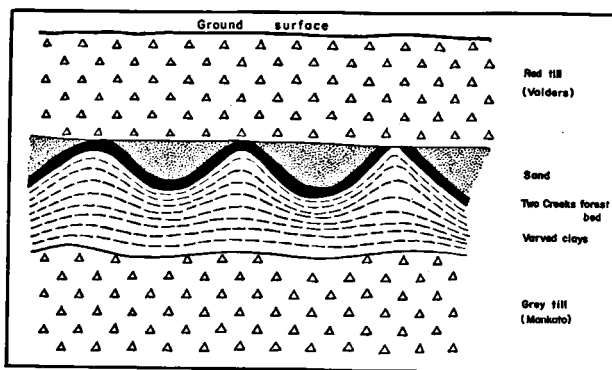


Fig. 4 Stratigraphy of the Two Creeks type section; sketched after Thwaites and Bertrand, 1957, p. 857 (not to scale)

the Two-Creeks forest bed in the Great Lakes area? It appears to be fairly and reasonably well established that the retreat after the Mankato ice readvance and the improvement of the climate that is in part correlative with it must have been initiated considerably before the growing of the Two-Creeks forest bed and its killing by the rising of the water of Lake Michigan. (Thwaites and Bertrand, 1957; Broecker and Farrand, 1963). Indeed, as will be seen below, the growing of the Two-Creeks forest itself may have been one of the several events that can be expected during a short warm episode of this sort.

As reported by Jelgersma (1962) and as quoted by Broecker and Farrand (1963, p. 799), the Mankato ice must have been in „full retreat” by 12,500 years ago (W. 824, $12,650 \pm 350$ years B.P.). As this date was obtained from the bottom sediments of a kettle hole well inside the Mankato drift border, its stratigraphic position does not appear in doubt (Jelgersma, 1962, p. 523 and 526).

Hence, the improvement of the climate that was conducive to the growing of the spruce forest along the shore of Lake Michigan is somewhat older than the time of the growing of the forest itself (v. d. Hammen, 1951). This conclusion is warranted also by the stratigraphy of the Two-Creeks type section itself, as reported by Thwaites and Bertrand (1957). A sketch (not to scale) of this stratigraphy has been prepared from the original paper of Thwaites and Bertrand (1957) and appears in fig. 4.

The poorly preserved varved clays underlying the forest bed represent an unknown number of years, and were deposited during the retreat of the Mankato ice from a position further to the south, while the sand above the forested bed was deposited by advancing Valders ice, the forest at Two-Creeks having been drowned as a consequence of the closing of the strait of Mackinac in northern Michigan by the Valders ice (according to Thwaites and Bertrand, 1957).

The material that constitutes the Two-Creeks forest bed proper has been studied by many authors. The latest of those studies is by West (1961). The macrofossils as reported by Thwaites and Bertrand (1957, p. 586) indicate the presence of abundant *Picea mariana*, and also that at least one other species of *Picea*.

However, *Picea mariana* appears to be the most abundant. The presence of balsam fir (*Abies*) is also reported but above the main forest bed. This position of *Abies* above the main forest bed appears to suggest that some species of that genus may prefer cooler temperature than the spruce species mentioned. The microfossil study of deposits presumably correlative of the Two-Creeks forest bed made by West (1961) reports a greater abundance of pollen grains of *Picea glauca* than of pollen of *Picea mariana*. As the identification of the pollen species is based on size, West (1961, p. 767) has only suggested that the identification of the species may have validity. The presence of the pollen of *Abies* is not reported by West (p. 771).

The study of the tree rings of the same material or material correlative with it (Thwaites and Bertrand, 1957, p. 856) indicates that they were thinner in the last twenty years of the life of the trees, indicating less than optimal conditions for growth. The maximum number of tree rings counted, as reported by Thwaites and Bertrand (1957, p. 856), is 142.

West (1961) has also given some indication of a deterioration of the climate in his study of the pollen assemblage of the Two-Creeks bed. A large percentage of herb pollen is very clearly shown in the upper part of his pollen diagram (p. 771).

Hence, the evidence brought together above from published sources indicate that the improvement of the climate that is conducive to the retreat of the Mankato ice is somewhat older than 12,000 years ago by an amount that may be of the order of several hundred years. It is certainly older than the dates of the Two-Creeks forest bed as reported by Broecker and Farrand (1963) and Broecker and Kaufman (1965) and as these authors (Broecker and Farrand, 1963) have argued themselves.

On the other hand, the deterioration of the climate that ultimately brought about the killing of the trees that grew at Two-Creeks is somewhat older than the date of the killing of the trees itself and is presumably in large part contemporaneous with their living. These trees appear to have been growing in the last spell of the climatic improvement that preceded the Valdres and in part during the deterioration of the climate. Hence, the conclusions of Broecker and Farrand (1963) that the Two-Creeks forest bed (or its correlative) grew during a climatic improvement equivalent to the Bølling appears to be warranted. The difference in age may be only apparent and due to the type of sediments used for dating. In Northern Europe, lake sediments have been used for dating, in which the change of vegetation type proper reflects more directly a change in climate (Broecker and Farrand, 1962).

Other peat dates corresponding approximately with Bølling dates reported by Broecker and Farrand (1963, p. 799) and Fries et al. (1961, p. 691) deserve to be mentioned here:

- W — 641, $12,000 \pm 500$ yrs. B. P.
- W — 762, $12,200 \pm 250$ yrs. B. P.
- W — 354, $12,030 \pm 200$ yrs. B. P.

The first two dates appear certainly to come from material correlative with the Two-Creeks, and related to the same area (Broecker and Farrand, 1963, p. 799). The third one appears to have a more controversial stratigraphic position, and its correlation with the warm episode of the Two-Creeks can be only very tentative.

In the present state of knowledge, the terms Valdres and Two-Creeks should not be used outside their type locality (Flint, 1963) or they should be used in a very informal way, as van der Hammen and Vogel (1966) have suggested by including both Bølling and Allerød in a Two-Creeks episode „sensu lato”. They feel there is no good moraine as a logical candidate for correlation with the Earlier Dryas.

Furthermore, another possibility must be examined, especially if one feels that the evidence for a deterioration of the climate indicated by the microfossil assemblage of the Two-Creeks forest bed is not strong enough. Indeed, the sand above the Two-Creeks forest may indicate a shallow water deposit; the forest bed may then have been buried under a sort of deltaic or other shore deposit during a low water stage. This idea has come in the course of discussions with Dr. van der Hammen and with Dr. Saskia Jelgersma who has visited the site (see also Jelgersma, 1966). In that case, the age of the Two-Creeks forest bed may be considered as fitting somewhere in the middle of an interstadial. Consequently, the lowest possible stratigraphic position of the Valdres readvance (maximum possible age) is delimited by the age of the Two-Creeks bed (sensu stricto, $11,900 \pm 100$ years B. P., Broecker and Kaufman, 1965), but its highest stratigraphic position (minimum age) remains in doubt (see fig. 3).

As suggested elsewhere in this paper and with the above discussion in mind, it would appear that the Highland Front Moraine system may correspond to the Earlier Dryas of van der Hammen and Vogel (1966) as this system must be older than the maximum age obtained on shells of the Champlain Sea (Gadd, 1964). The general and rapid deglaciation of the St. Lawrence Lowlands may correspond to the warmer Allerød episode of the European workers.

Broecker, Ewing and Heezen (1960) have discussed the evidence brought about by C^{14} dating of North American material (and also other material), for a general improvement of the climate around 11,000 years ago. However they used a certain number of dates that fall in the range between 11,000 and 11,500 years ago to build up their argument; hence the improvement of the climate that they are dealing with must have started somewhat before 11,500 years ago, and culminated around 11,000 years ago, as the Allerød episode. The St. Narcisse readvance, which overrode the Champlain Sea sediments in the Trois-Rivières area (Gadd and Karrow, 1959) may then be correlative of the Younger Dryas. As for the Champlain Sea itself, it is „definitely” younger than the Two-Creeks „sensu stricto” (Broecker and Farrand, 1963, p. 801).

In the Southwestern United States, Martin and Mehringer (1965, p. 440) appear to be skeptical about the existence, in the pollen diagrams of that area, of the evidence for the oscillations observed elsewhere in the temperate regions. However there appears to be a striking correspondence in the dates of the charcoal horizon (A-378, $10,940 \pm 100$ years B.P.) of the Lehner Mammoth site as reported by Mehringer and Haynes (1965, p. 20), and various other dates made on charcoal found elsewhere in the world and reported by van der Hammen (1965). For example, a charcoal layer found in the Mondoñedo formation at the edge of the Sabana de Bogotá has yielded ages of $10,840 \pm 110$ years B. P. and $10,760 \pm 160$ years B. P. (GrN-4209 and GrN-4210 respectively; van der Hammen, 1965).

Dates for a charcoal horizon in northwestern Europe have yielded ages corresponding to the end of the Allerød period. They are reported by van der Hammen (1965) as follows: $10,880 \pm 160$ years B. P. (Y-139/2) and $10,795$ years B.P. (GrN-937).

As these ages appear to date a change from a warm to a cold phase, the ecological interpretation made by

van der Hammen is the following: the deterioration of the climate caused by the incoming cold phase killed forest trees, at least some of them, so that they became an easy prey for fire. This is a very plausible interpretation because climatic changes are thought to occur over wide areas and that actually this phenomenon (presence of charcoal in late-glacial sediments) has been observed in widely separated places. Some charcoal is reported in the present work in the pollen diagram of St. Hilaire and St. Bruno. Its quantitative expression, however, must be interpreted cautiously. Whether the charcoal horizon of the Lehner site deserves the same ecological interpretation as the other occurrences is a problem in itself, as the expectancy of forest fire in the southwest (arid?) may be greater than in the northern more temperate regions of the world. However the coincidence of the dates is certainly positive and cannot be ruled out, especially if one agrees with the idea that deteriorations of the climate (ice readvances in higher latitudes) are correlative with a more humid climate (higher precipitation) in the lower latitudes (Maarleveld and van der Hammen, 1959; Broecker and Kaufman, 1965).

CHAPTER III

ABSOLUTE CHRONOLOGY

Before discussing sea level changes it appears opportune to say a few words here about the C^{14} dating principles and the reliability of the results.

The content of this paragraph has arisen from discussions with Dr. J. C. Vogel during a short visit to the C^{14} laboratories in Groningen and has been written with his collaboration. It is mostly a resumé of the literature, and part of it is based on Dr. Vogel's paper: „Use of Carbon isotopes in groundwater studies" (1963). Though Dr. Vogel has critically read this paragraph, the application of the principles to the particular situation dealt with here or any other error remains with the author.

The C^{14} dating method itself relies on three basic assumptions:

- 1) The organic matter, when living had a C^{14}/C^{12} ratio that is approximately the same as surrounding atmosphere, where this ratio is the result of an equilibrium between the bombardment of nitrogen atoms by cosmic-ray-produced neutrons and radioactive decay.
- 2) The C^{14}/C^{12} atmospheric ratio is the same today as at the time the organic matter dated was living.
- 3) The C^{14}/C^{12} ratio is not changed by any other means than that of radioactive decay of C^{14} after the burial or fossilization of the organic matter.

With those assumptions in mind, it can be seen that C^{14} dating cannot be accepted blindly if results appear anomalous. Especially the third assumption is dependent of the nature of the material dated and is the reason for differences in the reliability of the results.

Only marine shells and lake sediments (gyttja) will be considered here.

a. Marine shells

Dates obtained from marine shells are considered today as fairly reliable, especially if the shells dated are shallow water forms (Mac Clintock and Terasmae, 1960, p. 239). The C^{14}/C^{12} ratio of these mollusks appears to be the same as that of contemporaneous wood; these conclusions are based on the measurement of C^{14}/C^{12} ratio of living mollusks in bodies of water comparable to a certain extent with the ancient ones (Broecker and Orr, 1958), and also on genera or species that are the same as the fossil ones.

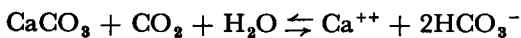
However, though we know now the approximate salinity of the ancient water bodies at various phases of their existence (Elson and Elson, 1959), there is still a discrepancy between those and the model studied; for example, the Champlain Sea has no counterpart in existence today, that would be comparable to it as far as location, extent or depth.

Hence, the dates obtained on marine shells of the Champlain Sea may still be in error for three reasons:

- 1) Surface waters around Spitzbergen where glaciers are still existing, have yielded ages of ± 400 years (Berglund, 1964, p. 7). This is due to upwelling of water from greater depth. However, this may not be serious in a body of water like the Champlain Sea, that had a depth of the order of 200 meters or less.
- 2) Admixture of fresh waters with the marine waters

may be more serious. In particular, the meltwaters from glaciers were abundant at the time of the marine invasion in the St. Lawrence Lowlands, and at one time the ice was in contact with the sea waters (St. Narcisse readvance). This water may have been stored as ice in the glacier for a few hundred years. Furthermore, shells living in continental fresh waters can appear up to 1,500 years too old, because ground water that reaches rivers may have been stored in the ground for 10,000 years or more (Vogel and Ehhalt, 1963, p. 391 and 393). Salinity values (23 ‰ to 28 ‰) for the Champlain Sea (Elson and Elson, 1959) deduced from the fossil "dwarf" faunas suggest that the dates obtained could be slightly in error, but no more than a few hundred years (of the order of two to three hundred years). It may be more serious for the dates obtained on marine shells from the Lake St. John area (Lasalle, 1965).

3) Post-depositional carbonates contamination by ground water especially at shallow depth where they could be in contact with the zone of biogenic activity. According to Vogel and Ehhalt (1963, p. 384) the solution of carbonate is effected by the CO₂ from the atmosphere or produced by "root respiration and decay of humus" (Vogel and Ehhalt, 1963, p. 385) in the following way:



The reaction is reversible, and carbonate can be reprecipitated around the shells, if the value of the product of solubility of the bicarbonate of calcium is exceeded. Hence a certain amount of younger C¹⁴ is added at the surface of the shells, and may make the shells appear younger. This may be serious in a climate where periods of strong precipitations alternate with periods of dryness. However, in the latitudes of the Champlain Sea, it may not be so serious, though caliche is observed in the gravel deposits in some places around Montreal. Furthermore, removal of the outer surface of the shells in pretreatment will diminish this source of error.

b. Lake sediments

Submerged plants growing in recently emerged ground water may be up to 1500 years too old. For shallow lakes as the St. Hilaire bog undoubtedly was, (configuration of the basin) and lake Hertel, (7 to 8 meters depth now), exchange of CO₂ with the atmosphere appears sufficient to keep the waters in equilibrium, and upwelling of ground water does not appear to be a serious problem. Furthermore, the overburden is rather thin on the St. Hilaire Mountain "except in the valleys" (Webber and Jellema, 1965, p. 45) and is constituted either of ground moraine or of looser ablation moraine; but in places, the cover is made only of weathering material that has accumulated since deglaciation. The hydrographic basin of the two lakes mentioned above being small, the water that is stored in the overburden from rain or otherwise, cannot be expected to travel for a very long time before reaching the lake basins themselves. Also, because of the high elevations of those lakes above the surrounding plain, water cannot have been stored in the overburden, or the bedrock, for a longer time than the time elapsed since the deglaciation (GSC-419); hence dates from the sediments of these two lakes appear to be reliable. In fact, complete overturn of the water of these lakes must occur or have occurred every year because of seasonal temperature variations.

