Géographie physique et Quaternaire

Quaternary Foraminiferal Stratigraphy in Sediments of the Eastern Champlain Sea Basin, Québec

Stratigraphie quaternaire sur foraminifères dans les sédiments du bassin est de la Mer de Champlain, Québec

Quaternärstratigraphie auf Foraminiferen in Sedimenten des östlichen Champlain-Meeresbeckens, Québec

Jean-Pierre Guilbault

Volume 47, numéro 1, 1993

URI : https://id.erudit.org/iderudit/032930ar
DOI : https://doi.org/10.7202/032930ar

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Citer cet article

Guilbault, J.-P. (1993). Quaternary Foraminiferal Stratigraphy in Sediments of the Eastern Champlain Sea Basin, Québec / Stratigraphie quaternaire sur foraminifères dans les sédiments du bassin est de la Mer de Champlain, Québec. *Géographie physique et Quaternaire*, *47*(1), 43–68. https://doi.org/10.7202/032930ar

Résumé de l'article

Des sédiments tardiglaciaires de la Mer de Champlain ont été échantillonnés à 18 sites dans les régions de Trois-Rivières et de Québec. Deux séquences d'écozones à foraminifères (eau profonde et peu profonde), semblables à celles précédemment décrites dans l'ouest de la Mer de Champlain, sont reconnues. Le contenu faunique indique une première phase hyposaline (pré-A) avec des indices sûrs d'eau douce seulement à la limite sud-ouest de la région étudiée. Durant cette période, la salinité a dû être déterminée par l'avancée et le recul d'un lobe glaciaire dans la région de Québec. Suit la zone A (salinité : 25-32 ‰), qui est en partie synchrone avec la formation de la Moraine de St-Narcisse. Cette zone a duré approximativement de 11,3 à 10,6 ka BP, peut-être jusqu'à près de 10,2 ka BP. Elle est suivie des zones B (10-25 ‰) et C (2-10 ‰) tandis que près des grands affluents d'eau douce, d'épaisses séries deltaïques dépourvues de foraminifères se substituent aux zones B et C. À l'est de Trois-Rivières, il semble que la zone B soit discontinue et ne se rende pas jusqu'à Québec. La zone C n'est observée qu'à un seul site, à l'ouest de Trois-Rivières. Deux zones peu profondes, EH et EA, contemporaines des zones A et B, se caractérisent par des salinités plutôt élevées (maximum annuel jusqu'à 30 ‰ pour EH, un peu moins pour EA), la zone EA indiquant d'autre part des étés plus tièdes. Les résultats obtenus concernant les paléosalinités ne permettent pas de détecter le détournement de l'exutoire du Lac Agassiz. Le débit estimé par certains auteurs n'a peut-être pas suffi à changer de façon détectable la salinité des eaux profondes de la dernière phase de la Mer de Champlain. Dans les eaux peu profondes, le changement pourrait avoir été plus sensible, mais sa datation est difficile à cause de la présence de carbonate ancien recyclé.

Géographie physique et Quaternaire, 1993, vol. 47, n° 1, p. 43-68, 16 fig., 5 tabl.

QUATERNARY FORAMINIFERAL STRATIGRAPHY IN SEDIMENTS OF THE EASTERN CHAMPLAIN SEA BASIN, QUÉBEC

Jean-Pierre GUILBAULT, Département de géologie, Université de Montréal, C.P. 6128, succursale "A", Montréal, Québec H3C 3J7.

ABSTRACT Sediments of the late-glacial Champlain Sea basin have been sampled at 18 sites in the Trois-Rivières and Québec City regions. Two successions of foraminiferal ecozones (deep and shallow water) comparable to those previously reported from the western Champlain Sea are recognized. Faunal composition indicates an early phase (pre-A) of hyposaline waters with consistent freshwater evidence only at the southwestern limit of the area. Salinity control in pre-A could be the result of advance or retreat of an ice lobe in the Québec City region. It is followed by zone A (salinity: 25-32‰) which is in part synchronous with the formation of the St-Narcisse Moraine. In the easternmost Champlain Sea, zone A lasted approximately from 11.3 until after 10.6 ka BP, possibly up to near 10.2 ka BP. In the western part of the area, it is progressively replaced by the less saline conditions of zones B (10-25‰) and C (2-10‰). Near major freshwater inlets, thick delta sequences barren of foraminifera substitute for zones B and C. East of Trois-Rivières, zone B is probably discontinuous and does not reach Québec City. Zone C is present at only one site, west of Trois-Rivières. The shallow water zones EH and EA, contemporaneous with zones A and B, record relatively high salinities (annual maximum of up to 30 ‰ for EH, somewhat less for EA), zone EA suggesting also warmer summers. The paleoecological results concerning salinity do not allow detection of the diversion of Lake Agassiz outflow. The discharge envisaged by some authors may not have been large enough to detectably change salinity in the deep, late Champlain Sea. In shallow waters, the effect could have been significant but would be difficult to date because of error due to recycled old carbonate.

RÉSUMÉ *Stratigraphie quaternaire sur foraminifères dans les sédiments du bassin est de la Mer de Champlain, Québec*. Des sédiments tardiglaciaires de la Mer de Champlain ont été échantillonnés à 18 sites dans les régions de Trois-Rivières et de Québec. Deux séquences d'écozones à foraminifères (eau profonde et peu profonde), semblables à celles précédemment décrites dans l'ouest de la Mer de Champlain, sont reconnues. Le contenu faunique indique une première phase hyposaline (pré-A) avec des indices sûrs d'eau douce seulement à la limite sud-ouest de la région étudiée. Durant cette période, la salinité a dû être déterminée par l'avancée et le recul d'un lobe glaciaire dans la région de Québec. Suit la zone A (salinité: 25-32 ‰), qui est en partie synchrone avec la formation de la Moraine de St-Narcisse. Cette zone a duré approximativement de 11,3 à 10,6 ka BP, peut-être jusqu'à près de 10,2 ka BP. Elle est suivie des zones B (10-25 ‰) et C (2-10 ‰) tandis que près des grands affluents d'eau douce, d'épaisses séries deltaïques dépourvues de foraminifères se substituent aux zones B et C. À l'est de Trois-Rivières, il semble que la zone B soit discontinue et ne se rende pas jusqu'à Québec. La zone C n'est observée qu'à un seul site, à l'ouest de Trois-Rivières. Deux zones peu profondes, EH et EA, contemporaines des zones A et B, se caractérisent par des salinités plutôt élevées (maximum annuel jusqu'à 30 ‰ pour EH, un peu moins pour EA), la zone EA indiquant d'autre part des étés plus tièdes. Les résultats obtenus concernant les paléosalinités ne permettent pas de détecter le détournement de l'exutoire du Lac Agassiz. Le débit estimé par certains auteurs n'a peut-être pas suffi à changer de façon détectable la salinité des eaux profondes de la dernière phase de la Mer de Champlain. Dans les eaux peu profondes, le changement pourrait avoir été plus sensible, mais sa datation est difficile à cause de la présence de carbonate ancien recyclé.

ZUSAMMENFASSUNG *Quaternärstratigraphie auf Foraminiferen in Sedimenten des östlichen Champlain-Meeresbeckens, Québec*. An 18 Plätzen in den Regionen von Trois-Rivières und der Stadt Québec wurden Sedimentproben des spätglazialen Champlain-Meeresbeckens entnommen. Zwei Abfolgen von Foraminiferen-Ökozonen (tiefes und seichtes Wasser) werden identifiziert, vergleichbar denen, die zuvor im westlichen Champlain-Meer festgestellt wurden. Die Zusammensetzung der Fauna weist auf eine frühe Phase (prä-A) mit hyposalinem Wasser mit sicherem Süßwasserbeleg nur an der südwestlichen Grenze des Gebiets. Die Kontrolle des Salzgehalts in prä-A könnte auf den Vorstoß oder Rückzug einer Eislobe in der Region der Stadt Québec zurückzuführen sein. Darauf folgt die Zone A (Salzgehalt: 25-32‰), welche teilweise synchron mit dem Gebilde der St-Narcisse-Moräne ist. Im östlichsten Teil des Champlain-Meeres dauerte die Zone A etwa von 11.3 bis nach 10.6 ka v.u.Z., möglicherweise fast bis 10.2 ka v.u.Z. Im westlichen Teil des Gebiets wird sie allmählich durch die weniger salzigen Bedingungen der Zonen B (10-25‰) und C (2-10‰) ersetzt. In der Nähe von bedeutenden Frischwassereinflüssen ersetzen dicke Delta-Sequenzen ohne Foraminiferen die Zonen B und C. Östlich von Trois-Rivières ist die Zone B möglicherweise abgebrochen und erreicht nicht die Stadt Québec. Zone C findet man nur an einer Stelle westlich von Trois-Rivières vor. Die seichten Wasserzonen EH und EA, aus der gleichen Zeit wie die Zonen A und B, belegen relativ hohen Salzgehalt (jährliches Maximum von bis zu 30‰ für EH, etwas weniger für EA), wobei die Zone EA wärmere Sommer vermuten läßt. Die paläoökologischen Ergebnisse bezüglich des Salzgehalts erlauben nicht, die Ablenkung des Lake Agassiz-Ausflusses zu ermitteln.

Manuscrit reçu le 2 juin 1992; manuscrit révisé accepté le 16 septembre 1992.

INTRODUCTION

This paper describes the vertical and areal distribution of foraminifera in the sediments of the eastern part of the Champlain Sea basin. Following the proposal of Elson (1969), the phrase "Champlain Sea" designates the late-glacial body of water which flooded the St. Lawrence/Ottawa Lowland west of Québec City following the retreat of the last Wisconsinan Laurentide Ice Sheet; the inundated areas further east are referred to as the Goldthwait Sea. Radiocarbon age determinations on marine shells have yielded values of between 12.8 and 9.8 ka BP (Occhietti and Hillaire-Marcel, 1977), which span the Younger Dryas cold interval as well as parts of the previous and subsequent warmer phases. Samples have been collected from 18 localities (Fig. 1 and Table I). A composite stratigraphic sequence of ecozones (*sensu* Feyling-Hanssen, 1964) is recognized and correlated with the zonal scheme of Guilbault (1989) established earlier for the central and western parts of the basin. Therefore, the zones will not be redescribed except for regional and local variations. The same zonal nomenclature (zone A, B, etc.) will be retained. No previous foraminifer based stratigraphic work is known bearing exclusively on the present area. Local data are available from Cronin (1979a) concerning in particular the St-Nicolas sand pit (see below) and from Wagner (1970) who includes many eastern Champlain Sea localities in her data.