Isotopic exchange between the water of a lake or ground water and the bedrock surrounding it (Vogel and Ehhalt, 1963, p. 287) may be serious. However, though unproved, it appears on theoretical ground that it cannot occur to a large extent because this phenomenon takes place in the solid state and movement of ions is indeed very slow (Vogel and Ehhalt, 1963 p. 287). This point is considered here because there are small outliers of limestone on the St. Hilaire Mountain. For lake sediments, there remains the serious problem of contamination by roots. This can be avoided by careful pretreatment. Hence, from the considerations made above, it appears that the dates quoted in the appendix in table 1 and concerning our area may be reliable in the present state of knowledge.

CHAPTER IV

SEALEVEL CHANGES

The elevations at which dated marine mollusks are found to-day cannot be used directly as indications for the stand of the sea-level at those dates because these elevations also depend on the amount of isostatic uplift at that particular locality furthermore shells of mollusks, unless found in the place where they lived, cannot be used as approximate indicators of sea level. Other workers have inferred a lowering of sea level followed by a relative rise (Mac Clintock and Stewart, 1965, p. 47; Elson and Elson, 1959; Elson, 1963) for the same period and in the same area that is of interest to us. Additional evidence is discussed in the present

work in the chapter dealing with the moraines. Two other lines of evidence can, however, be pursued, both pointing in the same direction.

First, in the pollen diagram of the St. Antoine core (marine sediments of the Champlain Sea, fig. 14) we have described a zone called the „*Glaux*” zone; we will not repeat the description here. The reader is referred to the section dealing with the St. Antoine core pollen diagram. However, this zone is interpreted as indicating shoaling of the seawaters, as *Glaux* grows particularly well on haline soils. As the pollen grains of this plant have been recorded only in

three consecutive samples, this zone is rather well defined. We can calculate the approximate age of it by using the rate of sedimentation during the Champlain Sea episode. The length of the St. Antoine core is 28 meters. The duration of the Champlain Sea episode being approximately 1500 years, the rate of sedimentation is then 1.8 meters per one hundred years. The „*Glaux*” zone appears to culminate at 17 meters above the bottom of the section. In number of years, these 17 meters represent approximately 8 to 900 years. If we accept the age of the beginning of the Champlain Sea as obtained from marine shells as being ca. 11,400 years B. P., and subtracting 900 years from this figure, we arrive at an age of approximately 10,500 years B. P. for the lowering of sea level corresponding to the „*Glaux*” zone.

Second, material (marine mollusks) collected in a gravel pit north of St. Hilaire Mountain and buried 3 to 4 meters below the surface of the terrace has yielded an age of $10,560 \pm 160$ years B. P. (Y-1558). This date suggests that the rise of sea level following the St. Narcisse readvance is posterior to 10,500 years approximately. However, as suggested by Elson (1963), the rise of sea level may be also in part related to crustal depression following the St. Narcisse readvance.

The two points considered above suggest that a lowering of sea level occurred in the St. Lawrence Valley sometime around 10,500 years ago; it was followed by a relative rise, but the sea did not appear to regain its initial earlier high stand (see also Elson, 1963).

CHAPTER V

POLLEN DIAGRAMS

1. REVIEW OF THE LITERATURE

It is not exaggerated to say that the pollen stratigraphic column in northeastern North America has been modelled on the work of Deevey 1943, 1949), and mainly on his zone sequence of Maine (1951). But the major contribution of the latter paper, as Deevey himself reports it (1951, p. 196), was that it recorded, for the first time in North America, large percentages of grass and sedge pollen in the lowermost sediments of his cores. Furthermore, an important fluctuation of this apparently treeless vegetation is recorded with zone L3 (also in Livingstone and Livingstone, 1958). But, just as much as *Pinus* is not recorded in the lower part of Andersen's diagram from George Reserve (1954), but is recorded in abundance in Deevey's diagrams, *Quercus* and *Fraxinus* are not recorded in such an abundance in the latter as they are in Andersen's where they appear to be a major element of the pollen rain.

Fraxinus and *Quercus* have been recorded in other pollen diagrams from the Midwest of North America, since Andersen's work (v.g. Fries, 1962, and others); it is now unacceptable to assume that such a large quantity of pollen of *Quercus* and other thermophilous trees as reported by Andersen has been redeposited.

Suffice it to say at this moment that wind directions and perhaps long distance dispersal may be responsible for this large quantity of *Quercus* pollen or also that of other thermophilous trees. Furthermore, looking at the present *Quercus* distribution, some species reach the southern limit of the boreal forest (Native trees of Canada, p. 170), and *Quercus* might have occurred not far from southern Michigan in late-glacial time.

Since 1951, new work has been completed, mainly by Leopold (1956) and Davis (1958, 1961, 1963, 1964), in southern New England. In these diagrams, especially those of Davis, *Quercus* and *Fraxinus* appear

to be at least a consistent element in the pollen rain, and the fluctuations of the abundance of their pollen recorded in all her diagrams are remarkable. Though Davis (1961, 1965) has been very critical recently towards the basis on which pollen analysis is resting, these recurrences of variations cannot be only due to a bias of the method of percentage calculations used.

There must be more to it, and the main problem is ecological: we have to know which species or genus, is replacing which other species or genus.

Deevey (1958) and Deevey and Flint (1957) have shown that the sequence as defined by other workers (including Livingstone and Livingstone, 1958) in various places in New England and northern Quebec appear to be comparable, on the basis of absolute chronology.

Further to the north, pioneering work has been done by Potzger (1953) and Potzger and Courtemanche (1956), but the main post-glacial pollen zones appear to be much more firmly set by the work of Terasmae (1960). The St. Germain bog (fig. 8) sequence is presented here in this paper in a modified way to make it more readily comparable to other pollen diagrams in the area. Furthermore, two C^{14} dates have been performed on the basal layer of this bog that gives its sequence an absolute chronologic beginning. The St. Germain bog, however, is almost entirely post-Champlain Sea (Terasmae, 1960), and not much was known of the sequence prior to the Champlain Sea time in the St. Lawrence Lowlands up to now.

In northern Vermont, the pollen diagram of Whitehead (1963; site 9, fig. 7) does not show a late-glacial sequence; according to the author it is however a preliminary one and the study of the mineral sediments may yield some late-glacial zones.

Further to the west, the sequence appears to be less

comparable, and without C^{14} dating, it would be difficult to establish a comparison.

Jelgersma (1961) however, has attempted a comparison. Though West (1961) has recognized the Valders readvance in his diagram, Jelgersma does not feel that any change is recorded in her diagram that can be correlated with the Valders.

As West (1961, p. 781) has contended, the continentality of the environment may be the cause of this non-recording of the herb zone; Wright et al. (1963) do not feel that any change in their diagrams can be linked directly with climatological change and argue that the changes are more of the type one would expect in a normal succession. This may be the case and, unless one has a recurrence of vegetation as in the eastern diagrams, it is difficult to link change to climatic amelioration or deterioration (except of course for the important migration of thermophilous trees in post-glacial time). For the Midwest, the reader is referred to the excellent resumé of Cushing (1965) as the large numbers of pollen diagrams from that area, precludes their discussion here.

2. LOCATIONS OF THE NEW DEPOSITS.

The St. Hilaire and St. Bruno Mountains are two of several hills (plate 1) of which the alkaline intrusive core was emplaced in Cretaceous times (Fairbairn et al. 1961).

There is no evidence that the Monteregian hills (as they are called) were volcanoes at the time of their emplacement. The St. Hilaire Mountain is made of two types of alkaline rocks: nepheline syenite on the east side and essexite (gabbro) on the west side (see fig. 5); there are also other minor alkaline differentiates, and moreover xenoliths and hornfels derived from the Ordovician sedimentary rocks.

The St. Hilaire Mountain geological setting resembles very much that of Mt. Omberg in Southern Sweden as described by Erdtman (1949, 1963). It is important to note here that it is not at all the intention of the present author to convey by those remarks that St. Hilaire was a nunatak during the Pleistocene glaciation. Striations have been found on the mountain itself (Gold, 1963). However, like Mount Omberg, St. Hilaire may have been deglaciated earlier than the surrounding terrane; its highest point is nearly 400 meters above present sea-level (see fig. 5) while the surrounding plain is for the most part 30 meters above sea-level now, or lower. If we remove the marine clays that were deposited following the deglaciation of the area, the terrane surrounding the mountain is 50 meters or more below present sea-level and 12,500 years ago, the thickness of the stagnant ice could not have been more than 400 meters; otherwise it is impossible to explain how the site of the St. Hilaire bog could have been open to sedimentation.

The lake may have been isolated, without any connection with other existing glacial lakes; the shore of the lake might have been bounded by land ice. There is evidence (Lasalle and Elson, 1962). on the east side

of the St. Hilaire Mountain, that stagnating ice was around the mountain at some time during the lateglacial episode; sand grains in the shales have tails (formed presumably by glacial erosion) that point to movement in a north-eastern direction. Until positive evidence of movement to the north is found in the area, the crag-and-tail forms are better explained by movement of stagnating ice around the St. Hilaire Mountain. The St. Hilaire bog was then certainly a lake with open waters as indicated by the diatom flora and the character of the 4.5 lowermost meters of sediments, which grade upwards from clay or silt gyttja to gyttja or diatom gyttja.

This sequence appears to be entirely normal for a lake in those latitudes (Swain, 1965). It generally goes from an oligotrophic stage to an eutrophic stage, which, if the lake fills up, grades into a dystrophic stage until the original lake is covered by forest. No marl was recovered (Swain, 1965) and the bottom of the core did not show calcareous material. At St. Hilaire, the surrounding Ordovician rocks include some limestones and calcareous shales; and furthermore the depression where the St. Hilaire bog is located may have been carved out in limestone or shales or less likely though, in hornfels (xenoliths). No positive evidence exists for that as the rock from the bottom has never been recovered (see map 5).

The upper part of the section of the sediments must have accumulated very fast, i.e. after the *Tsuga* minimum that is prominent in other pollen diagrams of the area. The sediments consist of little decomposed organic matter, with tree trunks that appear to occupy a horizon rather than disseminated throughout the upper part of the section. As this level of the tree trunks appears to coincide with the *Tsuga* minimum, it is to be wondered whether it has any climatic significance. This point will have to be investigated further; it may suggest a period of drought during the Sub-boreal.

The other lake on the St. Hilaire Mountain of which the sediments were investigated is lake Hertel. The surface of that lake is at approximately 173 meters (572 feet) above present sea-level. Why this lake did not fill like the actual St. Hilaire bog is an interesting question. Perhaps the configuration of the basin has a strong relation to the kind of sediments that appear in those two lakes. The St. Hilaire bog is a long narrow depression that has approximately 100 meters in width at its maximum. It is tapering at both ends and presumably as the lake was filling with detrital organic and mineral matter, the vegetation could easily gain access to the middle of the depression.

As for lake Hertel it is approximately rectangular in form and the distance between the closest points on its shores is approximately 450 meters (or 1500 feet). It is also possible that the bottom of the depression is made of an outlier of limestone or hornfels and that the original depression now occupied by the lake is due to glacial erosion. There is no evidence for that matter around the lake however.

The presence of water in this lake has been a puzzle to

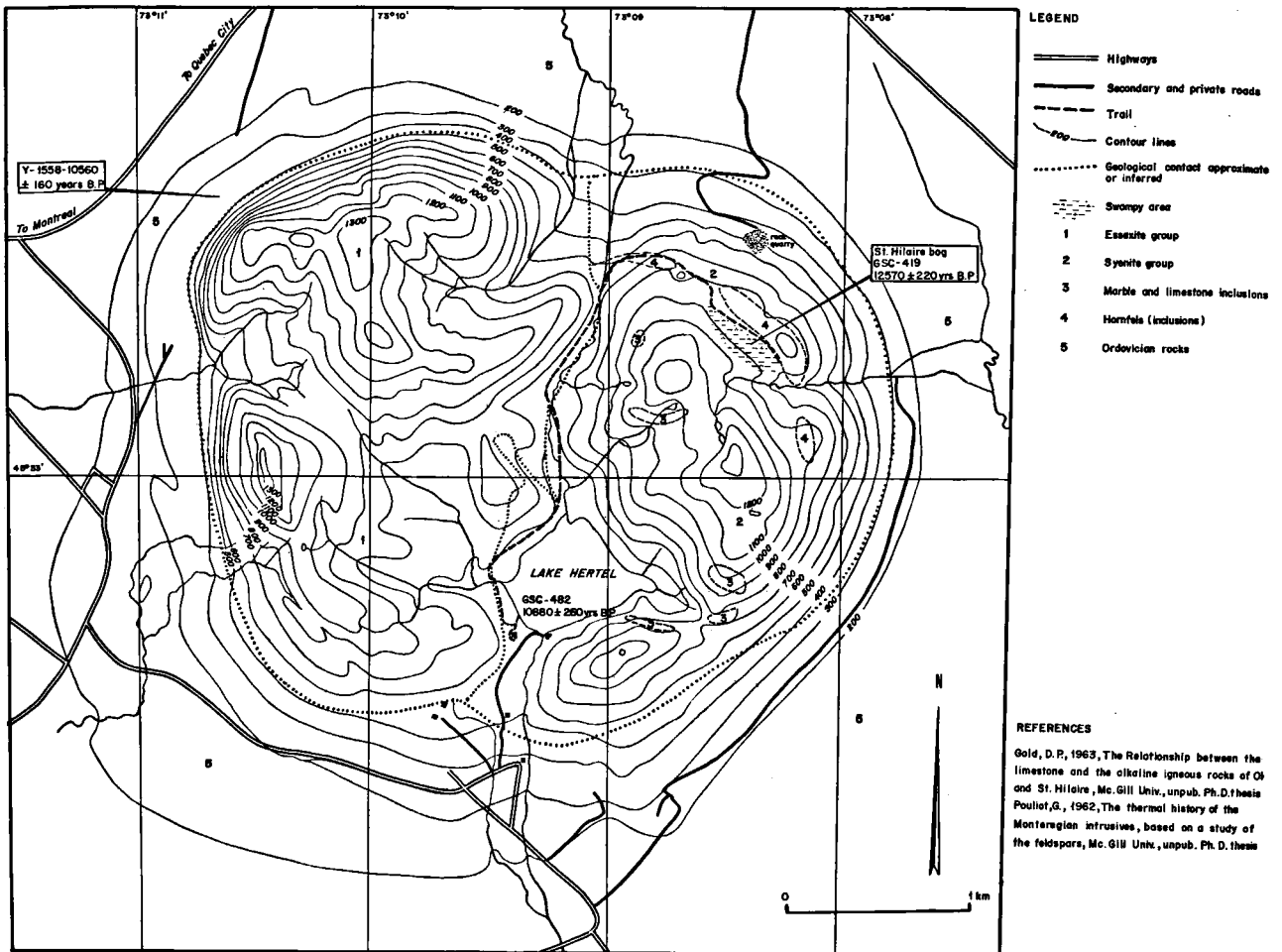


FIG. 5. TOPOGRAPHICAL AND GEOLOGICAL MAP OF MOUNT ST. HILAIRE, P.Q., CANADA. (modified after D.P. Gold, 1963; sources of information of D.P. Gold: T.H. Clark, Quebec Dept. of Mines, Map no. 848; additions from G. Pouliot, 1962, J. Goddard and J.J. O'Neill, Geological Survey of Canada, Map no. 401A) Geological mapping by D.P. Gold. Contour line after P.D. Baird, from D.P. Gold.

the inhabitants of the area and a current „theory” is that there is an underground passage linking this lake (Hertel) to lake Champlain. Of course, this is absolute fantasy. The lake is a reservoir for the city of Beloeil. Its water comes from the rain and snow by streams that drain into the lake mainly from the northern part of the mountain. There is storage of water in the soil, and at dry periods there is certainly drawing on that storage, but this lake has definitely no underground connection with anything.

Since the pollen sequence starts later than the one of the St. Hilaire bog (as indicated by C^{14} dating and the pollen assemblage), it is possible that ice surrounding the St. Hilaire Mountain or occupying the basin, prevented organic sedimentation. Diatoms (brackish and marine forms, definitely less than one percent) however, have been recovered below the level of the C^{14} date.

As the dated material included a 14-cm interval, the C^{14} date (GSC-482) is better thought as the age of the top of that interval. Certainly there was some organic sedimentation before the level of the dating. The pollen however is extremely rare. It may indicate marine sediments (?) which as Deevey (1951) sug-

gested are mostly barren. However, as the threshold of the plausible entrance for the marine waters into Lake Hertel is very close to the marine limit in the Montreal area (565-570 feet or ca. 170 meters: Elson, 1963), it cannot be expected that the sea got into the lake for a long time. But the diatom flora appears to indicate that the sea was very close to it, as will be discussed later.

The St. Bruno Mountain is made up entirely of essexite. The Mountain itself has its highest point at an elevation that is considerably lower than the highest point on the St. Hilaire Mountain (St. Bruno: 180 meters approximately or ca. 600 feet; see fig. 6). The St. Bruno bog itself is located at an elevation of approximately 130 meters (or ca. 425 feet). Today, it is a dystrophic lake with a floating mat of vegetation advancing into the lake from its western part. The amount of herb pollen recovered is low in the lowermost part of the core. This basin must have decidedly been occupied by marine waters during the Champlain Sea episode, which may be the reason why the lowermost samples of the core (marine clays?) proved to be barren of pollen.

However, the pollen sequence found upward in the

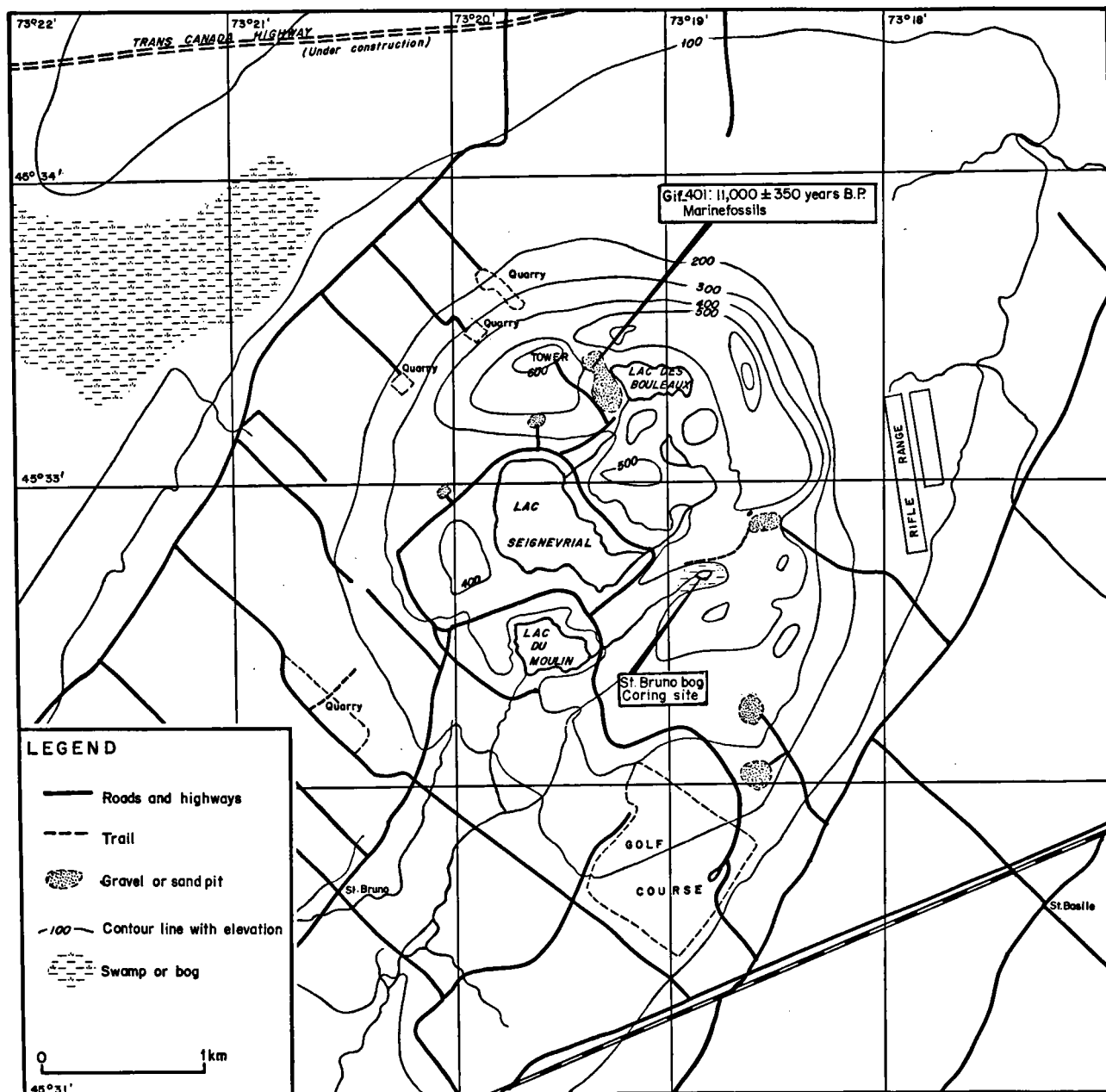


FIG.6. TOPOGRAPHICAL MAP OF THE ST. BRUNO MOUNTAIN AND SURROUNDINGS, P.Q., AFTER NATIONAL TOPOGRAPHIC SHEET NO. 31 ^H/₁₁, WEST HALF.

section appears to be normal for the area (*cf. fig. 13*). The location and description of the sites of the St. Antoine (marine sediments) and Lake Kenogami cores will be given with the description of their pollen diagrams as they do not require long comments.

3. THE NEW POLLEN DIAGRAMS

a. General discussion

At the time E. B. Leopold published her paper recording the sequence of the late-glacial sediments of Durham and Tokoket bog (*fig. 7 sites 13 and 14*),

there was only Deevey's sequence of Northern Maine (*fig. 7 site 2 and 3*) describing a late-glacial sequence for northeastern North America, with fluctuations of the herb percentages. (L1 and L2 in Deevey's diagrams, 1951).

Since then, several late-glacial sequences have been published for the New England area. However, in the St. Lawrence Valley, the present St. Hilaire bog sequence is the first to show a late-glacial sequence.

In general, the St. Hilaire deposits appear to fit in well with the sequence outlined by Deevey (1951),

Deevey and Flint (1957), Davis (1958) Livingstone (1958), Beetham and Niering (1961).

In the calculation of the percentages, the total pollen sum of the terrestrial plants has been used including the rarer herbs. We have not tried to separate the *Pinus* species, as Whitehead (1964) has casted doubt on their identification based on their pollen. The separation of the *Betula* species is even more uncertain.

A certain number of grains have been listed as types. These grains occur generally in minor amount.

Also some grains remained unidentified because of crumpling or breaking, while some other types appearing occasionally as a single grain only were entirely unknown to us: they have been lumped together as unknown or broken (some of them are shown on plates no. 9 to 14).

The breaking of the conifer pollen grains may partly have occurred because of overexposure to ultrasound, since slides prepared at the Geological Survey of Canada, on the same material, without ultrasound, revealed almost no breaking. However, Livingstone and Livingstone (1958, p. 345) have reported a certain amount of broken pollen grains of „*Abietinae*”. (To our knowledge, they did not use ultrasound in the preparation of the pollen slides.)

Cushing, in a recent paper (1964, p. 1081—1084) has taken up this problem for Andree bog. He concluded also that breaking appears to occur as a result of techniques of preparation of the slides. At St. Hilaire and St. Bruno, the sediments from which broken grains of conifers were obtained did not appear to be significantly different from other sediments of the same deposits from which unbroken grains were obtained (all green diatom gytja).

Hence, presumably, post-depositional chemical action „in situ” can be ruled out. We therefore agree with Cushing that the preparation techniques, especially an over-exposure to ultrasound may be the most important factor in the breaking of pollen grains. However, in the counting, grains of conifers can generally be identified and counted as halves, and consequently the percentage values are not affected.

Redeposition of pollen grains has not been taken into account, as it seemed to us that rebedded grains did not appear to constitute a significant part of the pollen assemblages found in the sediments studied. For setting apart pollen grains as redeposited one must either know the pollen grains present in the plausible „mother” formation, or otherwise they must reveal characters (color, degree of preservation) that permits to consider them redeposited.

Davis (1961) and Cushing (1964) have discussed the problem of redeposition for north-american deposits. Cushing (1964, p. 1086) especially has „concluded that the occurrence of pollen grains of deciduous trees in the *Picea*-dominated pollen zone in east-central Minnesota (AB-1 at Andrea Bog) cannot be ascribed to secondary redeposition”. It appears also that this conclusion can be applied, in particular, to the pollen grains of thermophilous trees found by Andersen in the sediments studied from the George

Reserve deposit (1954). The thermophilous trees must have also been growing in significant number within pollen dispersal distance of the St. Hilaire bog and Lake Hertel in late-glacial time.

Other microfossils found have been reported in the pollen diagrams, like epidermal fragments provided with *stomata* of conifer needles. The genera to which they belong has been tentatively identified by comparison with recent material (*Picea* or *Pinus* needles) prepared at Leiden.

The presence of *Hystrichosphaeridae* (Ewitt, 1963; Deflandre, 1964; see also Faegri and Iversen, 1964, p. 166, 167) has also been recorded. Undoubtedly, some of the ones noted though in very small quantity may have been redeposited from Ordovician rocks. However two of the microfossils have been found at all levels in the Lake Hertel sediments, one of them in large quantities (photo 1—3, plate 14). A curve of its variation (as a fraction of the pollen sum) is included in the pollen diagram of Lake Hertel. These microorganisms have certainly not been redeposited from earlier deposits. They appear to be part of the plankton (*Dinoflagellatae*) of the eutrophic phase of a freshwater lake, like Lake Hertel. They have not been observed in the sediments of St. Hilaire and St. Bruno bogs. Other *Hystrichosphaeridae* have been observed at the levels between the samples 68 and 73 of Lake Hertel. A photograph of them is shown on plate 14 (photo 5—7).

We refrain from concluding to a marine environment at the level at which they were found in the Lake Hertel sediments. They may have been washed from marine sediments deposited during an earlier brief invasion of the sea, a fact that cannot be entirely ruled out because of the diatom flora present in the lowermost layers of the Lake Hertel basin.

However no marine sediments have ever been observed by the author around or in the very immediate surroundings of the depression that is now occupied by Lake Hertel. The above hypothesis is only considered because of the more or less accepted opinion that at least some *Hystrichosphaeridae* are remains of brackish-water microorganisms (Sarjeant, 1961, p. 107).

These microfossils have not been found in the sediments of the St. Hilaire bog, which was definitely out of reach by the marine waters during the Champlain Sea episode. But as the plausible entrance for marine waters in the Lake Hertel basin was just at the known marine limit for the Montreal area, the presence of the *Hystrichosphaeridae*-like microfossils cannot be assigned with certainty to a fresh water environment. Nevertheless, as will be discussed later, the diatom flora at the same level where the *Hystrichosphaeridae*-like organisms have been found, shows no trace of marine influence.

Finally for an easier comparison with our pollen diagrams we have recalculated and redrawn Terasmae's type section of the St. Germain bog (Terasmae, 1960, p. 3; redrawing fig. 8). We have used as basic sum the total of AP and NAP pollen as they appear

in Terasmae's paper. It does not alter significantly the general trend of the percentage curves. We have also redrawn some of Deevey's diagrams (1951) that had been published in the form of histograms (fig. 9). In the redrawn way the changes appear to be more readily observed. We have also modified slightly Davis' diagram of Williams' bog at Taunton (Davis, 1960) and included only the species that are of interest to our problem (fig. 10). It is hoped that we have done justice to these authors in doing so.

b. The pollen zones

We have used as much as possible the code of zoning of other workers who have published papers dealing with the late-glacial deposits in eastern North America, in particular Deevey (1951, 1957), Leopold (1956) Davis (1958), and Beetham and Niering (1961). This is not to mean that the pollen zones in our diagrams are strictly contemporaneous with the New England zones but rather that their pollen assemblages are similar. Terasmae (1955; 1960) has mainly investigated deposits resting on the sediments of the Champlain Sea and hence younger than the latter. Furthermore, Terasmae himself has stressed the essentially geological purpose of his work on the bogs of St. Lawrence Lowlands; the stratigraphy that he has established has been successfully used as a chronological basis for correlation of events related to the Champlain Sea in part, or posterior to it. Further-

more, as the present work is based essentially on lake sediments or marine sediments, slight differences can be expected.

We have considered that the boundaries of the pollen-zones (which correspond in general to climatological „units“) should be established „on the basis of changes in the relations of vegetation components that were already present previous to the change in climate and not on the basis of the first appearance of new components“. (van der Hammen, 1951, p. 84). We feel that the change of climate must precede somewhat any change in vegetation, that must always be lagging a little behind the climatological changes.

c. The St. Hilaire bog diagram (fig. 11)

The T zone (Davis, 1958; Leopold, 1936) is characterized by a high content of herb and shrub pollen, almost 50 % of the total sum.

Salix sp. has been included in the herb total sum as it is a shrub or under-shrub that is likely to be part of this type of open vegetation (Faegri and Iversen, 1964, p. 91). We are unable to state, however, which species of *Salix* were present. Some leaves were present in the samples collected at the level of the T zone that resembles very much *Salix* leaves. But we refrain from further commitments until the macrofossils of the deposits are studied completely.