Since the paper of Guilbault (1989), important publications have been issued concerning the Champlain Sea, especially in connection with the 1986 Champlain Sea symposium (Gadd, 1988). Of particular interest is the work of Anderson (1988) concerning pollen stratigraphy of the Ottawa Valley – Lake Ontario region, that of Rodrigues (1988) synthesizing

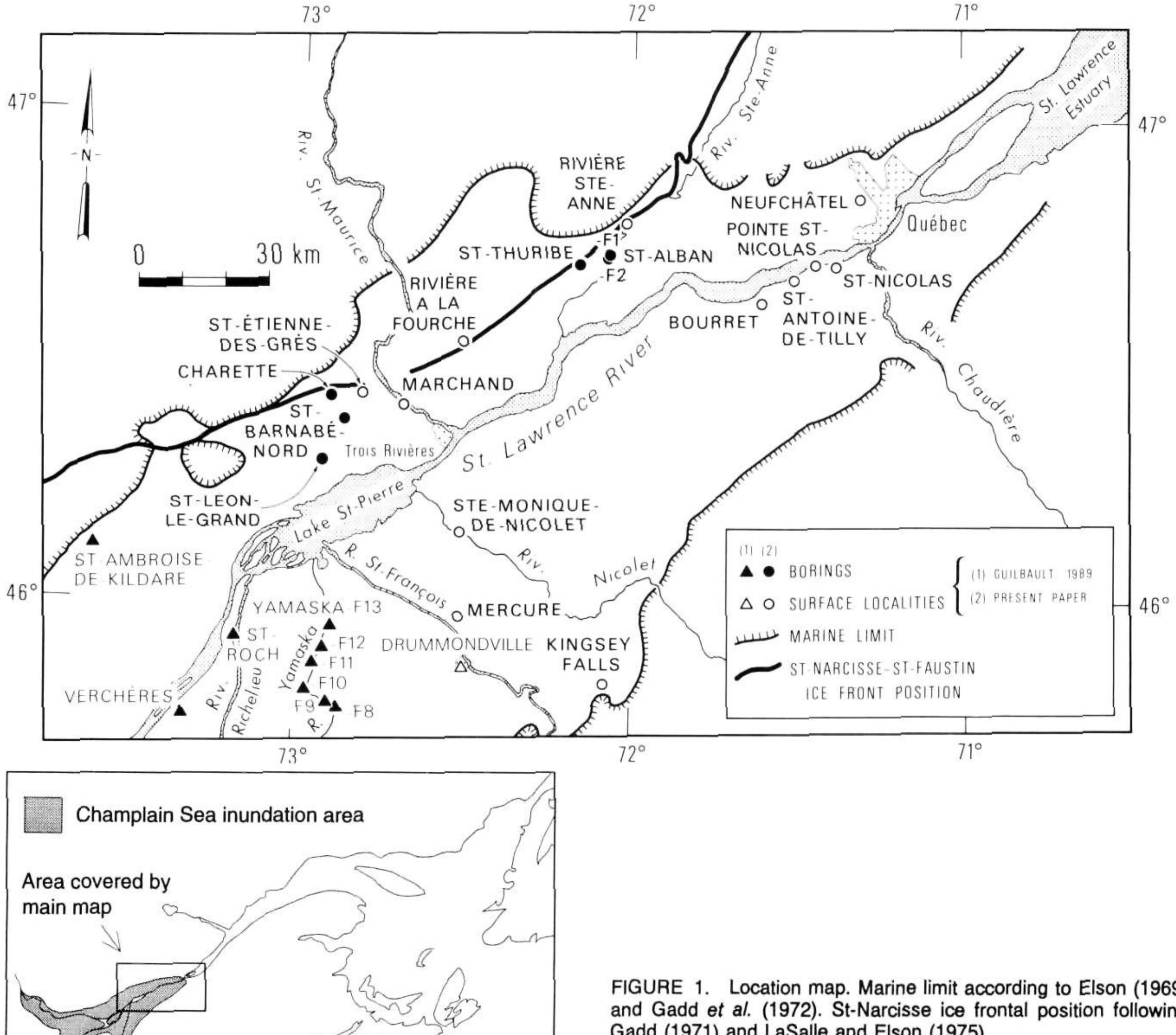


FIGURE 1. Location map. Marine limit according to Elson (1969) and Gadd *et al.* (1972). St-Narcisse ice frontal position following Gadd (1971) and LaSalle and Elson (1975).

Carte de localisation. Limite marine d'après Elson (1969) et Gadd et al. (1972). Position du front glaciaire de Saint-Narcisse d'après Gadd (1971) et LaSalle et Elson (1975).

western Champlain Sea micropaleontological data and that of Hunt and Rathburn (1988) about Lake Champlain ostracodes and foraminifera. In addition, de Vernal *et al.* (1989) made the first report on Champlain Sea dinoflagellate cysts, allowing us the first glimpse on surface conditions.

Just before going to press, the author got acquainted with the latest Champlain Sea publication of Rodrigues (1992). It concentrates on the transition between pre-Champlain Sea lacustrine environments and the period of maximum salinity conditions, corresponding with the present pre-A phase and early zone A. It includes two new eastern Champlain Sea sites: Ste-Monique-de-Nicolet (different from the section described here) and St-Lambert, in addition to the Rivière Landry section (Parent, 1987: see below).

GEOLOGICAL SETTING

Lithostratigraphic information for the eastern Champlain Sea basin suggests that deglaciation was immediately followed by brackish conditions. Lacustrine deposits below the marine sediments, as indicated by rhythmic deposits (such as reported by Gadd, 1986), or by the dominance of non-marine ostracodes (*Candona*) are rare occurrences. *Candona*-bearing rhythmic deposits are absent from most of the area of study and have been reported only by Parent (1987) and Rodrigues (1992) at Rivière Landry, in the southeasternmost part of the region, east of Drummondville. LaSalle *et al.* (1977) report unfossiliferous rhythmites from St-Antoine-de-Tilly, near Québec City, but are not sure of their age.

On the north side of the basin, during the overall glacial retreat, the ice front readvanced or stood still in the Champlain Sea. Evidence for these readvances or standstills are the St-Narcisse Moraine and the glacial-marine diamictons associated to it. Pre-St-Narcisse readvances have been suggested as the cause for the deposition of fossiliferous diamictons in the Québec region (LaSalle *et al.* 1977; LaSalle, 1984, 1987) based on the radiocarbon age of included shells (11.1 to 11.34 ka BP; LaSalle *et al.*, 1977; Parent and Occhietti, 1988).

The St-Narcisse Moraine is a complex set of ridges interpreted by LaSalle and Elson (1975) as a halt in the ice retreat caused by a cold climatic event dated between 11.0 and 10.6 ka BP. Hillaire-Marcel *et al.* (1981) compared the St-Narcisse Moraine with the Sakami Moraine of the James Bay area and suggested that both result from topographical control. Parent and Occhietti (1988) believed that the synchroneity of various segments of the St-Narcisse complex is not firmly established but that the segment we are interested in (the lower St-Maurice region) is probably between 11.3 and 10.8 ka BP old. The same authors believed that the location of the Moraine may be due to geomorphologic factors, but do not exclude the possibility of some readvance from a more northerly position. Savoie and Richard (1979) reported palynological data from a site north of the St-Narcisse Moraine (N of Montréal) suggesting that climate immediately following the retreat of the ice was as cold as before.

The St-Narcisse glacial deposits are overlain by deltaic sediments north of Trois-Rivières (Trois-Rivières Delta, Gadd, 1971) and along Rivière Ste-Anne (Rivière Ste-Anne Delta, Occhietti, 1977). North of Trois-Rivières, the deltaic deposits are thick enough to bury completely the St-Narcisse Moraine. Thus, the buildup of the Moraine must have ended at a time when relative sea levels were still rather high, and have been followed by a period of important deltaic sediment

TABLE I

Altitudes and UTM coordinates of localities
(altitudes are for tops of sections or boreholes
unless otherwise indicated)

Locality	Altitude (m a. s. l.)	Surface	Borehole	UTM coordinates
Kingsey Falls	115	X		18T YF 270 806
Mercure	70-75	X		18T XF 925 948
Ste-Monique-de-Nicolet	40	X		18T XG 915 140
St-Léon-le-Grand	10 (sampled level)	X		18T XG 588 303.5
St-Barnabé-Nord	55		X	18T XG 644 386
Charette	105		X	18T XG 621 447
St-Étienne-des-Grès	90 (sample 18)	X		18T XG 687 448
Marchand	10 (base of section)	X		18T XG 754 437
Rivière à la Fourche	100	X		18T XG 911 568
St-Thuribe	60		X	18T YG 172 755
St-Alban boreholes				
borehole F1	70		X	18T YG 237 780
borehole F2	70		X	18T YG 235 773
Rivière Ste-Anne	68 (base of section)	X		18T YG 280 860
Neufchâtel	45	X		19T CB 226 883
St-Nicolas	60	X		19T CB 180 743
Pointe St-Nicolas	60	X		19T CB 124 742
St-Antoine-de-Tilly	80	X		19T CB 087 719
Bourret	68	X		19T CB 035 681

input from the north. A similar deltaic phase associated with the late phases of the Champlain Sea occurs on a larger scale in the Ottawa Valley (Gadd, 1986).

LOCALITIES STUDIED

The 18 localities include 5 boreholes and 12 outcrops. The boreholes were drilled by the geotechnical laboratory of the Québec Department of Energy and Resources in 1976 and 1977 under the supervision of Jacques Lebuis. The drilling was done with equipment used for the collection of geotechnical samples, which collects undisturbed sediment cores of 75 cm in length. Usually, one sample in every core was set aside for micropaleontology. At St-Thuribe, coring was continuous resulting in one sample every 75 cm; in other boreholes, samples were taken as much as possible at 3 m intervals. This is rather large, but considering the thickness of the sequence, it was adequate to discern broad trends in faunal composition. Borehole lithostratigraphic data are personal communications from J. Lebuis.

The surface localities were for the most part sampled by the author between 1976 and 1978 and in 1988. Sampling was not done at a preset interval but instead was adapted to reflect variations in lithology. The Rivière Ste-Anne section was sampled by Serge Occhietti of Université du Québec à Montréal (lithologic description in Occhietti, 1977). The classic St-Nicolas sand pit (Gadd *et al.*, 1972) was the object of two parallel sample collections, one by S. Occhietti and the other by the author. More detailed statistics about the zones are available in Table II.

METHODS

Laboratory methods are the same as in Guilbault (1989). Samples from two localities were sieved through a 63 μm screen (Pointe St-Nicolas and the StNO series from St-Nicolas) while all others were sieved through either a 100 or 106 μm screen. At St-Nicolas, where both screen sizes were used side by side on two separate but correlative suites of samples, the finer mesh did not significantly alter the pro-

TABLE II

Summary of Champlain Sea zones

a) EAST ≥ 50 specimens: 117 samples*		0 to 49: 62 samples						b) CENTRE & WEST (Guilbault,1989) ≥ 50 specimens: 100 samples*				0-49: 104 samples	
ZONE		Pre-A	A	B	C	EH	EA	Pre-A	A	B	C	EH	EA
samples with ≥ 50 determined specimens		3	72	9	none	9	10	4	21	39	6	7	16
Walton's faunal diversity**	max.	4	8	6	—	11	10	5	9	3	1	9	7
	min.	2	2	1	—	7	2	3	1	1	1	5	2
	average	2.67	3.86	3	—	9.44	5.78	4.33	4.57	1.42	1	7	3.79
species abundance (%)													
Elphidium excavatum	max.	53	73	95	—	64	91	83	23	100	100	58	64
	min.	0	0	61	—	17	21	9.1	0.2	81	95	19	24.5
	average	23.9	19.2	83	—	41.7	57.6	34.3	5.3	95.4	98.8	36	24.5
Cassidulina reniforme	max.	88	90	4.1	—	16	23	70	99	8	0	4.9	13
	min.	21	2.8	0	—	1.3	0.5	8.4	20	0	0	0	0
	average	62.9	48	1.2	—	9.2	8	50.2	58.9	0.9	0	1.4	2.1
Islandiella spp.	max.	9.3	93	4.3	—	38	20	12	68	1	0	25	17
	min.	0	0.3	0	—	1.7	0	0	0.3	0	0	0.4	0
	average	3.4	19.6	0.8	—	13.2	5.9	4.6	28.3	0	0	14.1	3.4
Elphidium hallandense	max.	0	1.8	2.3	—	8.1	5.1	0.6	0.5	0.4	0	13	2.3
	min.	0	0	0	—	2	0	0	0	0	0	3.4	0
	average	0	0.2	0.3	—	3.6	1.5	0.2	0.1	0	0	7.8	0.4
E. albiumbilicatum	max.	0	1	8.6	—	8.9	28	0	2.1	0.5	0	3	91
	min.	0	0	0	—	0	7.8	0	0	0	0	0	0
	average	0	0.1	2.4	—	2.7	18.5	0	0.2	0	0	1.2	40.9
Virgulina schreibersiana	max.	16	85	2.1	—	23	0.6	4	0.9	3.9	0	1.9	0
	min.	0.2	0	0	—	0.3	0	0	0	0	0	0	0
	average	5.6	9	0.4	—	4.5	0.2	1.3	0.2	0.1	0	0.5	0

* Not all of these samples are attributed to a zone. Some have a transitional composition (AB samples), others contain only tests that are interpreted as reworked, such as, in particular, at St-Nicolas.

** Species % are computed for samples with 50 specimens or more and Walton's faunal diversity for those with 100 specimens or more. Most pre-A samples, especially in the central and western parts, contain too few foraminifera to have their Walton's faunal diversity computed: the values and averages given thus tend to be unrepresentatively high.

portions of any of the species present. At Pointe St-Nicolas, there is an exceptionally high frequency of the small species *Eoeponidella pulchella*, *Buliminella elegantissima* and *Virgulina schreibersiana*. Despite this, *E. pulchella* and *B. elegantissima* remain sufficiently rare so as to have no effect on the paleoenvironmental interpretation, which is based on the major species. On the other hand, *V. schreibersiana* may be locally abundant but its elongated and extremely light test may be easily displaced by *post-mortem* transport. Therefore its presence or absence may not be diagnostic.

REMARKS ON DIVERSITY INDICES

The diversity indicators used in the present paper are: Walton's faunal diversity (Walton, 1964), faunal dominance (percentage of the most abundant species) and Fisher's α-index (Fisher *et al.*, 1943; graphic representation after Murray, 1973). Diversity indices are clues to environmental "stress" on the assemblages, but do not say anything about the nature of the stress which has to be deduced from the stratigraphic context. They are statistical measurements and are more significant when a larger body of data is available. The reason for relying on diversity patterns is that one of them, the Shannon-Wiesner index, has been successfully used in the Champlain Sea by Cronin (1979b). Diversity indices are more likely to give useful information in areas where faunal distributions are controlled mostly by physical parameters such as salinity and temperature. Those parameters are likely to have been much more effective as a control of faunal distribution in the Champlain Sea than in offshore, oceanic, stable settings where biological accommodation between species is a prime factor. Thus, high diversity values in the Champlain Sea may be interpreted as resulting from higher and less variable salinities, as demonstrated by the contrast between zones A and B (Guilbault, 1989). Other physical factors however, in particular sediment influx, summer heat and sunlight, may also affect diversity indices which must not be automatically perceived as salinity indicators.

Walton's faunal diversity is computed only for samples with more than 100 specimens in the counted fraction. Between 50 and 100 specimens, it is recorded on the distribution charts as a question mark and below 50, it is not noted at all.

RESULTS

The succession of zones observed in the eastern part of the basin is similar to that earlier reported from the central Champlain Sea by Guilbault (1989) (Table III). The pre-A levels are represented by assemblages suggesting reduced salinities (< 25 ‰, *Islandiella helenae* absent) but neither oligohaline nor lacustrine conditions. Zone A, the most saline deep facies, is extensively represented but shows variations in diversity indices according to whether it is close to or far from the St-Narcisse ice front; its thickness varies considerably (Fig. 2). It differs from its central and western occurrences by having much fewer *Islandiella norcrossi* (max 7.1%, average 0.4% against 26.2% and 9.7% in the centre and west).

TABLE III

Summary of western, central and eastern Champlain Sea foraminiferal assemblages, modified from Guilbault (1989).

ZONE	ASSEMBLAGE
a) Deep water sequence:	
Post-C	Post-Champlain Sea. Usually unfossiliferous or containing a few specimens redeposited from zones A or B. Lacustrine or extremely hyposaline, less than 2‰.
C	Small numbers of *Elphidium excavatum*, some of which are large and belong to a morphotype characteristic of this zone. Other species are rare or absent. Salinity 2 to 10‰.
B	*E. excavatum* (⩾ 60%). Low numbers of *Haynesina orbiculare* and *Cassidulina reniforme*. Faunal diversities: low to very low. Salinity: 10 to 25‰.
A	*Cassidulina reniforme* and *Islandiella* spp. Variable amounts of *Elphidium excavatum*. Faunal diversities: from low to high. Salinity: 25-32‰.
Pre-A	Usually poor and undiversified. Most common foraminiferal species: *Elphidium excavatum* and *Cassidulina reniforme*. Oligohaline ostracodes common, at times the only microfossils present, except in eastern sector. Salinity: from fresh to brackish, rarely above 25‰.
a) Shallow water sequence:	
Lampsilis or post-C	Lampsilis: deposits with the freshwater mollusk *Lampsilis*. Not investigated micropaleontologically. Freshwater. Post-C: as above.
EA	*Elphidium excavatum, Haynesina orbiculare* and *E. albiumbilicatum*. Faunal diversities: high to low. Salinity (annual maximum): around 10-15‰ near Montréal, up to 25‰ near Québec City.
EH	*Elphidium excavatum, Haynesina orbiculare, E. hallandense* and *E. incertum*. Variable proportion of *Islandiella* spp. Faunal diversities: high. Salinity (annual maximum): 25‰ to 30‰.
pre-EH?	There is no sample from this level within the present material. Cronin (1977a, 1979a) reported from the Lake Champlain area a pre-*Hiatella* "transitional" zone consisting of elphidiids, haynesinids and oligohaline ostracodes. Faunal diversities: low. Salinity: like pre-A.

The contacts between the deep water zones is transitional and in the case of the A to B transition, there are a few samples of intermediate composition that are difficult to assign to either zone. This is in part due to the wide difference in composition between both zones and in part to the fact that three taxa are involved in defining them. These samples will often be labeled "AB", as in Guilbault (1989). Contrary to that paper, which assigned a subzonal value to the A-B transition, it now seems more reasonable to state that zone B follows zone A through gradational contact, the "AB" designation reflecting the existence of transitional conditions.

Zone B is present as far east as Rivière Ste-Anne but has not been recorded with certainty further east; its *Elphidium excavatum* dominance is less strong than in the central Champlain Sea. Zone C is present at one site only, west of

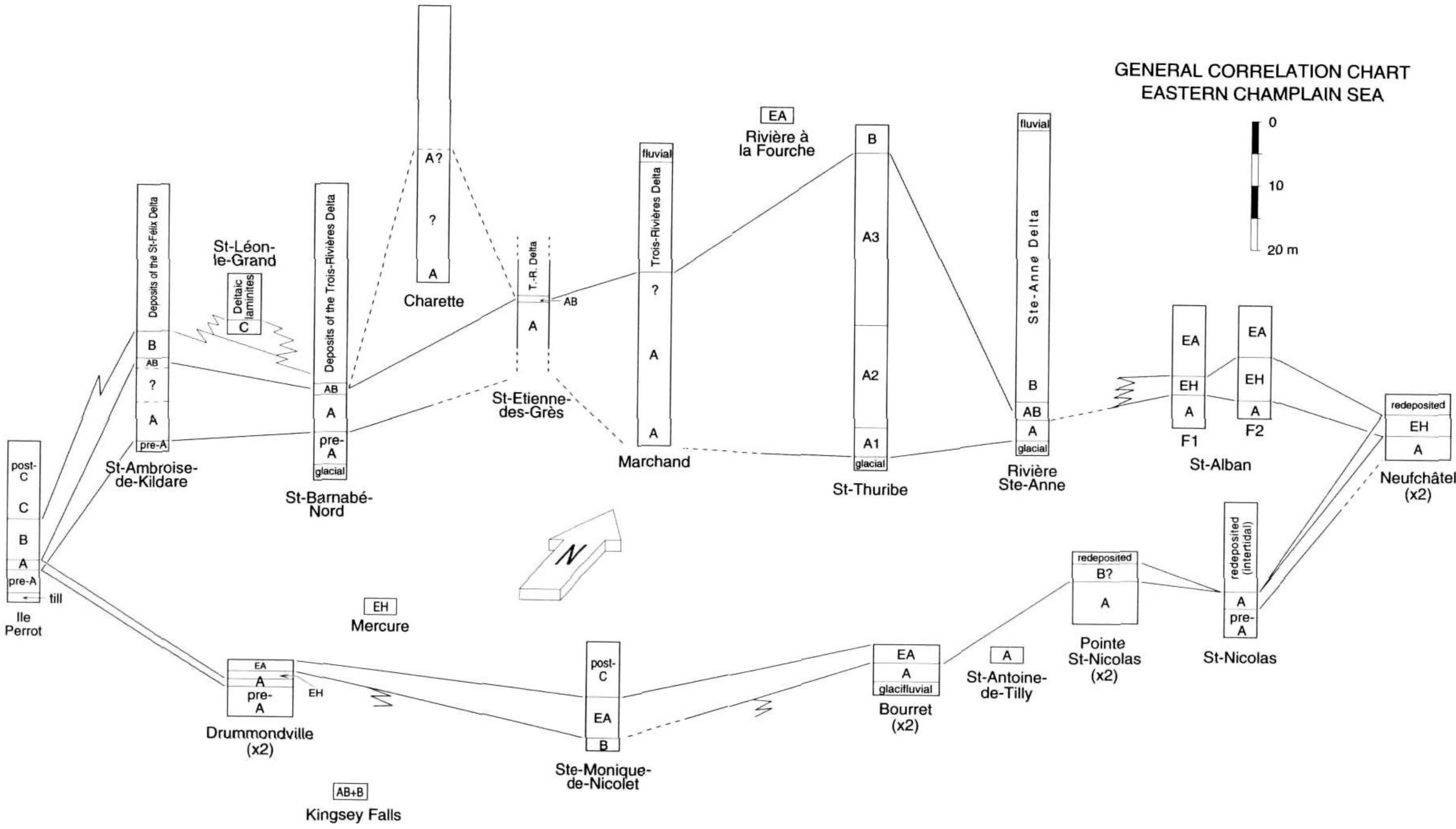


FIGURE 2. General correlation chart, designed as a fence diagram with the north shore of the St. Lawrence River at the back. Drummondville, Bourret, Pointe St-Nicolas and Neufchâtel are reproduced at twice the scale of the rest of the figure. Île Perrot, St-Ambroise-de-Kildare and Drummondville are central Champlain Sea sites described by Guilbault (1989).

Diagramme général de corrélation conçu comme un fence diagram, *la rive nord du Saint-Laurent étant située à l'arrière. Drummondville, Bourret, Pointe St-Nicolas et Neufchâtel sont reproduits à une échelle double du reste de la figure. Île Perrot, Saint-Ambroise-de-Kildare et Drummondville sont des sites du centre de la Mer de Champlain décrits par Guilbault (1989).*

Trois-Rivières. Similarly, post-C deposits are reported from a single site: Ste-Monique-de-Nicolet. Post-C is a broad concept including all post-Champlain Sea lacustrine deposits other than those containing *Lampsilis*. Contrary to what is suggested by Guilbault (1989), it is not specifically deep water and its presence above EA at Ste-Monique-de-Nicolet and Ste-Philomène (Guilbault, 1980) is not contradictory.

The deltaic deposits present at many localities must not be confused with the post-C deposits; deltaic deposits may appear in the succession as early as the transition between A and B. At Mer Bleue, Guilbault (1989) made an attempt at zoning the deltaic deposits. Except for three samples containing more than 50 specimens, all zonal identifications were accompanied by a question mark. In the eastern Champlain Sea, the fossil content of deltaic deposits is very low and no attempt was made at zoning them.

Zones EH and EA have been sampled only sporadically; an A-EH-EA succession was observed at St-Alban, with EA showing much higher diversity values than in the central Champlain Sea.

A description and comment of sampled localities is presented first, followed by a paleoenvironmental discussion and its bearing on paleogeography; the discussion synthesizes data from the eastern as well as the central and western Champlain Sea. Table IV is a list of all foraminifer species mentioned in the text with their original reference and Table V gives radiocarbon ages related to localities described herein.