It would tend to indicate the presence of *Salix* growth very close to the sites. Furthermore a cluster of pollen

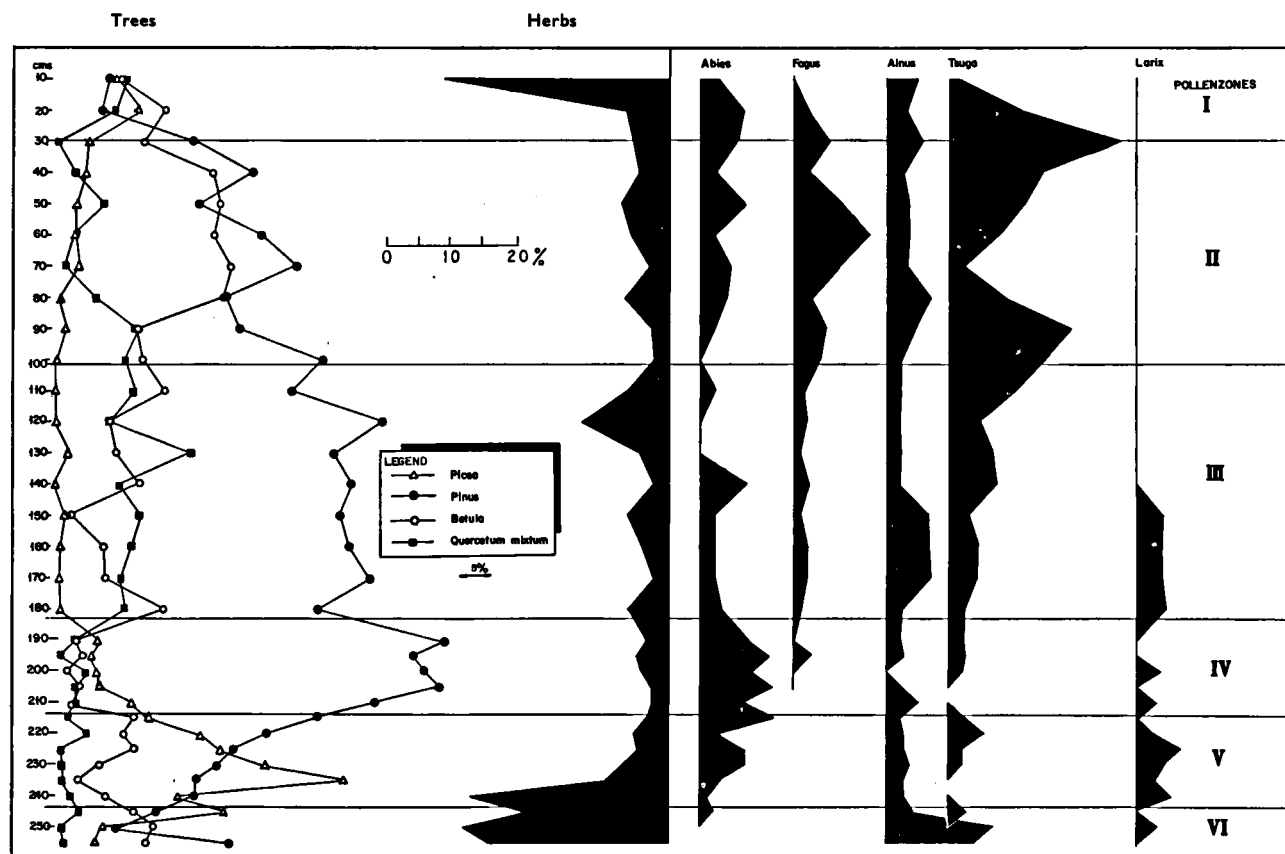


Fig. 8. St. Germain bog pollen diagram, modified after Terasmae, 1960 p. 3 (on map fig. 7, site no. 4)

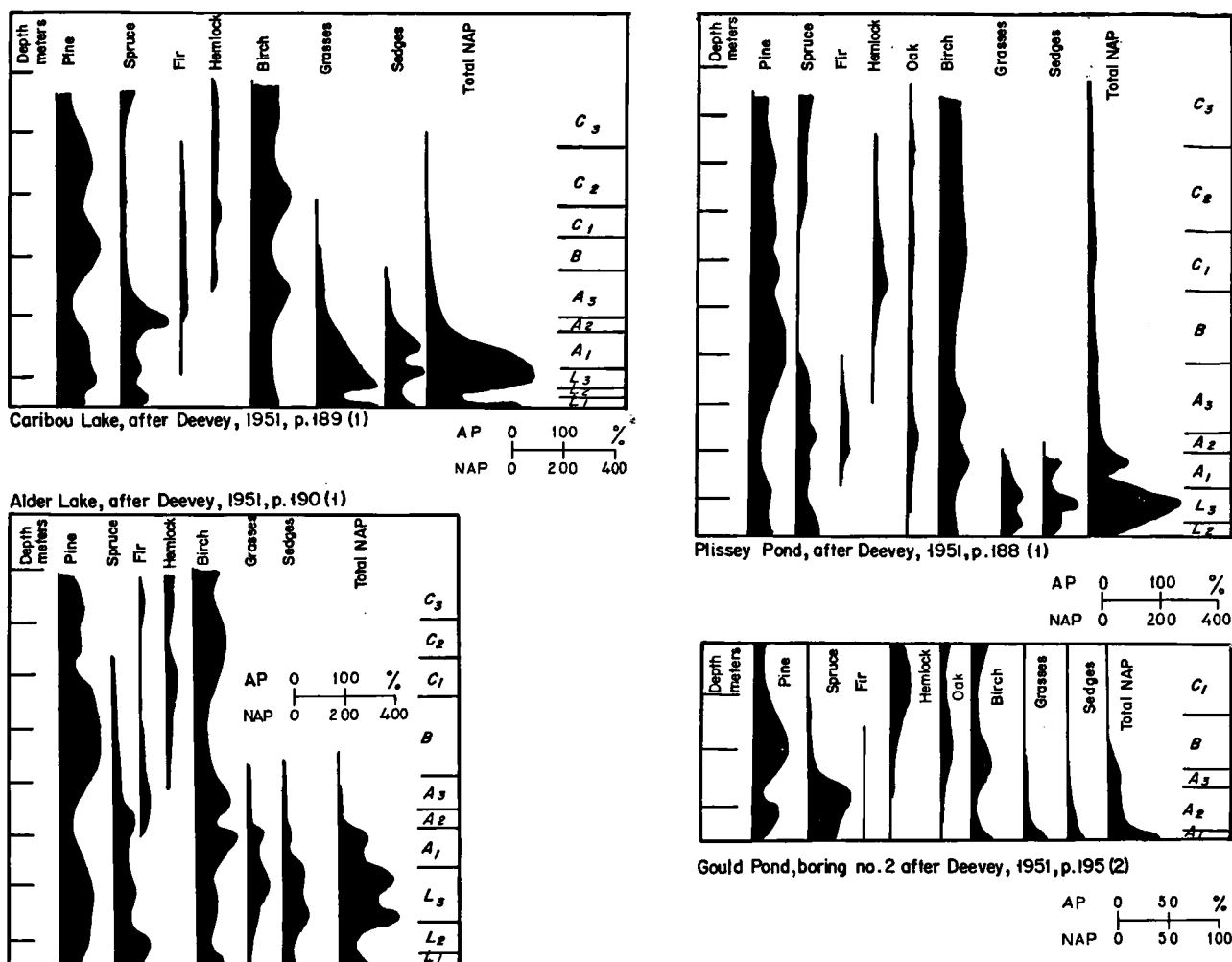


Fig. 9 Pollen diagrams from eastern North America, modified after various authors. Numbers in parentheses refer to map, fig 7.

grains of *Salix* sp. was found in the slides corresponding with a depth of 940 cms. This cluster of grains of *Salix* is likely to be from an anther that fell into the open lake or that has been carried by an insect that fell into the lake. We feel that this phenomenon could occur only if the tree or shrub was growing close to the site of sedimentation. Most of the herbs represented are *Cyperaceae*, *Gramineae*, *Compositae*; among the latter, we have separated only the *Artemisia* type. The other *Compositae* have been lumped together (mostly pollen of the *Compositae tubuliflorae* type). *Saxifraga oppositifolia* (plate 9, photo 1—3) and *Dryas* type pollen have also been recorded.

Epilobium has been recorded as single grain per slide. *Shepherdia canadensis* (plate 6, photo 1—4) is also present in small amount. The presence of this plant has been reported in late-glacial deposits of eastern and central North America including Saskatchewan either as microfossils (pollen) or as macrofossils.

Alnus reaches a peak in the upper part of this zone. The pollen grain of this genus has been observed consistently in the lowermost zone of late-glacial deposits. It is likely to be a local tree on the margin

of bogs. Furthermore, its distribution reaches up to the tree limit today (cf. *Alnus rugosa*, Bull. 61, Dept. of Forestry, p. 89). It may then have been growing close to the site at St. Hilaire.

We did not find, however, the pollen of *Armeria sibirica* reported by Ogden (1958) for the pollen section of Martha's Vineyard. As the pollen of this plant (arctic, according to Ogden, 1958) has not been observed at other sites in New England (except at Cambridge, Davis, 1958), it was inferred that it could be expected only at sites close to the coast like Martha's Vineyard (Ogden, 1958). Perhaps it is the reason why we failed to find this pollen type at St. Hilaire.

As for the presence of the other trees close to the site of sedimentation of the St. Hilaire bog, the presence of *Picea* can only be suggested from the finding of stomata of this genus in the lowermost sample of this section. As *Pinus* and *Betula* are producing a large abundance of pollen, it is likely that the pollen of these genera was blown from a distant area, most probably from the south. The same conclusion can be applied to the presence of small percentages of pollen of thermophilous trees. We have also counted the spores of a

fungus that remains otherwise unidentified. These spores occur as polyads or monads and disappear completely at the upper boundary of the T zone. Their percentages are expressed as a fraction of the total sum of pollen grains and so they have not been included in the sum itself.

Freshwater algae like *Pediastrum* and *Botryococcus* are also present. A few pieces of charcoal have also been found at the top of this zone. Finally a date of 12,570 ± 220 yrs B. P. (GSC-419) has been obtained on material coming from the lower part of this zone.

The A-1-2-3 zones (Leopold, 1956; Davis, 1958) have been lumped together, as Davis has done for the Massachusetts deposits (1958, 1961). We did not feel confident that the minor fluctuations that can be observed in the various components could be interpreted otherwise than due to statistical variations in the counting.

This A 1-2-3 zone is characterized by a pronounced *Pinus* maximum in the upper part, while *Betula* shows a slight maximum before the *Pinus* maximum. *Quercus* increases to a maximum in the upper part of the zone but is present throughout in lesser amount. *Picea* is

present also and its abundance does not appear to vary significantly during the time represented by this zone.

The NAP percentages (herbs and shrubs) vary significantly from these in the lower T zones. One grain of *Elaeagnus* has been found at the 865 cm. level. It is most probably *Elaeagnus commutata* as this grain appears to fit the description of that species given by Andersen (1954) (our photo nos 1—4, plate 5). *Shepherdia canadensis* occurs constantly throughout this zone. *Epilobium* is also present as single grain. Bits of charcoal have also been recorded but their quantitative expression must be interpreted carefully. Indeed, it is difficult to find a way of recording the relative abundance of charcoal. However, it is significant that it is definitely present in this zone. The top of this zone (corresponding to the *Quercus* maximum) is also marked by a large abundance of diatoms. Though they were present in the lower part of the section, it is at the top of zone A-1-2-3 that, for the first time, the flora is very diversified and reaches a large abundance of individuals. On the first occasion that pollen slides were prepared for this

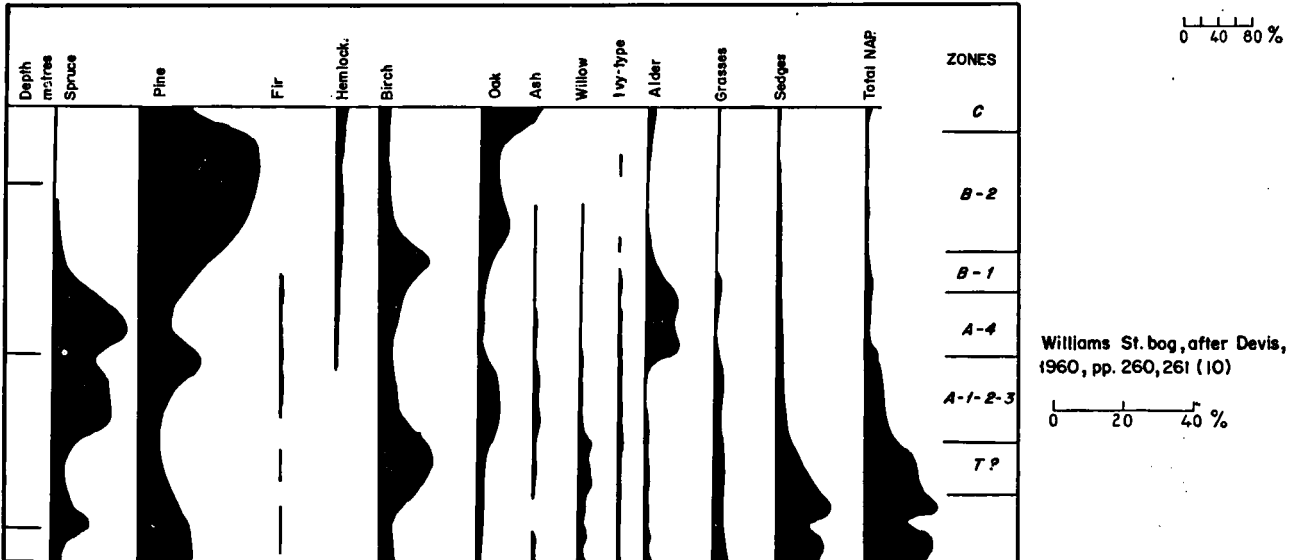
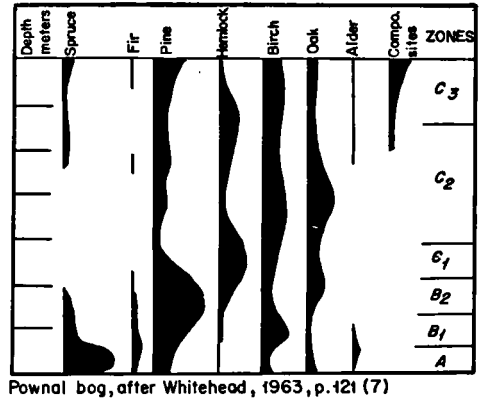
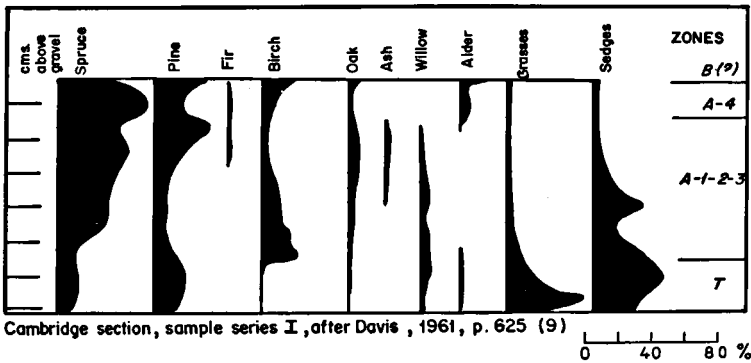


Fig. 10. Pollen diagrams from eastern North America, modified after various authors. Numbers in parenthesis refer to map, fig. 7.

level of the core, we got almost only diatoms at the depth of 855 cm and very few pollen grains. The *Desmidiaceae* are also abundant in this zone and appear in all slides. Dr. Kuno Thomasson of the University of Uppsala has identified a few of them for us during a stay in Uppsala: *Tetradion minimum*, *Euastrum montanum*, *Cosmarium impressulum*, *Staurastrum* sp.