DISCUSSION OF SAMPLED LOCALITIES

Ste-Monique-de-Nicolet

By its microfauna, macrofauna (*Portlandia arctica* only) and fine-grained sediment, zone EA at this site (Fig. 3, 4) looks like a transitional environment between the surface waters harbouring zone EA and the deeper waters inhabited by B and C assemblages. As in the case of the limit between zones A and EH (Guilbault, 1989), it is not possible to give a value in metres to the depth of this transition. The presence of morphotype C specimens of *E. excavatum* (*sensu* Guilbault, 1989) in samples 3 and 7 implies at least a partial synchronism between zone C and zone EA in the area of Ste-Monique-de-Nicolet.

Post-C sediments show occurrences of *Macoma balthica* at the 12.6 and 13.7 m stratigraphic level (in living position at 13.7 m) and of oligohaline to lacustrine ostracodes at 13.7 and 16.4 m. These belonged to *Ilyocypris gibba* and *not* to *Candona* sp. as at pre-A levels. There were no freshwater *Lampsilis* shells. The post-C period would, at least in this region and stratigraphic interval, have witnessed minor incursions of marine water on the bottom of Lake Lampsilis, while surface waters in the Montréal area were fresh enough to harbour *Lampsilis*.

St-Barnabé-Nord

This locality (Fig. 5) is similar to the borehole at St-Ambroise-de-Kildare reported on by Guilbault (1989). At both localities the succession begins with a hyposaline — not oligohaline — pre-A interval. The presence of a single oligohaline ostracode in the pre-A interval suggests proximity to freshwater but the abundance of foraminifera weighs in favour of a brackish interpretation. Even though the Gentilly Till is not observed, the recorded decrease in faunal content below zone A probably means that we are witnessing the earliest phases of Champlain Sea sedimentation. Otherwise, St-Ambroise and St-Barnabé are similar as far as the thicknesses of zone A is concerned, and also by the fact that the upper parts of both sections are made up of deltaic sediments containing only rare foraminifera of common Champlain Sea species, probably redeposited.

TABLE IV

List of foraminiferal species mentioned in the text and distribution charts, and their original designation (the name is not repeated when it is the same as the original designation).

Astacolus hyalacrulus Loeblich and Tappan, 1953.
Astrononion gallowayi Loeblich and Tappan, 1953.
Buccella frigida (Cushman): *Pulvinulina frigida* Cushman, 1922.
Buliminella elegantissima (d'Orbigny): *Bulimina elegantissima* d'Orbigny, 1839.
Cassidulina reniforme Nørvang: *Cassidulina crassa* var. *reniforme* Nørvang, 1945.
Cibicides lobatulus (Walker and Jacob): *Nautilus lobatulus* Walker and Jacob, 1798.
Elphidiella arctica (Parker and Jones): *Polystomella arctica* Parker and Jones, 1864.
Elphidium albiumbilicatum (Weiss): *Nonion pauciloculum albiumbilicatum* Weiss, 1954.
Elphidium excavatum (Terquem): *Polystomella excavata* Terquem, 1876.
Elphidium hallandense Brotzen, 1943.
Elphidium incertum (Williamson): *Polystomella umbilicatula* var. *incerta* Williamson, 1858.
Elphidium magellanicum Heron-Allen and Earland, 1932.
Eoeponidella pulchella (Parker): *Pninaella pulchella* Parker, 1952.
Fissurina laevigata Reuss, 1850.
Haynesina orbiculare (Brady): *Nonionina orbicularis* Brady, 1881.
Islandiella helenae Feyling-Hanssen and Buzas, 1976.
Islandiella norcrossi (Cushman): *Cassidulina norcrossi* Cushman, 1933.
Melonis zaandamae (van Voorthuysen): junior synonym of *Melonis pompilioides* (Fichtel and Moll, 1798).
Nonion labradoricum Dawson, 1860. Synonym: *Nonionellina labradorica* (Dawson) Voloshinova, 1958.
Nonionella auricula Heron-Allen and Earland, 1930.
Patellina corrugata Williamson, 1858.
Quinqueloculina frigida Parker, 1952.
Recurvoides turbinatus (Brady): *Haplophragmium turbinatum* Brady, 1881.
Robertina arctica d'Orbigny, 1846.
Rosalina globularis d'Orbigny, 1826.
Scutuloris tegminis Loeblich and Tappan, 1953.
Silicosigmoilina groenlandica Cushman: *Quinqueloculina fusca* var. *groenlandica* Cushman, 1933.
Spiroplectammina biformis (Parker and Jones): *Textularia agglutinans* var. *biformis* Parker and Jones, 1865.
Triloculina oblonga (Montagu): *Vermiculum oblongum* Montagu, 1803.
Virgulina concava Höglund, 1947.
Virgulina schreibersiana Czjzek, 1848.

TABLE V

Radiocarbon ages related to described localities

Locality	Foraminiferal zone dated	Sediment type	Dated material	Age (years BP)	Laboratory number	Reference
St-Étienne-des-Grès	AB transition	clay + silt	*Hiatella arctica*	10,230 ± 155	QC-1463	Occhietti, 1980
Rivière à la Fourche	EA	silt	*Hiatella arctica*	10,000 ± 150	GSC-1739	Occhietti, 1976
Rivière Ste-Anne	A	clay + silt	*Balanus hameri*	10,600 ± 160	GSC-2090	Occhietti, 1976
Rivière Ste-Anne	AB transition	clay + silt	*Macoma calcarea*	10,200 ± 90	GSC-2150	Occhietti, 1976
St-Nicolas	A	clay + silt	*Balanus hameri*	10,890 ± 125	UQ-39	Parent and Occhietti, 1988
St-Nicolas	reworked	sand	*Hemithyris psittacea*	10,000 ± 150	GSC-1451	Lowdon and Blake, 1979
St-Nicolas	reworked	sand	*Hiatella arctica*	9355 ± 115	UQ-64	Parent and Occhietti, 1988
Pointe St-Nicolas	A	diamicton	*Balanus hameri*	11,200 ± 170	GSC-1476	Parent and Occhietti, 1988
Pointe St-Nicolas	A	diamicton	*Balanus hameri*	11,340 ± 180	UQ-40	Parent and Occhietti, 1988
Pointe St-Nicolas	reworked	sand	*Mya truncata*	11,260 ± 290	QU-20	Samson *et al.*, 1977
Pointe St-Nicolas	reworked	sand	*Hiatella arctica*	9460 ± 190	UQ-206	Parent and Occhietti, 1988

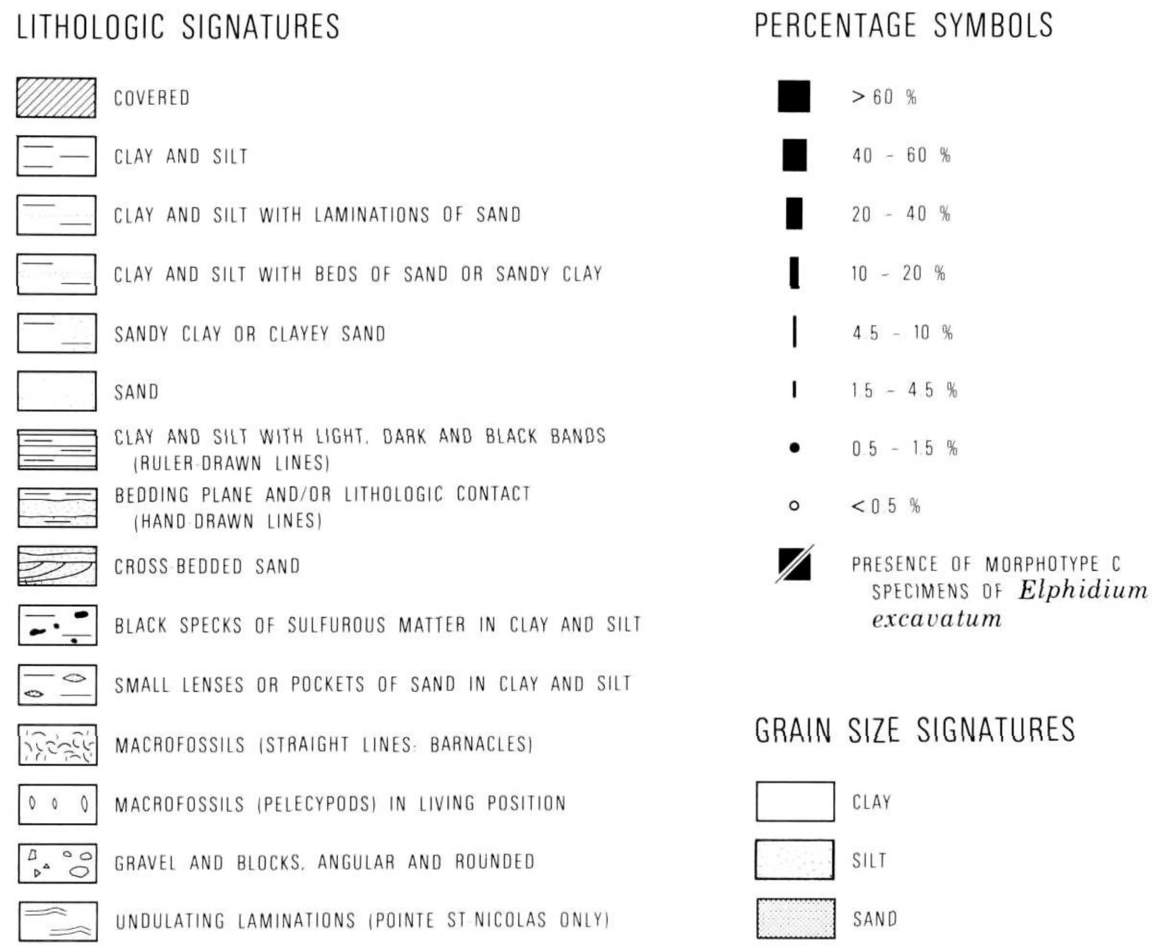


FIGURE 3. Explanation of symbols for distribution charts. *Légende des diagrammes de distribution.*

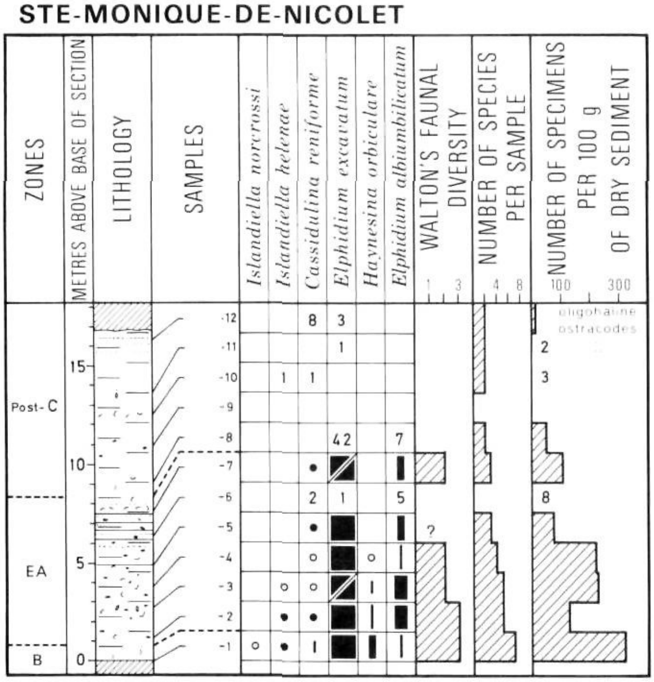


FIGURE 4. Faunal distribution chart for the Ste-Monique-de-Nicolet section. When the total number of counted specimens in a sample is less than 50, percentage symbols are replaced by the number of individuals and the number of specimens per 100 g of dry sediment is given by a number instead of a bar. These remarks apply to all distribution charts.

Diagramme de distribution faunique de la coupe de Sainte-Monique-de-Nicolet. Quand le nombre de spécimens comptés dans un échantillon est inférieur à 50, les symboles de pourcentage sont remplacés par le nombre d'individus et le nombre de spécimens par 100 g de sédiment sec est indiqué par un nombre au lieu d'une barre. Ces remarques s'appliquent à tous les diagrammes de distribution.