The next zone above, zone A4a has been named again after the zone A4 of Davis (1958). However, we have felt necessary to divide the latter into two sub-zones. The zone A4a is marked by a definite increase in herb and shrub pollen. *Cyperaceae*, *Gramineae*, *Elaeagnaceae* reach low peaks together with *Alnus* and *Salix*, while *Quercus* decreases significantly. One grain of *Elaeagnus commutata* has been found at this level. The *Shepherdia* pollen, found in this zone, in larger abundance than at any other level, has rather strong *costae pori* (Faegri and Iversen, 1964, p. 23. Photographs of this grain are shown in plate 6, photo 1—4). We have examined the slides of *Elaeagnaceae* pollen available to us both at Leiden and in the Geological Survey of the Netherlands, Haarlem. We have come to the conclusion that this pollen grain type represents *Shepherdia canadensis*. Slight variations due to the methods of preparation of the recent material and, especially for *Shepherdia canadensis*, the use of HF, may bring out the *costae pori*. Sometimes also the pores are slightly bulging (Erdtman, 1954, p. 157). When only KOH is used for recent material, the features of the pores appear to be fainter. Furthermore, the pores of *Shepherdia canadensis* in our material appeared sometimes slightly elliptical. It may be that a slight variation can be expected within one species.

The zone A4b is marked by a sharp increase in *Picea* pollen; this increase is also well marked in the lowermost layers of the St. Germain bog (fig. 8) and appears in the same position relative to a lower herb zone (Terasmae, 1960).

In our material, this *Picea* maximum was detected twice on two different preparations of the same level and it does not appear to be fictitious; *Picea* pollen maxima have also been reported by Leopold (1956, p. 864—865) for late-glacial sediments of southern New England. Whether we are dealing with the same feature is difficult to prove. However as Leopold has shown (1956), *Picea* appears to prefer the climate that is existing before a cooler interval or the climate that follows the same cooler interval.

In the zone A4b, the herb percentages are lower than in A4a. *Quercus* however has not yet regained its maximum abundance. *Abies* appears with a low maximum.

The B-zone is characterized by a marked increase in *Pinus* pollen and a return of *Quercus*, while *Tsuga* is always present in small amounts. *Betula* has a marked increase from the low percentages of sub-zone A4b. The pollen of thermophilous trees begin to appear in this zone in significant quantities.

The C1 zone is distinguished from the others by the first peak of *Tsuga* as it appears in most pollen diagrams of Eastern North America; it is the main feature of

this zone as defined by Deevey (1951, p. 201). For the uppermost part of the core, pollen sections have been prepared but they revealed very poor pollen preservation. We have not studied it further.

d. The Lake Hertel diagram (fig. 12)

The Lake Hertel diagram starts with a rather high percentage of herbs including *Artemisia*, *Cyperaceae*, *Gramineae* together with *Salix*.

Above that zone there is a marked increase in the pollen percentages of the thermophilous elements (*Quercus*, *Fraxinus*). The latter mark a strong decrease that coincides with a *Betula* maximum as well as an *Abies* maximum. The *Betula* maximum hence certainly influences very much the trend of the curves of the thermophilous elements.

The diagram appears to be readily comparable with Davis's diagram of Pleasant St. Bog (1958, no 8 site on our map fig. 7.). Furthermore, a date of 10,880 ± 260 years B. P. (GSC-482) has been performed on organic material that is coming from the boundary between zone (A-1-2)-(A-3) (cf. Lake Hertel diagram, for exact location of dated material). It is possible that this date may be slightly too young because the dated material stretched over an interval of 14 cm. However it tends to confirm or at least suggest that our comparison with Davis' diagram may be valid. Indeed a date of 10,800 years B. P. approximately has been obtained for zone A-3 of Pleasant St. Bog (cf. Davis, 1965, p. 389: dates nos.: M-413 and W-361). The date is properly the temporal fall of the *Quercus* curve, considered by us the limit of zones A3 and A4.

In our diagram, zone A-1-2 is characterized by a high percentage of NAP, *Salix*, *Pinus* and *Picea* as well. It is possible that this zone coincides in the St. Lawrence Lowlands with the beginning of the marine transgression. This problem will be taken up later in the discussion of the diatom flora of the lowermost samples of the Lake Hertel core.

The next zone A-3 is defined mainly on the basis of a decreasing NAP percentage, while the percentages of pollen of thermophilous trees increase together with the percentages of *Pinus* and *Betula*.

The definition of zone A-4 is mainly based on a lower QM (viz. *Fraxinus*, *Quercus*) while the herb percentages mark a slight increase. *Abies* attains a maximum in this zone. It may be that the relatively coarse sampling (10 cm) has not permitted the detection of a definite increase in the herb zone, as we believe that this zone A-4 (A4a and A4b in the St. Hilaire bog diagram) is correlative with the St. Narcisse readvance.

The B zone, as originally defined (Deevey, 1951) refers to a large increase in *Pinus* pollen in early post-glacial time (Deevey, 1951, p. 199—200).

The next zones above, the C zones, have been defined by Deevey (1951, p. 201) mainly on the basis of the trend of the *Tsuga* curve as already indicated above. In the Lake Hertel diagram, however, the low *Tsuga* of zone C-2 appears to be very much protracted,

though the first maximum of the *Tsuga* curve (C-1) is well marked.

The C-zones have then been defined mainly on the following basis:

- C1: *Betula*, *Quercus* and *Tsuga*
 C2: *Tsuga* decreases while *Fagus* increases; *Betula* and *Pinus* remain high.
 C3a: *Tsuga* regains high values, but *Fagus* remains also high.
 C3b: This zone is marked by an increase in *Pinus*, and decrease of *Tsuga* and *Fagus*. At the top of the zone, the herb pollen attains high values; the beginning of that rise must mark the beginning of the forest clearance coinciding with the settling period. It indicates mainly an increase of the area without closed-tree canopies (Fries, 1965, p. 59).

It is analogous to the expansion of the heliophilous herbs in late-glacial time, but not for the same reason; the genera are probably not represented by the same species.

e. *The St. Bruno bog diagram* (fig. 13)

The pollen diagram of this site is particularly difficult to analyse because the sequence appears to be compressed. However, it resembles very much the one obtained by Whitehead for Pownal Bog (fig. 10).

We feel that the basal part of the diagram may correspond to zone A4 in general and therefore, may be contemporaneous and correlative of the St. Narcisse readvance for the following reasons:

- 1) the presence of a low peak of the NAP percentage above the base of the diagram.
- 2) the presence of a small amount of *Artemisia*, *Salix*, and *Cyperaceae* and *Shepherdia canadensis* which in other diagrams of the same area (St. Hilaire Mountain) appear to be associated with that readvance (cf. the St. Hilaire bog diagram).

Before passing to the zone division, we would like to discuss first the *Myrica* peak.

This feature appears also in approximately the same position in the sediments of the St. Antoine core, and also in all the diagrams of Davis (1958, 1960, 1961) and always approximately at the same position (zone A3), when included in the total sum. It is questionable whether this maximum is fictitious and consequently, an artifice of percentage calculation. In the Pleasant St. bog, for example, it coincides with the *Quercus* maximum in zone A-1-2-3. It is difficult to imagine that *Myrica* pollen may have regional significance.

The fact that it comes at approximately the same level in a sequence may have some significance, but probably only successional, and in local situation, around bogs or shallow lakes.

Zone A4 has been defined hence on the basis of a low herb peak made of *Artemisia*, *Cyperaceae*, *Shepherdia*, coinciding also with the presence of *Salix*, *Alnus* and *Abies*.

The zone B1 is mainly defined on the basis of the *Betula* peak (see Davis, 1958), and the increase in the *Quercus* percentage together with the sharp decrease of the *Picea* percentage, which is in agreement with the end of the A zones (in general).

In the New England diagram *Pinus* also reaches lower values in that zone and we see also in the same zone the appearance of the thermophilous trees in larger percentages.

The zone B2 is defined in our diagram mainly on the recovery of the pine curve to its post-glacial peak, i.e. the main B zone of Deevey (1951).

Last, we may mention the presence in the sediments of this core of some bits of charcoal and also the presence of one grain of *Elaeagnus commutata*.

f. *The St. Antoine core diagram* (fig. 14).

The St. Antoine core represents a 30 m.-section of the marine clays of the Champlain Sea. The coordinates of the collecting site of the St. Antoine core are the following: latitude: 48° 48'; longitude: 73° 18' (Jean Bérard, personal communication). This site is within the limit of the St. Antoine parish in the Verchères area (Lasalle, 1963; see also fig. 7). The core has been collected with a stationary piston sampler and supplied to us through the courtesy of Dr. Jean Bérard and the Ecole Polytechnique, University of Montreal.

As students of microfossils know, it is often particularly difficult to obtain microfossils from marine clays. Because of the small size of their particles (silt and clay size), and principally because the particles are electrically charged, it is necessary to use a dispersing agent (or deflocculating agent) „to get the particles into suspension in a liquid medium and to keep them from reaggregating or flocculating” (Gray, in Kummel and Raup, 1965, p. 536).

After a number of experiments, we have succeeded to obtain a variable number of pollen grains from the marine clays by treating them in the following way:

boiling for 3 to 5 minutes in 10 % KOH, additioned of approximately 2 to 3 grams of „calgon” (household detergent).

acetolysis and HF treatment, followed by heating up to the boiling point with HCl 10 %
 bromoform flotation (density 1,8)

As is seen by the pollen sum indicated to the right in the diagram, results have been satisfactory for the uppermost samples, but not entirely satisfactory for the lower ones.

Pollen grains are then extremely rare at the base of the 30-meter core. It is to be wondered whether the rate of mineral sedimentation was exceedingly high in the basin of the Champlain Sea during the time of the first part of the marine episode, or if the pollen is rare in the core because we are dealing with an off-shore section, deposited in much deeper waters than the upper part.

Indeed, it is to be expected that if the rate of sedimentation is high, the pollen rain will be diluted, and hence it

becomes necessary to treat a relatively large quantity of sediments to obtain a satisfactory sum. The marine waters were close to the glaciers for most of the duration of the marine episode, or even at some time in contact with it (Gadd and Karrow, 1959). Meltwaters brought large quantities of rock debris (rock flour) from the Precambrian terrane to the north; and in some places, 40 meters or more of sediments accumulated during the marine episode, that lasted some 1500 years. It is a very high rate of sedimentation compared with the St. Hilaire bog, for example, where 10 meters of sediments accumulated since deglaciation.

Furthermore, as is obvious from the pollen diagram, it is possible that pollen grains adapted for dispersal either by air or by water will be more represented in an off-shore section. Hence, it is supposed here that both distance to nearest shore and nature of pollen grains combined to make the pollen rare in the sediments of the lower 15 meters of the section.

The length of the core must be considered at this point before discussing the pollen diagram. As indicated above, there are places where the sediments above the upper till sheet reach a thickness greater than the length of our core. These longer sections accumulated in depressions or valleys existing at the time of deglaciation; the topography of the last mentioned localities was largely influenced by the bedrock topography itself.

Considering that the non-marine sediments (fresh water varved clays) immediately underlying the marine sediments do not reach considerable thicknesses (Terasmae, 1960, p. 19, 1 meter approximately) and that in some places they may have been eroded prior to the marine invasion (MacClintock and Stewart, 1965, p. 46), it is to be expected that only the lowermost sample may not be marine in our section. From the experience of the present author (Lasalle, 1963) this section should represent only the marine episode, as it must have been collected over a bedrock „high”.

Considering now the pollen diagram, it is obvious that the conifer pollen type is dominant in the lowermost half of the section; *Pinus* appears to be dominating over *Picea*. As we are dealing here with a large sedimentation basin, this pollen assemblage originates from widely separated localities, but mainly from an area to the south of the Champlain Sea. The large NAP percentage at the beginning of the upper half of the section is principally due to the large abundance of one pollen type, identified as *Glaux maritima* var. *obtusifolia* Fernald. In the analysis of the sample no 35 (11 meters), 48 grains of this type were counted. The maximum observed cannot be fictitious, as this pollen type was observed in samples of 3 consecutive different levels. We have compared it with the recent material of *Glaux maritima* var. *obtusifolia* from Rivière-du-Loup, Canada, and also with the pollen of *Glaux maritima* var. *maritima* from Elgin, England. This material was obtained from the Rijks-herbarium in Leiden, through the courtesy of Dr. S. J.

van Ooststroom. We feel that our fossil material (plate 4, no. 4 to 9) fits the description of the recent material, as given by Faegri and Iversen (1964, p. 187) and as observed in slides of recent material.

The grain is tricolporate, per-reticulate, with a micro-reticulum that is sometimes barely visible except under oil immersion. Furthermore, the *costae equatoriales* (Faegri and Iversen, 1964, p. 23) are well developed in both the fossil and recent material. Sometimes, it can also be observed that the endexine is thinning towards the polar area.

Glaux maritima grows particularly well on haline soils, that is, for example, on marine sediments, and mud flats (salt marshes). Hence, its abundance in sediments should increase consecutive to a lowering of sea-level, when extensive areas arose above sealevel, covered very soon with *Glaux*.

Following the above reasoning, we feel that the peak of *Glaux* in our diagram is consecutive to a lowering of sea-level because of the St. Narcisse readvance, and hence correlative with zone A4a in the diagram of the St. Hilaire bog, the lowermost part of the diagram being in turn correlative with zone A-1-2-3, because of the high abundance of *Pinus* and *Picea* pollen. Furthermore, there appears to be an increase of *Artemisia* pollen type, a genus including a number of heliophilous species, at the same level as the *Glaux* maximum, which is in agreement with the diagram from the St. Hilaire bog (Zone A4a).

As we have tried to estimate the age of the *Glaux* zone by using the rate of sedimentation in Chapter IV this discussion will not be repeated here.

The upper part of the St. Antoine diagram is marked by a *Pinus* and *Picea* pollen maximum, a diminishing herb proportion, and an increasing percentage of the pollen of thermophilous trees. We feel that this part is correlative of zone A4b in the St. Hilaire bog.

It is difficult, however, to explain why the usual sequence that appears to be *Picea-Betula-Pinus* is not followed. It has been found that the pollen sedimentation of a large basin is very much disturbed (as mentioned already above) by wind and currents (Fries, 1962, p. 85, 87) and hence that long distant transport is favoured. It is probably the case for the *Pinus* maximum immediately following the herb fluctuation in the upper part of the St. Antoine diagram.

Resuming the above, we may conclude the pollen of the Champlain Sea sediments tends to supply evidence for a temporal lowering of sea-level during the colder time of zone A4a. The sea-level was apparently higher during the sedimentation of the lower half of the section (corresponding to zone A-1-2-3). After this temporal lowering, the sea did not regain, however, its former earlier depth.

g. The Lake Kenogami diagram (fig. 15)

This partial diagram has been obtained from the sediments of a small kettle (site no. 1, fig. 7) located at the west end of Lake Kenogami in the Lake St. John district.