St-Étienne-des-Grès and Marchand

These two outcrop localities (Fig. 6) are characterized by the association of zone A with compact diamictons, adjacent to the St-Narcisse Moraine system. According to the map of Gadd (1971), the St-Étienne-des-Grès section is located within the area of the St-Narcisse complex and is covered by deposits of the Trois-Rivières Delta. In-between the poorly fossiliferous diamictons of zone A and the essentially barren delta deposits (only the basal part of the delta is represented on Fig. 6), there is a thin interval consisting of a layer of gravel (sample 17) overlain by a clay bed with pelecypods, mainly *Hiatella arctica*, in living position (sample 18). The clay contains an AB transitional foraminifer assemblage. Enclosed within the clay is an irregular-shaped mass of sediment (sample 19), rich in shell fragments, of probable allochtonous origin (ice-rafting?). An age of 10,230 ± 155 BP (QC-1463) has been obtained for *Hiatella arctica* shells from this interval (Occhietti, 1980) but it is not known whether they were in living position or collected from the allochtonous material.

Parent and Occhietti (1988, Fig. 3b) give a stratigraphic column for the Marchand section (see also Occhietti, 1980). Their "delta" and "prodelta" units correspond roughly to the present "deposits of the Trois-Rivières Delta". Zone A, represented by samples 1 and 2, spans the "distal glaciomarine" and the beginning of the "marine inundation" units of Parent and Occhietti (1988). The base of their "marine inundation" unit probably coincides with the limit, on the lithologic column of Figure 6, between the thick-bedded sandy, gritty clays and the massive diamictons and is thus clearly within zone A.

At the top of the thickly bedded clay, sample 3 does not contain enough fauna to be indicative of any zone; it is too low in the succession to belong to post-C deposits and could be contemporaneous with late zone A in the region. The low foraminifer number could be a local anomaly. A tighter sampling might show zone A to extend to the top of the thickly bedded clays.

St-Thuribe

This is an exceptional locality (Fig. 7) in the sense that core recovery is nearly continuous and sampling is at closer intervals than anywhere else in the Champlain Sea. The St-Thuribe borehole is located 800 m SE of the St-Narcisse Moraine.

No obvious pre-A interval can be detected at St-Thuribe. The three specimens extracted from the basal sample must not be considered relevant. Zone A can be subdivided into three broad intervals. In the first interval, designated subzone A1 (from sample 165A up to 155 inclusively), foraminifer numbers are low to moderate and diversity indices low; *Elphidium excavatum* is more abundant than *Islandiella helenae*. Note that exceptionally, Fisher α-index and dominance are plotted on the distribution chart in an attempt to make subtler stratigraphic differences stand out. Subzone A2 (152.5 to 102.5) exhibits low diversity indices and in most cases low foraminiferal numbers, and *I. helenae* is in much greater numbers than *E. excavatum*. The change between samples 102.5 and 100 is rather sharp and might be the consequence of a hiatus, although no trace of it has been found in the lithology. Subzone A3 (100 to 17.5) shows foraminifer numbers and diversities that are high near the base but decrease afterwards; *E. excavatum* dominates over *I. helenae*. Only A2 is fully conform to the concept of zone A. A1 and A3 are, at least in part, of intermediate composition between A and B, *E. excavatum* making more than 50%. Since these intervals are too extensive to be viewed as simple transitions between A and B, it was decided to give them a subzone status.

The thickness of zone A at this locality is exceptional, taking into account the fact this is not a diamicton but a clay-silt occurrence. Compared to other clay-silt occurrences such as St-Alban or St-Nicolas or the central Champlain Sea localities, zone A at St-Thuribe contains fewer specimens per 100 g of dry sediment and is much thicker. Assuming that zone A at the present locality should not have lasted longer than further east, its thickness must result from faster sedimentation or fewer hiatuses, or both. Faster sedimentation could have resulted from the proximity of an active ice front; stratigraphic continuity may be due to the fact this boring was performed in a local depression or valley in the bedrock (seismic results communicated by J. Lebuis) which could have acted as a sediment trap.

The paleoenvironmental interpretation of zone A at the present site rests on various factors which point at times in opposite directions. If we use the *I. helenae/E. excavatum* ratio as an indication of paleosalinity (following the results of Vilks *et al.*, 1979, for the Beaufort Sea), we must conclude that waters were the most saline during A2. However, we observe that foraminifer numbers and diversity indexes are lower in A2 than in A3, suggesting more adverse conditions. The percentage of *Virgulina schreibersiana* is high in A1 and A3 but low in A2. *V. schreibersiana* is usually associated with deep and quiet conditions but its living requirements are not really known. Its abundance in a topographic low could be explained by the ease with which it can be redeposited. The low number of specimens and high proportion of *I. helenae* make subzone A2 more similar to the fauna of the ice-rafted diamicton at Marchand and St-Étienne-des-Grès than to other parts of the present section. At St-Thuribe, the amount of sand and granules, which probably results from ice-rafting, starts to increase at approximately the level of sample 130 but does not decrease until around sample 60. Once again, the various data do not coincide although in this case, the amount of ice-rafted detritus is so low in comparison with Marchand that a parallel with this last site is questionable.

In summary, the St-Thuribe core presents for most of its length paleosalinities that are typical of zone A. Fine varia-

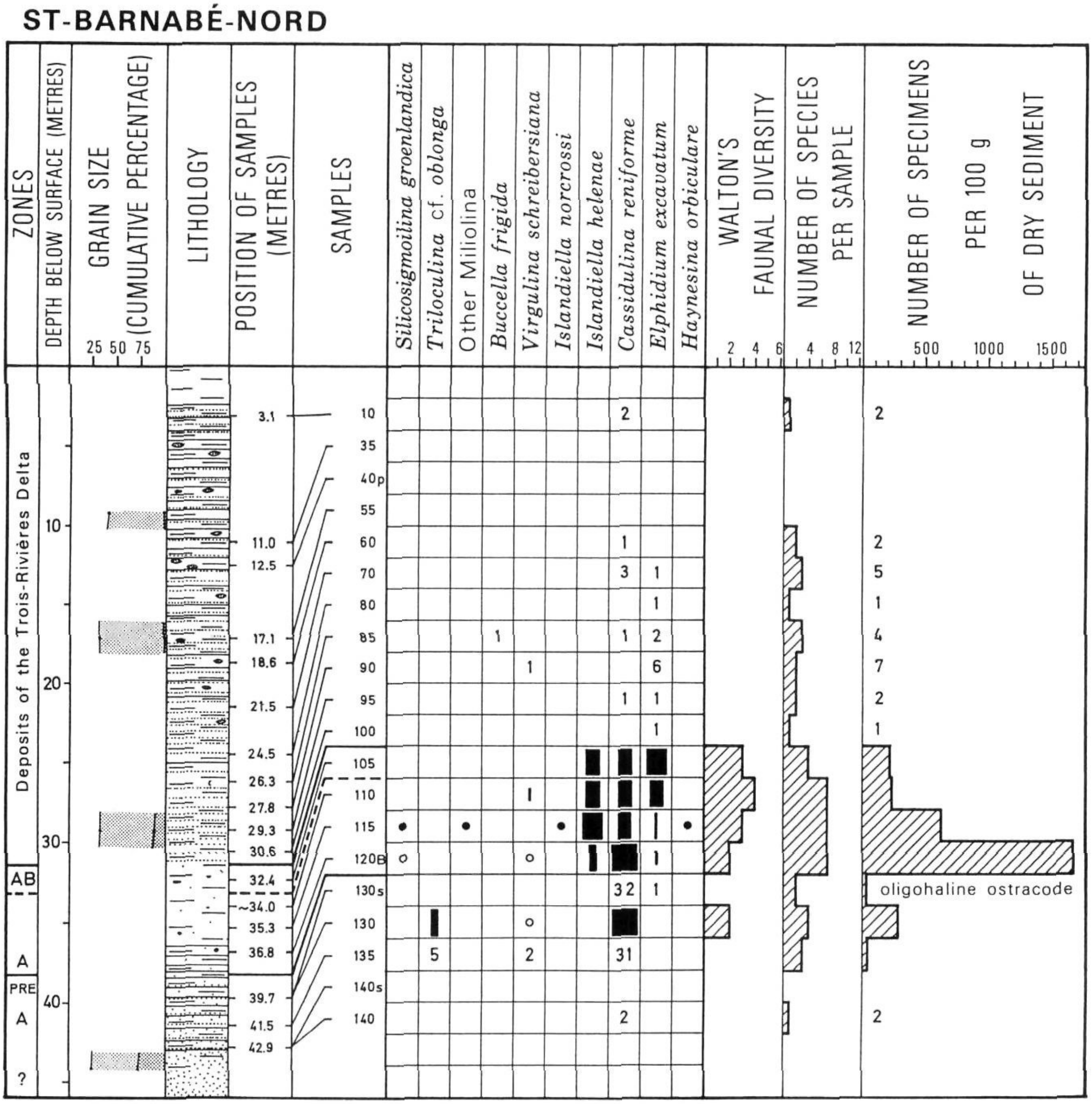
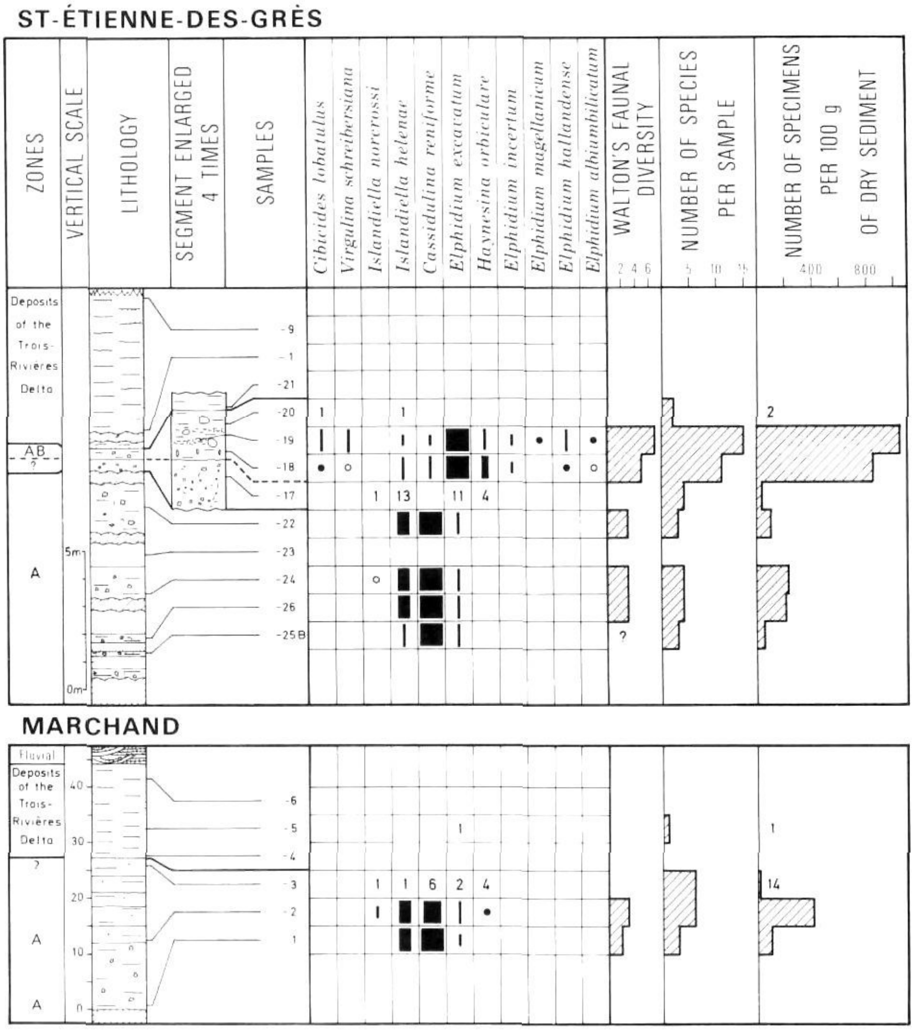


FIGURE 5. Distribution chart for the borehole at St-Barnabé-Nord. *Diagramme de distribution du forage de Saint-Barnabé-Nord.*

FIGURE 6. Distribution charts for the sections at St-Étienne-des-Grès and Marchand.