It is related to the present study in the Lowlands only

so far as it shows the vegetation succession in the area north of it, where there was also a marine transgression later (?) than the Champlain Sea itself (Lasalle, 1965). However, in our opinion, the transgression never reached the kettle we are describing here (Lasalle, 1966, in prep.)

The site nearest to this kettle from where a section has been analyzed for pollen stratigraphy is located at Shipshaw, P. Q., some 30 kilometers to the east of the present site. The pollen diagram of Radforth (1945) however has not been divided into zones, as at the time it was studied, it was thought to represent the sediments of an interglacial (Sangamon). From recent fieldwork by the present author in this area, it appears that the material analyzed was part of a peat bog buried under river sand. The organic material slipped into the river waters because of landsliding or was covered by riversand because of flooding. (Lasalle, 1966). As the latter phenomenon involved marine clays, the material studied by Radforth may be dated approximately 7 to 8000 years B.P. and possibly younger (see appendix, table 3).

Accordingly, we have used our own system of zoning, used for this diagram only. The zone K-1 is characterized by a high *Betula* pollen percentage, with *Pinus* and *Picea* in subordinate amount. The percentage of the herbs is rather low at the base; but we do not think to have missed the lowerpart of the section because the sediments were not recovered.

The reason for this low herb content may be found in the fact that the site of our kettle is in the Lowlands of the Lake St. John area, and in the axis of the

Lake Kenogami valley. Consequently, the beginning of the organic sedimentation may have been delayed somewhat with respect to the highlands; whatever the reason may be, the sediments recovered were very sandy at the base.

The *Pinus* pollen recovered in zone K1 as well as the QM may for the greater part, have come a long distance from the south.

The zone K2 is defined by an increasing amount of *Pinus* pollen while *Betula* is in subordinate amount to *Picea*. There is also in the zone a small peak of *Abies*.

The zone K3 is defined on the basis of the appearance of *Tsuga* for the first time at the top of the zone while the *Pinus* pollen percentage reaches a peak that may indicate that the *Pinus* forest was nearby.

The sequence defined by zones K-1, K-2 and K-3 resembles very much the one outlined by Deevey (1957, p. 34) for the Northern Maine and Nova Scotia area. The description of his zones appears to fit the sequence in the Lake Kenogami area; however, our zones are certainly slightly younger, as the minimum age for the deglaciation of the area of Lake Kenogami is of the order of 9 to 10,000 years ago (Lasalle, 1965 and also appendix, table 3, for dates in the Lake St. John area). A correlation with the results of Deevey (1957) and also of Livingstone and Livingstone (1958) is suggested in fig. 15. Finally it may be wondered why the usual succession: *Picea-Betula-Pinus* is reversed in zone K-2 where *Picea* becomes dominant over *Betula* again. Zone K-2 may indicate the time of the immigration of *Picea* in larger number in this area.

CHAPTER VI

PROPOSED CORRELATION AND VEGETATION HISTORY IN THE ST. LAWRENCE LOWLANDS

According to van der Hammen (1951, p. 94—95), the boundary between the pleniglacial and the late glacial time in pollen diagrams in Europe may be indicated by the *Artemisia* rise.

As the curve of *Artemisia* appears to rise from lower percentages at the base of the diagram of the St. Hilaire bog, this genus must then have been present at the very onset of deglaciation of the St. Hilaire Mountain, or other high points in the St. Lawrence Lowlands. This is also in agreement with the principles set forth by Iversen (1954). The genus *Artemisia* (and also a number of other genera of the *Compositae*) does not tolerate shade and it may grow in open places, provided cold temperatures during the summer time do not go to extremes (van der Hammen, 1951, p. 94).

Hence, in the St. Lawrence Lowlands, the pollen diagrams (lower parts) amply demonstrate that in early late glacial time, the vegetation was then open, of a grass-shrub type (*Salix*, *Alnus*), much like the earliest vegetation of northwestern Europe (van der

Hammen, 1951; Iversen, 1964; Fries, 1965).

As mentioned elsewhere, a clustering of grains of *Salix* found in zone T of the St. Hilaire bog is only to be explained by the presence of this shrub close to the site (discussed in the paragraph on the pollen zones of the St. Hilaire bog.).

It is difficult to know which trees were present then within a close distance of the latter site. The needle fragments with stomata of *Picea* in the sediments of zone T indicate that this genus was occurring near the St. Hilaire bog very early. Complete needles of conifers, however, have not yet been observed in the sediments of that deposit. In the zone T, pollen of *Quercus*, *Fraxinus* and *Ulmus* must have come from distant sites far to the south. (Deevey, 1951, p. 203, 204; also, see diagrams of Fries, for Sweden, 1965, plate I).

Undoubtedly, some species of *Betula* were present (*Betula nana*) and probably also *Alnus* sp. (as explained above).

In the next zone (A-1-2-3), the vegetation appears to be closing as the pollen of the herbs is considerably diminished. As *Pinus* and *Betula* are abundant pollen producers, the high percentages of the pollen of those genera do not necessarily prove their occurrence close to the site of the St. Hilaire bog, though likely they were growing nearby.

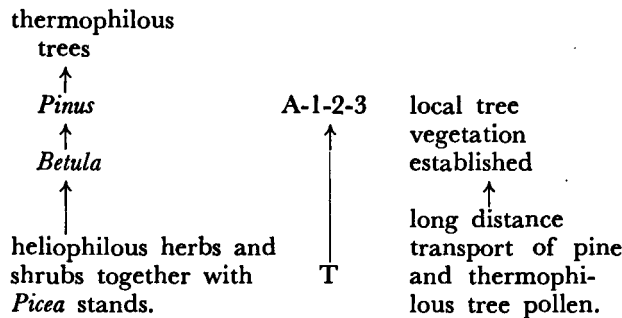
As explained by Faegri and Iversen (1964, p. 106, 107 and 118) the curve of a large pollen producer, an „A” species, — in any association — may be continuous and even reach substantial values without any local or regional presence of the species.”

The St. Hilaire Mountain was an island for a considerable time (in the ice and then in water) before the lower area surrounding it was available for colonization by trees. It may be assumed, however, that well drained sites (ablation till and gravel deposits) existed on the St. Hilaire Mountain and others of the Montereian Hills, and were available very early for colonization, especially by *Pinus*.

As *Pinus* abundance appears to be favoured by (or at least to be influenced by) forest fires (Horton and Bedell, 1960, p. 53; Terasmae, 1961, p. 665) the association of high *Pinus* pollen percentages with bits of charcoal is noteworthy. However, its quantitative expression may be significant only in a general way.

As for the thermophilous trees, they were probably present in small number in the vegetation of zone A-1-2-3 in the St. Lawrence Lowlands. At least, at the top of zone A-1-2-3, their percentages appear to increase in such a way (especially *Quercus*) to warrant the interpretation that they were growing notably nearer to the site than in the lower part of zone A-1-2-3.

Hence in late-glacial time, as the climate was improving, the succession appears to have been as follows:

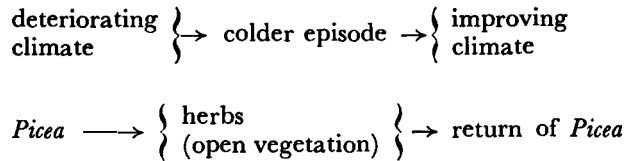


How much of this succession has been influenced by forest fire is difficult to assess. However it appears to be similar to the one postulated by Fries for southern Sweden (Fries, 1965; in this connection, see also Deevey, 1951, p. 205).

In zone A4a there appears to be a return to a more open vegetation as the herbs and shrubs reach a small maximum. This fact is clearly demonstrated in the diagram of the St. Hilaire bog only; in the other two diagrams the sequence appears to be too compressed. Furthermore, as explained elsewhere, the emergence of the St. Bruno bog may coincide with the

regression of sea level attendant upon the St. Narcisse readvance.

It is to be remarked also that *Picea* appears to reach higher percentages before zone A4a in the St. Hilaire bog and after zone A4b. Leopold (1956) has demonstrated that *Picea* was to be favoured as well by the deteriorating climate from a warmer episode to a cooler one; *Picea* seems also to be the first forest tree to come back (Leopold, 1956) after a cooler episode. The sequence as demonstrated by Leopold (1956) appears to be following:



In our diagrams of the St. Hilaire bog, Lake Hertel, and St. Bruno bog, it appears that *Betula* may be the next tree to immigrate in succession before *Pinus* (see also Fries, 1965).

The climatic improvement that follows zone A4b in the St. Hilaire bog and the A zone in general of the other diagrams appears to be related to the post-glacial hypsithermal interval (Deevey and Flint, 1957). Only in the Lake Hertel diagram, we can observe the development of the vegetation up to the present (the recent sediments of Lake Hertel have been analyzed).

As mentioned above, the first thermophilous trees to be present were probably *Quercus* and *Fraxinus*, followed by *Tsuga*, *Fagus*, *Tilia*, *Acer* and other minor constituents of the present forest of the St. Lawrence Lowlands (cf. Lebrun, 1961). Undoubtedly, man has changed its composition lately. Throughout the C zones however *Pinus* appears to have been a dominant tree, with *Picea* in a much lesser abundance. During the hypsithermal interval, the part of *Picea* may have been reduced to local areas which were influenced by edaphic conditions.

The low *Tsuga* percentage of zone C2 is a consistent feature of the pollen diagrams of eastern North America, which so far remains undated, and unsatisfactorily explained. This phenomenon is a general one and is not considered fictitious because of the percentage method of presentation of the data. We do not know very much about the ecology of this tree. Properly, its present area in eastern Canada is the area where the natural vegetation has been most disturbed by man (Great Lakes-St. Lawrence Forest Region; for distribution of *Tsuga canadensis*, see Native trees of Canada, p. 50). It does not occur quite as far north as the *Pinus* species today (Horton and Bedell, 1960, p. 52).

Tsuga is apparently very tolerant of shade (Native trees of Canada, p. 50). Hence, its decrease must have been related to other factors viz. soil, humidity, or temperature. Today „it sometimes forms pure stands but is more often mixed with white pine, the red and

white spruces, balsam fir, and various hardwoods" (Native trees of Canada, 1961, p. 50). If it can grow in a mixed vegetation like this, the solution of the problem may be in seed preservation (?) or perhaps also in their resistance to fire (?). It is difficult to compare the ecology of different species belonging to the same genus, as the ecology is generally very specific. However, the two western species of *Tsuga* appear to prefer moister conditions. From Mosher and Lunnum (1962) we take the following information:

Tsuga heterophylla occurs on moist humus soils and an abundance of atmospheric moisture is favorable; it grows in the shade.

Tsuga mertensiana prefers moist, well drained soils; this timberline tree is found at elevations of 3100 to 7000 feet.

If this information is applicable to *Tsuga canadensis*, then it may be suggested that the low *Tsuga* percentage of the diagrams may correspond to the somewhat drier period of the Sub-boreal. This may lend support to the idea that the distribution of *Tsuga* is linked with the occurrence of forest fires (see discussion by

Davis, 1965, p. 382, 383). In the St. Hilaire bog, the low *Tsuga* pollen frequency seems to coincide with a layer of tree trunks (?). The ecological interpretation of that layer (at approximately 4.5 meter depth, provided that the tree trunks have not sunk) may indicate a dry period.

In the uppermost part of the diagram of Lake Hertel (zone C3), it remains uncertain whether the vegetational succession records a deterioration of the climate together with the influence of man. The latter is more probable because of the increase of the herb percentages. The *Pinus* maximum that is recorded may be the result of forest fires caused by man to clear the land (Fries, 1965). *Pinus* was replaced partly by *Betula*, *Picea*, and the heliophilous herbs.

A correlation is proposed (fig. 16) between our diagrams and other published diagrams of the St. Lawrence Lowlands and the surrounding areas. This correlation is based on available C¹⁴ datings and other evidence at hand. It can only be tentative, at least in part.

CHAPTER VII

FOSSIL DIATOM FLORAS

The author was led to the study of the diatoms of St. Hilaire and St. Bruno Mountains by the discovery of valves of *Navicula* in the slides of the St. Hilaire bog prepared for pollen studies. Some of the sections (v.g. at the level 855 cm depth in the St. Hilaire bog) consisted almost only of diatoms and contained only very few pollen grains.

It was then decided to prepare special slides for diatom studies of all three cores available. Some were prepared in Haarlem, at the Geological Survey of the Netherlands by Mr. A. du Saar and Mr. de Wolf. Additional sections were prepared in Leiden by the author. All of the samples prepared revealed an abundant flora, both qualitatively and quantitatively. The poorest flora was found in the lowermost samples as expected.

1. DEFINITION AND LITERATURE

„Diatoms are unicellular algae, usually microscopic, that are characterized by having a cell wall of silica. This wall consists of two valves that are more or less flat surfaces held together by a band or girdle" (This definition is taken entirely from Patrick, 1959, p. 171).

Diatoms are found in practically all kinds of environments. As some of them have rather specific requirements as far as salinity is concerned, they have been used as indicators for the presence of sea waters in some fossil environment (viz. Florin, 1957; Berglund, 1964).

However, ecological interpretation in those cases must take place carefully and be based on groups of diatoms,

rather than on a single species. The quantity of individuals present in a flora is also important, as animals, especially birds, and wind at rough sea periods, may transport small quantities of them from one sedimentary environment to another viz. from seashore to inland lakes. Furthermore, some species appear to occur in widely divergent types of environment. These cannot consequently be used for paleoecological interpretation.

Diatoms have apparently been the subject of research in North America during this century only. The first comprehensive works that appeared were those of Boyer (1926, 1927). Most other studies in North America were based on the results of the work of Dr. Ruth Patrick, of the Academy of Natural Sciences in Philadelphia. She has published the monographs about the diatoms of Linsley Pond (Patrick, 1943) and Bethany Bog (Patrick, 1954) that are pertinent to the present work.

Next to those, the work of Sovereign (1958) dealing with the diatoms of the Crater Lake area, is particularly relevant, because of its description of the new species *Navicula aurora*, also found in the cores of the St. Hilaire bog, Lake Hertel, and St. Bruno bog. To the author's knowledge, the only recent contribution concerning fossil diatoms in Canada has been made by Terasmae, in his list of diatoms found in the Don beds at Toronto (Terasmae, 1960, p. 36).

After the completion of this manuscript, the publication of a treatise dealing with the diatoms of North America (Patrick and Reimer, 1966) has been brought to the attention of the author; but it has not been available yet for consultation.

2. FOSSIL DIATOMS

The lists of fossil diatoms that appear below are not exhaustive, especially with regard to Lake Hertel. That list is far from complete, as there may be twice as many species as the number listed (150). Some of the diatoms are illustrated on plates 15 to 23.

a. Particular cases

In this paragraph some fossil diatoms of special interest are described:

Navicula aurora Sovereign: this diatom is described as a new species by Sovereign (1958, p. 120, with illustrations p. 113). As quoted from the latter paper, it is „a relatively large diatom reaching a length of 128 μ , is somewhat variable in outline and very clearly lined in our material by Dr. Maj-Britt Florin, of the University of Uppsala, and is illustrated here on plate 19, photo 1 to 4. It was found in all the cores of the St. Hilaire bog, Lake Hertel and St. Bruno bog. The alkalinity of the waters in the latter environments (discussed below) appears to be comparable to the alkalinity of Crater Lake from where its presence is reported by Sovereign, as well as from other lakes in the „Pacific Northwest.”

Melosira teres Brun: This diatom is reported by Evans (1964) as present „in the lateglacial deposits of the lakes in the English Lake district” (Evans, 1964, p. 413). The same author refers also to the alkalinity of the waters of the English Lakes where this diatom is found as a fossil (1964, p. 415). Evans has also reviewed some of the literature dealing with this diatom and has reported other sites where it has been found as a fossil. It has been identified in our material by Dr. Maj-Britt Florin, in the second lowermost sample of Lake Hertel. It is illustrated on plate 17, photo 1.

Cyclotella antiqua W. Smith: This diatom is described in Hustedt (1962, p. 349). It has been found in our material at the depth of 875 cm in the sediments of the St. Hilaire bog. It is suggested by Hustedt that it is an alpine and northern species. It is illustrated on plate 21, photo 1, 2, 3. Mr. A. du Saar, of the Geological Survey of the Netherlands, Haarlem, has made the identification.

b. Fossil diatoms of the St. Hilaire bog

Achanthes calcar Cleve
Achanthes flexella (Kutzing) Brun
Amphora ovalis Kutzing
Amphora ovalis Kutzing var. *libyca* (Ehrenberg) Cleve
Caloneis silicula (Ehrenberg) Cleve
Campylodiscus noricus Ehrenberg var. *hibernica* (Ehrenberg) Grunow
Cocconeis pediculus Ehrenberg
Cocconeis placentula Ehrenberg
Cyclotella antiqua W. Smith
Cyclotella comta (Ehrenberg) Kutzing

Cyclotella meneghiniana Kutzing
Cymbella lanceolata (Ehrenberg) van Heurck
Cymbella prostrata (Berkeley) Cleve, (small form)
Cymbella similis R. Patrick
Cymbella ventricosa Kutzing
Diploneis ovalis (Hilse) Cleve
Epithemia argus Kutzing
Fragilaria brevistriata Grunow
Fragilaria construens (Ehrenberg) Grunow
Fragilaria construens (Ehrenberg) Grunow var. *venter* Ehrenberg (Grunow)
Fragilaria leptostauron (Ehrenberg) Hustedt
Gomphonema acuminatum var. *coronata* (Ehrenberg) Rabenhorst
Gyrosigma attenuatum Ehrenberg
Navicula aurora Sovereign
Navicula cuspidata Kutzing
Navicula tuscula Ehrenberg
Navicula vulpina Kutzing
Nitzschia denticula Grunow
Opephora martyi Héribaud
Stauroneis phoenicenteron Ehrenberg
Tabellaria fenestrata (Lyngbye) Kutzing

c. Fossil diatoms of Lake Hertel

Achnanthes calcar Cleve
Achnanthes clevei Grunow
Achnanthes conspicua A. Meyer
Achnanthes delicatula Kutzing
Achnanthes exigua Grunow
Achnanthes exigua Grunow var. *heterovalvata* Krasske
Achnanthes flexella (Kutzing) Brun
Achnanthes lanceolata (Brebisson) Grunow
Achnanthes lanceolata (Brebisson) Grunow, var. *elliptica* Cleve
Achnanthes linearis (W. Smith) Grunow
Achnanthes peragallii Brun et Héribaud
Amphipora ornata Bailey
Amphora ovalis Kutzing var. *libyca* (Ehrenberg) Cleve
Amphora ovalis Kutzing var. *pediculus* Kutzing
cf. *Amphora coffeaeformis* var. *dussienii*
Anomeoneis exilis (Kutzing) Cleve
Anomeoneis serians (Brebisson) Cleve, var. *brachysira* (Brebisson) Hustedt, forma *thermalis* (Grunow) Hustedt
Caloneis silicula (Ehrenberg) Cleve
Campylodiscus noricus Ehrenberg, var. *hibernica* (Ehrenberg) Grunow
Cocconeis diminuta Pantoscek
Cocconeis pediculus Ehrenberg
Cocconeis placentula Ehrenberg
Cocconeis placentula Ehrenberg var. *euglypta* (Ehrenberg) Cleve
Cocconeis thumensis A. Meyer
Coscinodiscus oculus iridis Ehrenberg (a single specimen)
Coscinodiscus kutzingii A. Smith (a single specimen)

- Cyclotella bodanica* Eulenstein
Cyclotella comta (Ehrenberg) Kutzing
Cyclotella glomerata Bachmann
Cyclotella kutzingiana Thwaites
Cyclotella stelligera Cleve et Grunow
Cymatopleura cf. *angulata* Greville
Cymatopleura elliptica (Brébisson) W. Smith
Cymatopleura solea (Brébisson) W. Smith
Cymbella aspera (Ehrenberg) Cleve
Cymbella caesati (Rabenhorst) Grunow
Cymbella caespitosa Kutzing
Cymbella cistula (Hemprich) Grunow
Cymbella delicatula Kutzing
Cymbella ehrenbergi Kutzing
Cymbella laponica Grunow
Cymbella microcephala Grunow
Cymbella norvegica Grunow
Cymbella similis R. Patrick
Cymbella sinuata Gregory
Cymbella tumida (Brébisson) van Heurck
Cymbella turgiga (Gregory) Cleve
Cymbella ventricosa Kutzing

Diatoma anceps (Ehrenberg) Grunow
Diploneis finnica (Ehrenberg) Cleve
Diploneis interrupta Kutzing
Diploneis marginestriata Hustedt
Diploneis ovalis (Hilse) Cleve
Diploneis smithii (Brébisson) Cleve (a single specimen)

Epithemia argus Kutzing
Epithemia argus Kutzing var. *alpestris* Grunow
Epithemia intermedia Fricke
Epithemia sorax Kutzing
Epithemia turgida (Ehrenberg) Kutzing
Epithemia zebra (Ehrenberg) Kutzing
Eunotia papilio Ehrenberg
Eunotia formica Ehrenberg
Eunotia praerupta Ehrenberg

Fragilaria brevistriata Grunow
Fragilaria capucina Desmazières
Fragilaria construens (Ehrenberg) Grunow
Fragilaria construens (Ehrenberg) Grunow var. *binodis* Ehrenberg (Grunow)
Fragilaria construens (Ehrenberg) Grunow var. *venter* (Ehrenberg) Grunow
Fragilaria leptostauron (Ehrenberg) Hustedt
Fragilaria pinnata Ehrenberg
Fragilaria pinnata (Ehrenberg) var. *intersedens* (Grunow) Meyer

Gomphonema acuminatum var. *coronata* (Ehrenberg) Rabenhorst
Gomphonema augustatum (Ehrenberg) Hustedt
Gomphonema constrictum (Ehrenberg) var. *capitata* (Ehrenberg) Cleve
Gomphonema intricatum Kutzing
Gomphonema parvulum (Kutzing) Rabenhorst
Gomphonema subtile (Ehrenberg) var. *sagitta* (Shumann) Cleve
Gyrosigma acuminatum (Kutzing) Rabenhorst

Gyrosigma attenuatum Ehrenberg

Hantzschia amphyxus (Ehrenberg) Grunow

Mastogloia grevillei W. Smith
Mastogloia smithii Thwaites var. *amphicephala* Grunow
Mastogloia smithii Thwaites var. *lacustris* Grunow
Melosira ambigua (Grunow) O. Müller
Melosira arenaria Moore
Melosira italica (Ehrenberg) Kutzing
Melosira teres Brun
Meridion circulare (Greville) Agardh

Navicula amphibola Cleve
Navicula anglica Ralfs
Navicula augustata (W. Smith) Grunow
Navicula aurora Sovereign
Navicula cuspidata Kutzing
Navicula dicephala (Ehrenberg) W. Smith
Navicula exigua (Gregory) Müller
cf. *Navicula globosa* Meister
Navicula graciloides A. Meyer
Navicula jarnefeldtii Hustedt
Navicula laterostrata Hustedt
Navicula minuscula Hustedt
Navicula oblonga Kutzing
Navicula placentula (Ehrenberg) Grunow forma *rostrata* A. Meyer
Navicula pseudoscutiformis Hustedt
Navicula pseudoventralis Hustedt
Navicula pupula Kutzing
Navicula pupula Kutzing var. *capitata* Hustedt
Navicula pupula Kutzing var. *rectangularis* (Gregory) Grunow
Navicula shonfeldii Hustedt
Navicula tuscula (Ehrenberg) Grunow
Navicula tuscula (Ehrenberg) Grunow, forma *angulata*
Navicula tuscula (Ehrenberg) Grunow, forma *minor* Hustedt
Navicula variostrata Krasske
cf. *Navicula vitabunda* Hustedt
Navicula vulpina Kutzing
Navicula wittrockii (Lagerstedt) A. Cleve
Neidium affine (Ehrenberg) Cleve
Neidium dubium (Ehrenberg) Cleve
Neidium iridis (Ehrenberg) Cleve
Nitzschia angustata (W. Smith) Grunow
Nitzschia denticula Grunow
Nitzschia kutzingiana Hilse
Nitzschia recta Hantzsch
Nitzschia sinuata (W. Smith) Grunow var. *tabellaria* Grunow

Opephora martyi Héribaud

Pinnularia borealis Ehrenberg
Pinnularia interrupta W. Smith
Pinnularia legumen Ehrenberg
Pinnularia transversa A. Schmidt
cf. *Pinnularia viridis* (Nitzsch) Ehrenberg var. *sudetica* (Hilse) Hustedt

Rhopalodia gibba (Ehrenberg) O. Müller

Stauroneis phoenicenterom Ehrenberg
 Stauroneis anceps Ehrenberg
 Stauroneis anceps Ehrenberg, forma gracilis (Ehrenberg) Cleve
 Stauroneis astrea (Ehrenberg) Grunow, var. minutula (Kutzing) Grunow
 Stauroneis hantzschii Grunow
 Stephanodiscus niagarae Ehrenberg
 Surirella linearis W. Smith, var. constricta (Ehrenberg) Grunow
 Surirella linearis W. Smith var. helvetica (Brun) Meister
 Surirella elegans Ehrenberg
 Synedra parasitica W. Smith
 Synedra ulna (Nitzsch) Ehrenberg

Tabellaria fenestrata (Lyngbye) Kutzing
 Tabellaria flocculosa (Roth) Kutzing
 cf. Tabellaria fenestrata (Lyngbye) Kutzing

d. Fossil diatoms of the St. Bruno bog

Achnanthes calcar Cleve
 Achnanthes cf. microcephala (Kutzing) Grunow
 Amphora ovalis Kutzing var. lybica (Ehrenberg) Cleve

Cymbella ehrenbergi Kutzing
 Cymbella lanceolata (Ehrenberg) van Heurck
 Cymbella similis R. Patrick
 Cymbella ventricosa Kutzing

Epithemia zebra (Ehrenberg) Kutzing
 Eunotia praerupta Ehrenberg

Fragilaria brevistriata Grunow
 Fragilaria construens (Ehrenberg) Grunow
 Fragilaria construens (Grunow) var. venter (Ehrenberg) Grunow

cf. Gomphocymbella ancyli (Cleve) Hustedt: we found a diatom that resembles this species but we are not sure if it is conspecific. The specimens are well preserved, but they require more careful examination

Mastogloia grevillei W. Smith
 Melosira italica (Ehrenberg) Grunow

Navicula aurora Sovereign
 Navicula oblonga Kutzing
 cf. Navicula praetexta Ehrenberg
 Navicula pupula Ehrenberg
 Navicula vulpina Kutzing
 Neidium iridis (Ehrenberg) Cleve

Pinnularia sp.
 Pinnularia major (Kutzing) Cleve
 cf. Pinnularia polyanca
 Pinnularia cf. subsolaris (Grunow) Cleve

Stauroneis phoenicenteron Ehrenberg

3. PALEOECOLOGY OF THE LAKES INVESTIGATED

The ecological conclusions to be drawn from fossil diatom floras reveal a complex problem. The fossil floras recovered will be dealt with only in a general way. Furthermore, the ecology of the individual species is only poorly known in many cases. As can be seen from the work of Florin (1957) and van der Werff (1960), conclusions can be based on groups of species or associations. It is hence unsafe to rely on a single species in drawing conclusions.

a. Comparison with the Crater Lake Flora

Sovereign (1958) has described the flora of Crater Lake; *Navicula aurora*, one of the new species mentioned by him is an element of the fossil flora of the three lakes that were investigated by the present author. Furthermore, sixty-four species, of the 150 species listed for Lake Hertel occur also both in the present Crater Lake flora and in other lakes of the Crater Lake area.

A comparison of the chemical composition of the waters of Crater Lake and Lake Hertel is given in table 4.

Table 4: Analyses (results in ppm) of the water of Crater Lake (Sovereign, 1958) and Lake Hertel (supplied by the Quebec Dept. of Natural Resources: results are preliminary).

	Crater Lake	Lake Hertel
CO ₃	16.7	
SO ₄	11.0	20.0
Cl	11.0	7.6
NO ₃	0.4	
PO ₄	0.1	
Ca	7.1	12.5
Mg	2.8	1.1
Na	11.0	2.18
K	2.2	0.74
Fe ₂ O ₃	0.1	
SiO ₂	18.0	

Two values are reported by Sovereign (1958) for the pH of the Crater Lake waters: 8.4 (p. 97) and 7.6 (p. 98). The pH of Lake Hertel today is 7.1.

SiO₂ is not reported in the chemical composition of the waters of Lake Hertel. However, as can be shown by the chemical composition of the rocks of St. Hilaire and other Monteregian Hills, silicium is an abundant element. The chemical composition of the most common rock type that constitutes the St. Hilaire Mountain, is quoted here in table 5 from Faessler (1962). The interested reader is referred to his compilation for more analyses (especially pp. 92, 93, 101, 104, 115 and 116).

Table 5: Analysis of rock sample no. 519, St. Hilaire Mountain (Faessler, 1963 pp. 101 and 115). Result in % weight.

SiO ₂	49.96	Na ₂ O	5.26
Al ₂ O ₃	18.83	K ₂ O	2.58
F ₂ O ₃	2.52	H ₂ O—	0.53
FeO	6.64	H ₂ O+	0.07
MgO	3.52	MnO	0.20
CaO	7.42	P ₂ O ₅	0.25
		Cl	traces

It can be seen that the fossil environment of the three sites described here was comparable to the present Crater Lake environment as far as alkalinity and probably also as far as temperature. Crater Lake is located at an elevation of approximately 2000 meters above present sealevel. The precipitation is mostly in the form of snow. Hence, it can also be considered as an „alpine” station.

b. Paleocology of the St. Hilaire bog

Navicula aurora together with *Campylodiscus noricus* var. *hibernica* is present in the early diatom flora of the St. Hilaire bog (depth 920 cm). *Fragilaria* valves however constitute most of the diatom remains recovered at that level. The same situation is repeated up to the level 875 cm. (see plate 20, no. 4, 5).