Diagramme de distribution des coupes de Saint-Étienne-des-Grès et de Marchand.



tions in salinity must have occurred but are difficult to pinpoint. It can only be suspected that the peak salinity coincided with the highest *Islandiella helenae/Elphidium excavatum* ratio, in subzone A2, this evidence being probably more reliable than the diversity values. Strongly hyposaline conditions of zone B become established at sample 10. An important part of the upper section may have been eroded away in view of the disproportionately thin zone B. Ice-rafting has been detectably more active between samples 130 and 60, but it has been much less active than at Marchand. There appears to be no correlation between ice-rafting and foraminiferal faunas. The regional meaning of these results, as well as the abundance of *Virgulina schreibersiana* in A3, will appear only when additional well-sampled sections are available nearby, in addition to ^{14}C datings.

St-Alban and Rivière à la Fourche

Two boreholes were drilled at St-Alban (Fig. 8), about 800 m apart. Both show the same zonal succession (A-EH-EA) as the Drummondville section of Guilbault (1989); therefore we are witnessing the passage from the deep to the shallow water sequence as relative sea level was dropping. Zone EA differs from its Ste-Philomène occurrence (Guilbault, 1989) by indicating fairly normal, shallow marine conditions in contrast with the more hyposaline situation existing in the region of Montréal. The single sample collected at Rivière à la Fourche, immediately to the north of the St-Narcisse Moraine and posterior to it (Table V), belongs to zone EA and has a composition comparable to the St-Alban occurrence of that zone.

The combination of age and altitude at St-Alban must have been such that the basinwide lowering of relative sea level brought, locally, a shift from the deep (A) to the shallow (EH) water sequence before basin freshening could change the deep water fauna to that of zone B. Alternatively, it could be that so close to the Goldthwait Sea, zone B never developed or was discontinuous (see Rivière Ste-Anne, next).

Rivière Ste-Anne

This section (Fig. 9) was studied and sampled by Occhietti (1977, 1980) and published by him under the name "St-Alban". The material investigated here comes from that study.

From sample I upwards, the type of sedimentation changes from one of ice-rafting or suspension to one that may be classified as extreme distal prodeltaic. Occhietti (1977, Fig. 6) put the base of the Ste-Anne delta at between 31 and

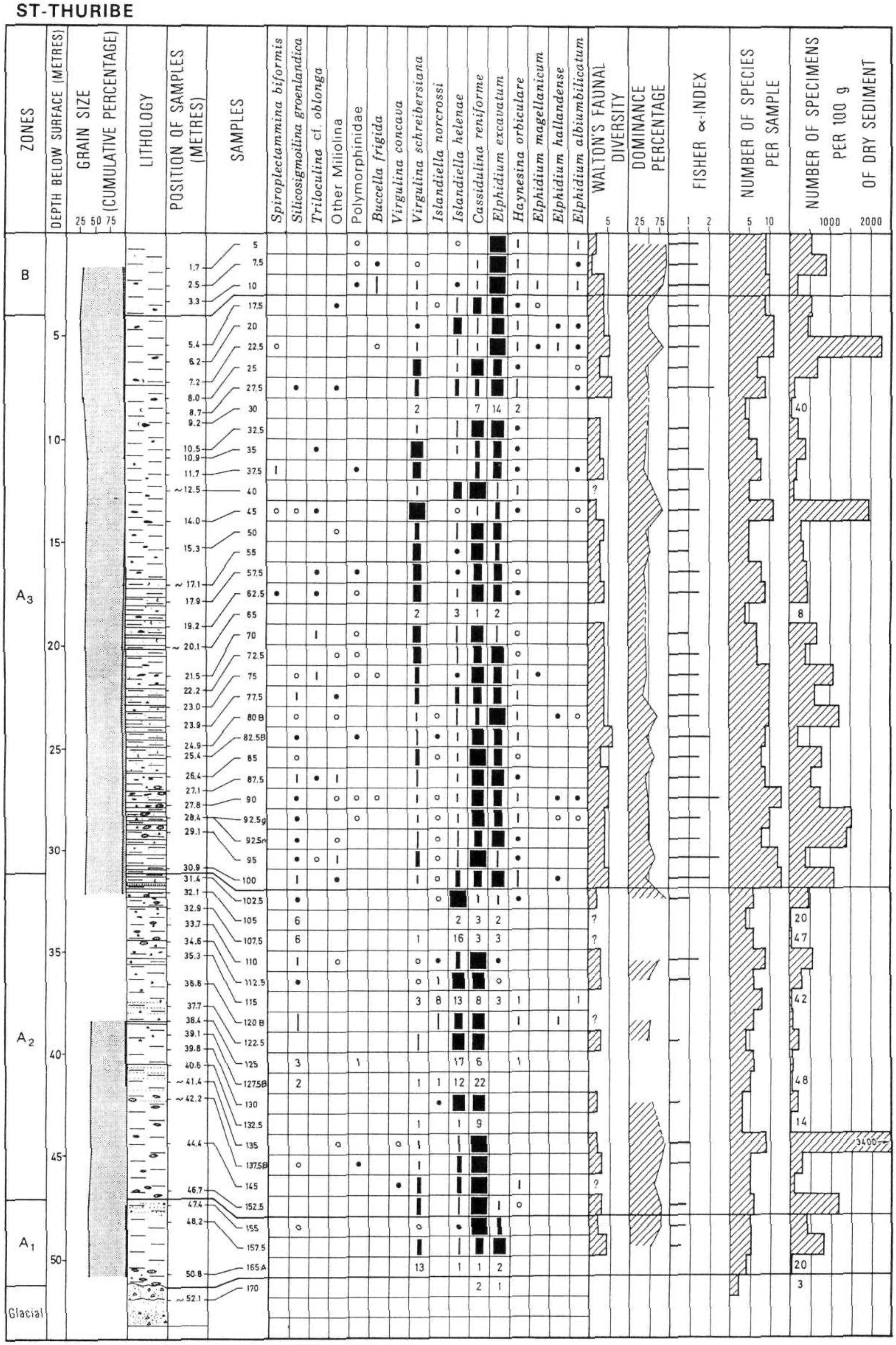


FIGURE 7. Distribution chart for the borehole at St-Thuribe. *Diagramme de distribution du forage de Saint-Thuribe.*

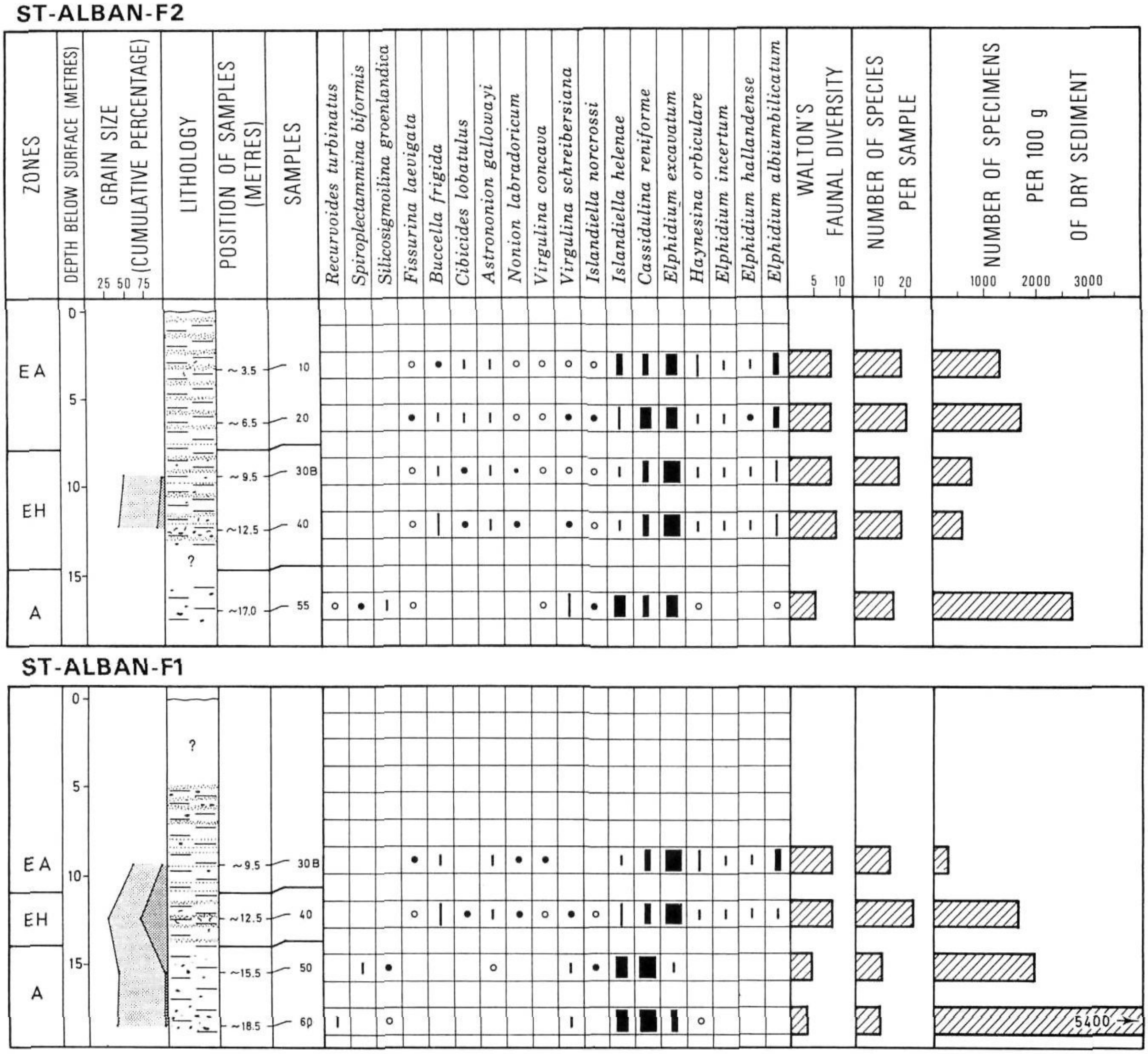


FIGURE 8. Distribution charts for the boreholes at St-Alban. *Diagramme de distribution des forages de Saint-Alban.*

34 m above the base of the section but did not intend to include extreme prodeltaic facies under the concept of prodelta. Strata between 9 and 31 m can be considered deltaic if a broader concept of prodelta is used (Occhietti, pers. comm.). On that basis, the succession can be compared to other deltaic formations such as those at St-Barnabé-Nord and St-Ambroise-de-Kildare. In contrast to those two localities, moderately rich assemblages unquestionably belonging to zone B are found above the base of the prodelta. This could mean that the Ste-Anne delta developed later than, for instance, the Trois-Rivières delta, a view implying that the A to B transition took place at the same time throughout the basin. On the other hand, one may assume that the contiguous mass of sediment making up zone B in the central Champlain Sea does not extend as far east as the Rivière Ste-Anne site, because of saltwater influence from the Goldthwait Sea. Zone B at the present site would thus result from local dilution due to freshwater from the early Rivière Ste-Anne; its advent would thus be chronologically unrelated to the A-to-B transition further west. Support for this idea comes from the fact that this occurrence of zone B is at higher altitude than even the highest parts of the St-Alban boreholes (Table I). If zone B did not develop at the altitude of St-Alban (see argument above), it could even less appear at Rivière Ste-Anne, unless it resulted from a local freshwater inlet such as the early Rivière Ste-Anne.

Balanus hameri from sample G (zone A) has been dated at 10,600 ± 160 BP (GSC-2090) and *Macoma calcarea* from sample H (AB transition, nearly B) at 10,200 ± 90 BP (GSC-2150) by Occhietti (1976).

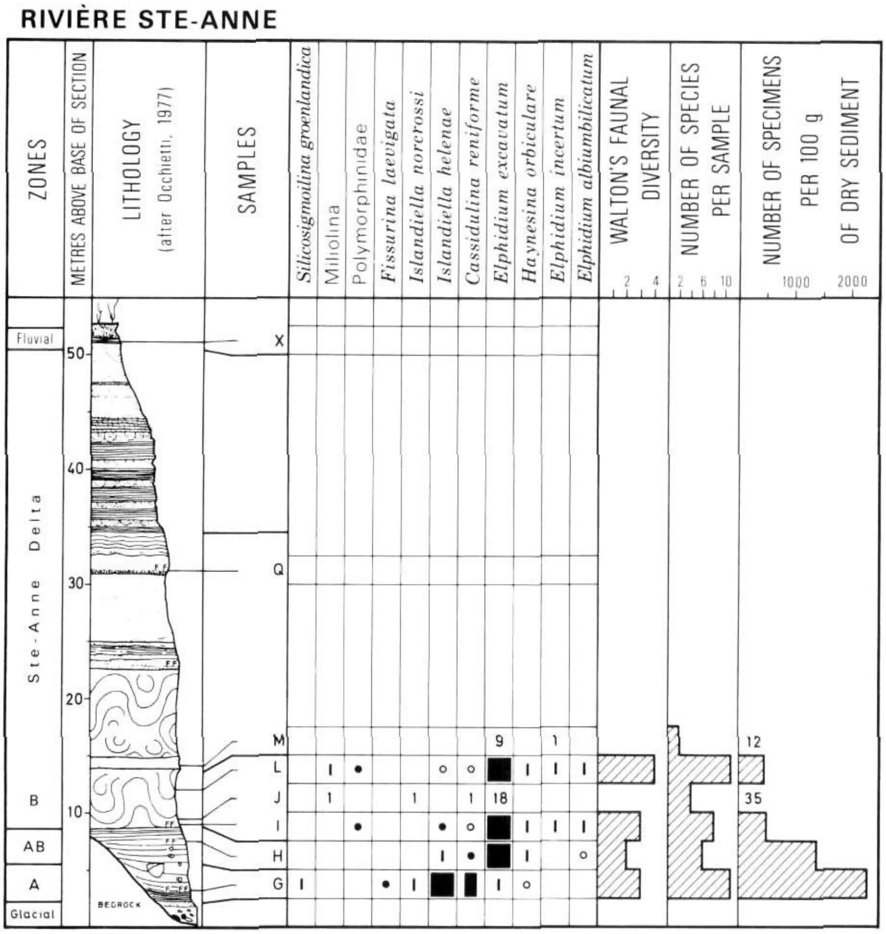


FIGURE 9. Distribution chart for the section along the shore of Rivière Ste-Anne near St-Alban.

Diagramme de distribution de la coupe de la rivière Sainte-Anne, près de Saint-Alban.

Neufchâtel

A foraminiferal assemblage whose composition is that of zone A (Fig. 10) occurs in a loose diamicton with abundant *Macoma calcarea* and *Hiatella arctica*. Marine diamictons elsewhere in the Champlain Sea are hard and compact and contain either *Balanus hameri* or *Portlandia arctica* or no macrofossils at all. The foraminiferal assemblage is much richer and diversified than in zone A in the St-Narcisse Moraine area and passes vertically into an even richer EH assemblage, without visible lithologic break or change in macrofauna.

Because of their faunal content, the present diamictons do not seem related to the Pointe St-Nicolas readvance. Zone EH at Neufchâtel is the most diverse assemblage (40 species) the present author ever found in the Champlain Sea. It contains forms that are absent or dwarf elsewhere in the basin with the exception of St-Nicolas: *Quinqueloculina frigida, Scutuloris tegminis, Elphidiella arctica, Rosalina globularis, Robertina arctica, Nonionella auricula*. Similar faunas have been observed by the author in stony clays of the Rivière-du-Loup area, approximately 200 km NE of Québec (two of these assemblages have been reported by Lortie and Guilbault, 1984, as samples 24 and 47b). One could say that the Neufchâtel assemblages belong more to the Goldthwait Sea than to the Champlain Sea. They may be classified as A or EH through a blunt application of the definition of these zones but this is an artificial conclusion as they should rather be classified within an eventual western Goldthwait Sea foraminiferal framework. The high diversities suggest these diamictons were formed under quite different and more open marine conditions than other diamictons discussed in this paper.

St-Nicolas

This paper reports the analysis of two series of samples from the classic St-Nicolas sand pit (Fig. 11) (Gadd *et al.*, 1972). One series (StN) was collected by the present author and the other by Serge Occhietti (StNO-792). Both sets of samples cover the same exposure but have been kept apart in the distribution chart. Samples 1B and 1C of Occhietti correspond approximately to samples 25 to 28 of the author.

As St-Nicolas is within the "Champlain I" area of Parent and Occhietti (1988), the pre-A phase here may not correlate with the marine pre-A of the rest of the basin. Zone A at St-Nicolas shows the highest diversities for that zone in the whole Champlain Sea and could have existed under salinities of 30 ‰ or more. Parent and Occhietti (1988) consider the cross-bedded sands as deposited by tidal currents. They contain a diverse assemblage of deeply abraded foraminiferal tests, probably reworked from an earlier marine deposit, along with the rich macrofossil content. The most frequent foraminifer is *Islandiella helenae*: this is probably the result of

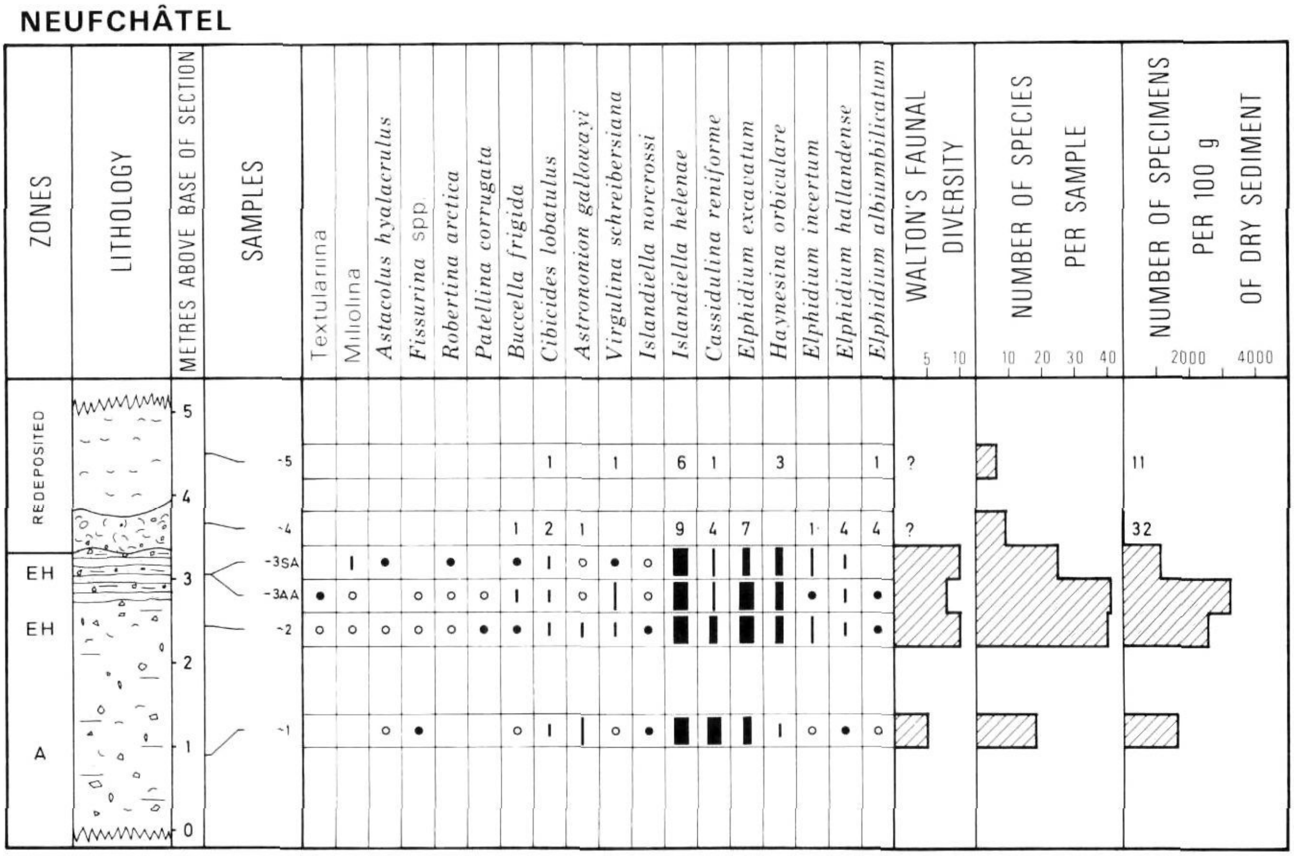


FIGURE 10. Distribution chart for the section at Neufchâtel, a suburb of Québec City.

Diagramme de distribution de la coupe de Neufchâtel, en banlieue de Québec.

the greater mechanical resistance of that species due to its thick umbonal boss. A minor component of the sand fauna is *Elphidium albiumbilicatum*; it is sufficiently frequent and the specimens are well-enough developed to indicate that zone EA assemblages were already living in the St-Nicolas area. The presence of pelecypod shell molds, some of them in living position, shows that marine conditions persisted up to the time of deposition of the upper silt unit. The radiocarbon dating on zone A reported in Table V is from section StNO-792. Both other dates are on shells from the overlying (intertidal) sand: UQ-64 from section StNO-792, the other from elsewhere in the pit.

Pointe St-Nicolas

The present series of samples was collected by the author at the Pointe St-Nicolas gravel pit reported on by LaSalle (1987), except for the two samples of section 791.52 which were collected by Serge Occhietti in an other part of the same pit (Fig. 12). Sieving was done with a 63 μm sieve. Neither the base of the marine succession nor the pre-A interval could be seen at section 1, but it is unlikely that the reported section covers less than two thirds of the marine strata deposited at the site. Zone A occurs in a compact diamicton, as compact as at Marchand. Walton's faunal diversities are higher than at Marchand and not much lower than at St-Nicolas. The diamicton fauna at Neufchâtel is much richer in terms of number of individuals and shows similarities with zone EH.

LaSalle *et al.* (1977) suggested the Pointe St-Nicolas diamicton could represent a glacial readvance from the St-Narcisse position. Parent and Occhietti (1988) described the same unit as a "deep-water reworked sediment", in other words a sediment deposited in deep water and reworked, in deep water, by bottom currents (pers. comm. from both M. Parent and S. Occhietti). The higher Walton diversities and the relatively high frequencies of *Astrononion gallowayi* and *Cibicides lobatulus* make the present assemblages more similar to those of St-Nicolas than to those of the St-Narcisse region. In consequence, even though the sediment was originally brought in by ice-rafting, the assemblage is probably *in situ* and represents rather favourable near-normal marine conditions. The possibility that it has been transported in by ice-rafting, along with the sediment, cannot be excluded, but one would have to answer the question of where it has been transported from.

The main differences between zone A at St-Nicolas and at Pointe St-Nicolas are the abundance of *Virgulina schreibersiana* and the smaller foraminiferal numbers at the second locality. The lower foraminiferal numbers may result from a higher sedimentation rate and the higher percentages of *V. schreibersiana* could result from the use of a smaller screen size at the present locality, in addition to possible *post-mortem* transport.

St-Antoine-de-Tilly

This locality was first reported on by LaSalle *et al.* (1977). It is a complex glacial-marine section, approximately one metre high and a few metres wide. The sediments range from pebbly clay or silt to till-like diamicton; the macrofossils are *Portlandia arctica* and *Balanus* sp. In a nearby ditch, LaSalle *et al.* (1977) observed probable varves underlying these glacial-marine sediments.