Patrick (1943) also found an abundance of *Fragilaria* sp. in the early sediments of Linsley Pond. Mr. A. van der Werff of the Geological Survey of the Netherlands, Haarlem, has found a similar development of *Fragilaria* in the fossil and present diatom flora of a volcanic lake (Myvatn) in Iceland, which has a pH of 7.0 to 7.5. There are glaciers in the area of that lake today and meltwaters are flowing into it. The sample studied was collected from a white band occurring on the rocks above the water surface. Several species of *Fragilaria* are also found in the present flora of Crater Lake (Sovereign, 1958, p. 107, 108).

Hence the early diatom flora of the St. Hilaire bog (late-glacial) indicates cool conditions, waters being relatively deep and clear (*Campylodiscus*); but *Fragilaria* indicates also that the water was not too deep in some parts of the basin, and that higher water-plants may have occurred as well. The lake was certainly oligotrophic to slightly mesotrophic at that stage. We have not studied the upper part of the core in detail, but as can be seen from the list of species present, the lake became somewhat richer in nutrients. But *Fragilaria* sp. remains as an important element of the flora. The abundance of *Fragilaria* indicates a higher water-vegetation and other species suggest more mesotrophic conditions than at the earlier stage. The flora has not been studied above the level of 5 meters.

c. Paleocology of Lake Hertel

First, we should like to discuss the relations of this lake with the marine waters during the Champlain Sea episode.

At present the threshold of the possible entrance of the marine waters into the basin of Lake Hertel is at an elevation of 172 meters (572 feet) above present sea level. The known marine limit in the Montreal area (Elson and Elson, 1959) is located at the 170 meter contour line. Hence the marine influence in the lowermost sediments of that basin cannot be expected to be but very slight.

In fact, the lowermost two samples of the core show only a weak contamination of the fresh water diatom flora by marine and brackish forms. Two specimens of *Coscinodiscus* sp., one specimen of *Actinocyclus* sp.,

and *Diploneis interrupta* (less than one percent of the total of valves present) have been observed among the diatom remains of the lowermost samples. Most *Coscinodiscus* sp. and all *Actinocyclus* sp. are marine forms, while *Diploneis interrupta* lives preferably in brackish waters. In the Netherlands it is found along the Wadden sea coast; it is a littoral species.

As for the freshwater species of the same samples, they reveal some characteristic of the Ancylus Lake (Late glacial, Sweden; see Florin, 1957). There is no direct comparison however. The following species can be mentioned:

Amphora ovalis Kutzing
Achnanthes clevei Grunow
Cymbella sinuata Gregory
Cymatopleura elliptica (Brébisson) W. Smith
Didymosphenia geminatum (Ehrenberg)
Fragilaria pinnata var. *intersedens* (Grunow) Meyer
Gyrosigma attenuatum Ehrenberg
Mastogloia smithii Thwaites var. *lacustris* Grunow
Melosira arenaria Moore
Opephora martyi Héribaud
Stephanodiscus astrea (Ehrenberg) Grunow

The same samples contain also some typically fresh water species:

Achnanthes exigua Grunow var. *heterovalvata* Krasske
Cocconeis placentula Ehrenberg
Epithemia zebra (Ehrenberg) Kutzing
Epithemia sorex Kutzing
Fragilaria brevistriata Grunow
Fragilaria construens (Ehrenberg) Grunow
Navicula graciloides A. Meyer
Navicula placentula (Ehrenberg) forma *rostrata* A. Meyer.

Hence, the diatom flora of the sediments of Lake Hertel shows every indication of a fresh water environment: it was of a shallow type with hydrophytic plant growth in some parts; the slight contamination by brackish and marine forms indicates only that the sea was very close, but probably never in the basin of the lake itself. The development of the flora of Lake Hertel in post-glacial time indicates that the lake became more and more eutrophic as can be seen from the diversity of the diatom flora and from the abundance of both dinoflagellate thecae and sponge needles.

d. Paleocology of the St. Bruno bog

The part of the core from the St. Bruno bog, that has been investigated for diatoms has not revealed a very diversified flora.

Furthermore, the threshold for the entrance of the marine waters into the basin of that lake is located at approximately 120 meters above present sea level. The latter figure is 50 meters lower than the known marine limit in the Montreal area.

The marine influence, however, has not been detected in the diatom flora of the lower part of the core. The

fossil flora shows nothing but fresh water species, if we except one specimen of *Coscinodiscus* sp. and the possible presence of *Navicula praetexta* Ehrenberg. This fact is difficult to account for and we cannot explain it. Only one satisfactory explanation can be offered here: the sampling of the lower part of the core was too coarse to detect the marine influence. Below the level at which the pollen diagram begins, diatoms are present, but pollen is extremely rare. Among the diatom remains recovered we find:

Fragilaria sp. (abundant)
Achnanthes calcar Cleve

Achnantes cf. *microcephala* (Kutzing) Grunow
Campylodiscus noricus Ehrenberg var. *hibernica* (Ehrenberg) Grunow

Above the depth of 650—655 cms, we found *Navicula aurora* together with other fresh water diatoms. But again, the most abundantly represented genus is *Fragilaria*. In some slides of that part of the core, *Fragilaria* amounts to 90 % of the diatom remains. This flora indicates shallow water, with growth of waterplants in some parts of the basin. The lake was oligotrophic to mesotrophic at that time. We did not study the uppermost part of that core.

CHAPTER VIII

THE ENDEMICS AND THE „LATE-GLACIAL CORRIDOR”

This subject is a difficult one to discuss, and any suggestion for a solution, in many aspects remains highly speculative. It is also possible that some of the presently known endemics may appear not to be real ones when the vegetation of North America is mapped in greater detail.

However, the fact that fossil *Elaeagnus* pollen has been found in our material of the Montreal area together with the diatom *Navicula aurora* deserves comment.

Sovereign (1958, p. 120) reports that *Navicula aurora*, a recent species known from several lakes in the Pacific Northwest, „has been found also as a fossil in a diatomite deposit in Lewis Co., Washington, tentatively regarded as Pliocene in age”. As indicated above, it is present in the St. Hilaire bog, Lake Hertel, and St. Bruno bog.

Elaeagnus may have had a much more continuous

distribution in late-glacial time according to some published reports (viz. Andersen, 1954). The same might appear to be true for *Navicula aurora* when more deposits are studied. It is not represented however in the recent diatom flora of Lake Hertel. As suggested above, the reason of its absence might be that it is an alpine species.

The distribution and migration of the „endemics” was not effected however in late glacial Wisconsin time only (Marie-Victorin, 1938). Several times during the Pleistocene, late-glacial conditions existed and interglacial episodes lasted thousands of years. It is highly probable that the „endemics” are old relics, almost certainly older than late-glacial Wisconsin. They probably simply migrated south during glacial stages, i.e. several times, consequently, during the Pleistocene period.

CHAPTER IX

GENERAL CONCLUSIONS

The results of the author’s research have been presented above in the least dogmatic way possible. The interpretations of the facts are partly in the form of working hypotheses. Only the factual background itself may not be liable to very much change.

With this in mind, the factual results of the present work are:

- 9 new C¹⁴ datings are published.
- 5 new pollen diagrams or parts of pollen diagrams have been compiled.
- some diatom data are contributed with the help of diatom specialists.

The following conclusions are drawn:

- I. Some parts of the St. Lawrence Lowlands were deglaciated earlier than others because of their elevation. These events appear to have taken place more than 12,000 years ago (GSC—419).
- II. Glacial lakes existed for some time in the ice around some of the Monteregian Hills (e.g. St. Hilaire, Rougemont).
- III. These glacial lakes expanded later on and merged with other glacial lakes in the Champlain valley and Lake Ontario area.

- IV. The Champlain sea episode then began as the marine waters from the east proceeded to invade the fresh waters in the Western part of the St. Lawrence Lowlands. The marine waters may then have been wedged for a short while between the Appalachian Highlands and the retreating ice.
- V. The evidence gathered here (GSC-482: 10,880 \pm 260 yrs. B. P.) appears to confirm that the age of the beginning of the Champlain Sea episode (ca. 11,400 yrs. B. P.), as obtained from marine shells, may be correct or at least not very much in error.
- VI. The marine limit in the Montreal area (570 feet or 170 meters, Elson and Elson, 1959) was confirmed by the lowermost diatom data of Lake Hertel.
- VII. The St. Narcisse readvance may have no counterpart in the Midwest but is rather correlative of the Younger Dryas. However, the possibility that it corresponds also to the Valdres readvance remains; the Cochrane readvance, referring to recent work by Hughes (1965) does not appear to have been any more than a very local phenomenon.
- VIII. Evidence for a low water stage during the Champlain Sea episode is brought to light by both the „*Glaux*” zone and the description of a fossil fauna that shows fresh and brackish water mollusks assembled in what was a shallow water environment. These shallow water sediments are in turn covered by deep water sediments (marine clays).
- IX. The new C¹⁴ dates place the marine invasion in the Lake St. John area sometime between 8,700 and 10,200 years ago approximately. Its duration was approximately 1500 years.
- X. The early vegetation of the St. Lawrence Lowlands (e.g. St. Hilaire bog) was an open one, with an abundance of heliophilous herbs and shrubs.
- XI. Close to the ice and at sufficient elevation, like at the St. Hilaire bog, ice readvance can be detected in the sediments by pollen analysis. The St. Narcisse readvance is not reflected strongly in the diagrams of the New England area (if we except Maine and Nova Scotia) because of distance (of the localities where sediments have been studied) to the ice front.
- XII. The late-glacial pollen zonation of the Northeastern United States can be applied to the pollen diagrams of the St. Lawrence Lowlands (at least to those of lake sediments).
- XIII. There is good evidence that the limit of pollen zone A3—A4a (temporal fall of *Quercus* and other features) may correspond to the boundary Allerød-Younger Dryas of Northwestern Europe.
- XIV. The proposed correlation of the North American pollen zones with the European sequence and with the glacial history of the St. Lawrence Lowlands is given here in fig. 16. It is partly a repetition of the correlations suggested by other authors.

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APPENDIX

Table I: C^{14} dates pertinent to the deglaciation and marine invasion in the St. Lawrence Lowlands and adjacent areas.

References	Locality	Altitude meters	Material	Lab.no.	Age. yrs. B.P.
Elson, 1962, N.E.I.G.C., Conf. Exc. Guidebook and personal communication.	Mt. Royal	171	shells	GrN-1697	11,490±110.
Elson, 1962, N.E.I.G.C., Conf. Exc. Guidebook and personal communication.	St. Philomène	43	shells	GrN-2031	10,870±105
Elson, 1962, N.E.I.G.C., Conf. Exc. Guidebook and personal communication.	Drummondville, P. Q.	80	shells	GrN-2034	10,590±100
Elson, 1962, N.E.I.G.C., Conf. Exc. Guidebook and personal communication.	St. Philomène P. Q.	56	shells	GrN-1696	10,450±80
Elson, 1962, N.E.I.G.C., Conf. Exc. Guidebook and personal communication.	Mt. Johnson, P.Q.	53	shells	GrN-2032	10,450±80
Elson, 1962, N.E.I.G.C., Conf. Exc. Guidebook and personal communication.	Oka, P. Q.	94	shells	GrN-2035	10,290±100
Dyck and Fyles, 1963.	Trois-Pistoles, P. Q.	166	shells	GSC-102	12,720±170
Dyck, and Fyles, 1963.	St. Epiphane, P. Q.	94	shells	GSC-63	11,410±150
Dyck and Fyles, 1963.	L'Isle-Verte, P. Q.	79	shells	GSC-70	10,600±170
Dyck and Fyles, 1963	Rivière-du-Loup, P. Q.	100	shells	GSC-61	10,340±130
Dyck and Fyles, 1963.	L'Isle-Verte, P. Q.	55	shells	GSC-69	9,690±150
Dyck and Fyles, 1963.	Cacouna, P. Q.	16	shells	GSC-68	9,830±130
Dyck and Fyles, 1963.	Pembroke, P. Q.	136	shells	GSC-90	10,870±130
Dyck, Fyles and Blake, 1963.	Kingsey Falls, P.Q.	121	shells	GSC-187	11,410±150
J. G. Fyles, personal communication	St. Hilaire, P. Q.	272	basal layer of a filled lake basin.	GSC-419	12,570±220
M. Stuver, personal communication.	St. Hilaire, P. Q.	91	shells	Y-1558	10,560±160
Preston, Person and Deevey, 1955	Uplands, P. O.	98	shells	Y-216	11,370±360
Preston, Person and Deevey, 1955	Hull, P. Q.	119	shells	Y-215	10,630±330
Preston, Person and Deevey, 1955.	Mt. Royal P. Q.	171	shells	Y-233	11,370±360
Yves, Levin, Robinson and Rubin, 1964.	Lake Alice, N. Y.	64	shells	W-1109	10,560±350
Olson and Broecker, 1961.	Drummondville P.Q.	ca. 91	basal layer of a bog.	L-441-C	9,430±250
G. Delibrias, personal communication.	St. Bruno, P. Q.	ca. 135	shells	Gif-401	11,000±350
J. Terasmae, personal communication.	St. Hilaire, P. Q. (Lake Hertel)	ca. 172 (pre- sent level of water surface)	silty organic mud.	GSC-482	10,880±260

Table 2: C_{14} dates pertinent to the history of Lake Iroquois and Lake Ontario.

<i>References</i>	<i>Locality</i>	<i>Material</i>	<i>Lab. no.</i>	<i>Age. yrs. B. P.</i>
Rubin and Alexander, 1960.	Cheery Tavern N. Y.	wood	W—507	12,000±300
Rubin and Alexander, 1960.	Lewiston, N. Y.	wood	W—861	12,660±400
Rubin and Berthold, 1961.	Lewiston, N. Y.	same as W—861	W—883	12,080±300
Stuiver, Deevey and Gralenski, 1960.	Hamilton City Hall, Ontario	wood	Y—391	11,570±260
Walton, Trautman and Friend, 1961.	Galt, Ontario	organic mud.	I(GSC)—29	11,950±350

Table 3: C_{14} dates pertinent to the deglaciation and marine invasion in the Lake St. John district.

<i>References</i>	<i>Locality</i>	<i>Altitude meters</i>	<i>Material</i>	<i>Lab. no.</i>	<i>Age. yrs. B. P.</i>
Lasalle, 1965	Desbiens, P. Q.	228—242	basal organic mud	Y—1557	7,430±160
Lasalle, 1965	Alma, P. Q.	129	shells	GSC—313	8,680±140
Lasalle, 1965	Metabetchouan, P. Q.	121	shells	GSC—375	9,430±160
J. C. Vogel, personal communication.	St. Fulgence, P. Q.	162	shells	GrN—4811	9,380±60
G. Delibrias, personal communication.	Metabetchouan, P. Q.	153	shells	Gif—400	10,060±350
G. Delibrias, personal communication.	Desbiens, P. Q.	119	shells	Gif—423	9,560±350
G. Delibrias, personal communication.	Metabetchouan P.Q.	113	shells	Gif—424	10,250±350
M. Stuiver, personal communication.	Chicoutimi, P. Q.	6.5	shells	Y—1700	8,680±80
M. Stuiver, personal communication.	Kenogami, P. Q.	ca. 121	shells	Y—1701	8,630±80