The low-diversity zone A assemblages are clearly different from those of Pointe St-Nicolas, St-Nicolas or Neufchâtel and seem to reflect locally less favourable living conditions. Possible interpretations include the following: 1) the foraminifera are not *in situ* but reworked along with the sediment from a low-diversity zone A area such as the St-Narcisse region, 2) the foraminifera are *in situ* in a sediment transported by ice-rafting and deposited possibly during the Pointe St-Nicolas readvance. The presence of an ice front in the

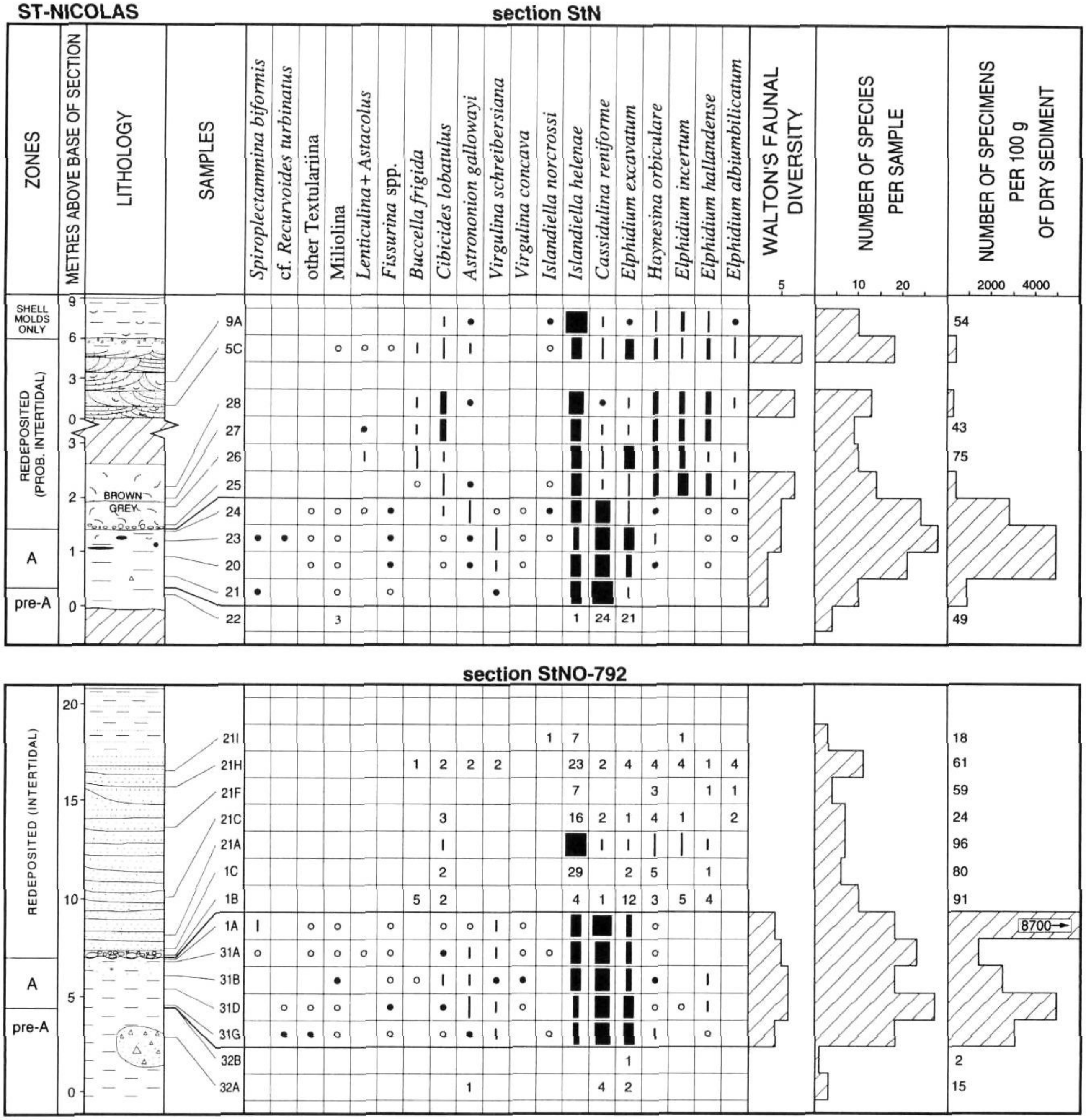


FIGURE 11. Distribution charts for the sand pit at St-Nicolas. The lithologic column for StNO-792 is from Parent and Occhietti (1988).

Diagramme de distribution de la sablière de Saint-Nicolas. La colonne lithologique StNO-792 est empruntée à Parent et Occhietti (1988).

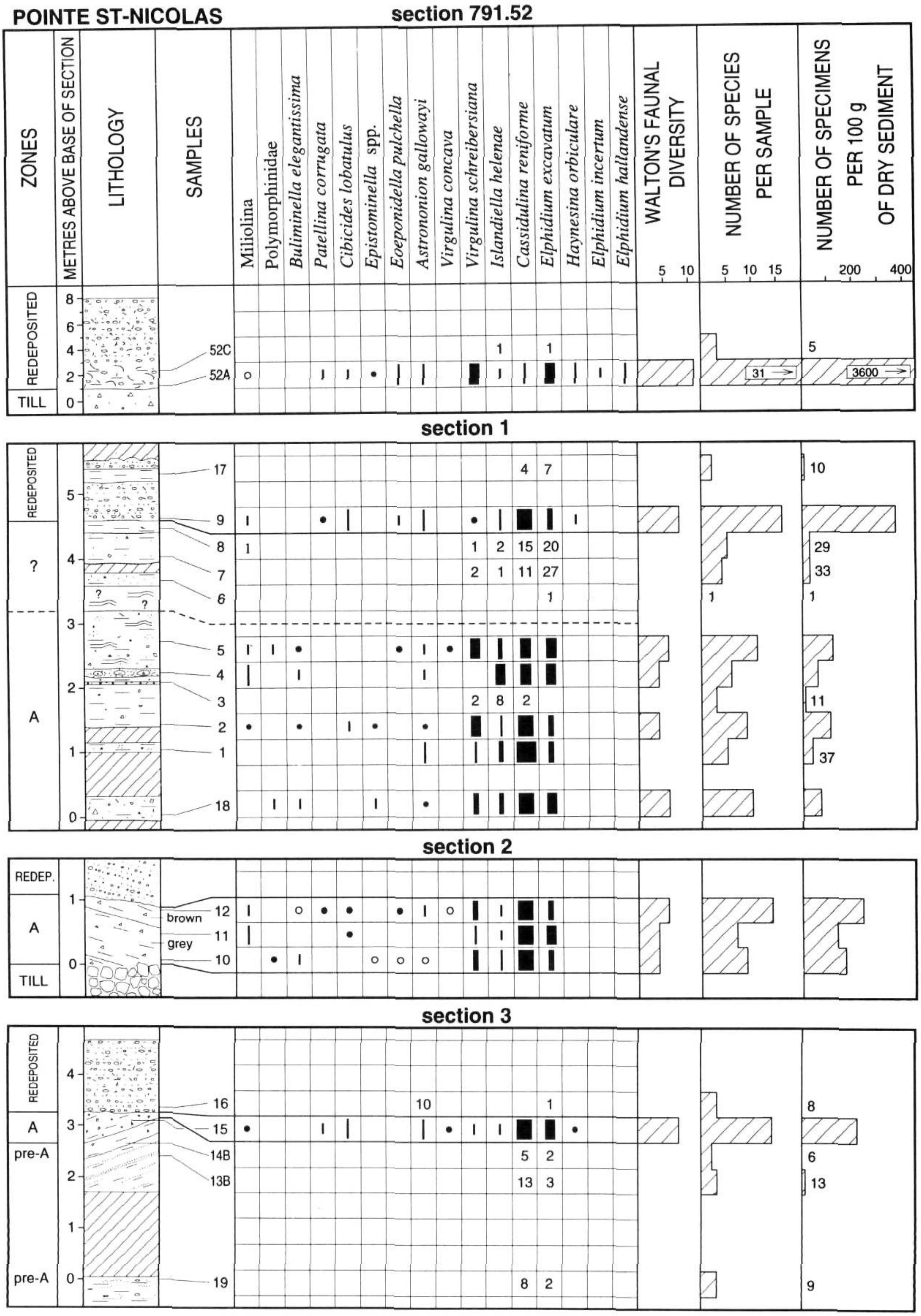


FIGURE 12. Distribution chart for the sections of Pointe St-Nicolas.

Diagramme de distribution des coupes de la pointe Saint-Nicolas.

neighbourhood would explain the low diversities. The second alternative appears natural but the first cannot be excluded.

Bourret

The samples reported here were collected at the "Bourret (2)" section of LaSalle (1989, p. 38). Two samples were collected in the gray calcareous compact diamicton containing *Balanus hameri*; a third sample was collected in the overlying loose sand with *Mya arenaria* in living position. One of the diamicton samples was completely barren while the other yielded a large number of well-preserved tests representing a zone A assemblage with low to medium faunal diversity. Diversities resemble more those from the St-Narcisse area than from St-Nicolas. LaSalle (1989) believes this deposit is glacial resulting probably from grounded ice associated with the St-Nicolas readvance. The assemblage indicates the existence, at the place where it lived, of St-Narcisse-like conditions (near-ice, probably less saline). The good preservation of the foraminifera and of the ostracodes does not suggest long distance transport under grounded ice; the absence of shallow water forms does not suggest transport either (nothing exotic to zone A). Therefore, the St-Antoine-de-Tilly interpretation applies here too: probably *in situ* near an ice-front, although the ice-rafting hypothesis cannot be definitely rejected.

The loose sand contains the most easterly EA assemblage observed until now. As at St-Alban and Rivière à la Fourche, its faunal diversity is quite high (number of species: 17, Walton's faunal diversity: 9). It was accompanied by *Mya arenaria* in living position.

Other localities

At St-Léon-le-Grand, 2 samples with zone C assemblages have been collected in 2 m of stratified clay.

At Kingsey Falls, 3 samples were collected in a freshly cut roadside ditch, within a few metres of one another. The stratigraphic relations between them is not clear. The object of this sampling was to find, if not the highest occurrence of zone A, at least the highest occurrence of *Islandiella helenae*. Two samples belonged to zone B and one was transitional between A and B.

At Mercure, one sample collected in a 1-metre fossiliferous section in a roadside ditch yielded an EH assemblage.

The 43-m deep borehole at Charette contained very little fauna, a good part of which was etched. Only the lowermost sample produced more than 50 specimens and could be reliably attributed to zone A. Three others are labeled "A?" on the grounds that most of the specimens registered were *Islandiella helenae*.

PALEOENVIRONMENTAL DISCUSSION

ZONE BY ZONE INTERPRETATION

Pre-A interval

The near-absence of freshwater forms and the presence of hyposaline assemblages underneath zone A imply that the retreating ice sheet was replaced at once by brackish water throughout most of the eastern Champlain Sea. Lack of information between Drummondville and St-Antoine-de-Tilly makes this conclusion less certain for the south shore but does not change the overall impression that the pre-A interval is essentially marine. This is comparable to the results obtained by Rodrigues (1992) for the eastern Champlain Sea and contrasts sharply with the situation in the western and central regions where pre-A intervals are indicative of either fully lacustrine conditions such as at Mer Bleue (Guilbault, 1989), Casselman (Rodrigues *et al.*, 1987), Sparrowhawk Point (Rodrigues, 1987), or more commonly of partly lacustrine settings demonstrated by mixed *Candona*-foraminifer faunas (Guilbault, 1989; Hunt and Rathburn, 1988; Rodrigues, various publications on eastern Ontario localities). As one goes further inland there is a progressively greater proportion of foraminifer-free *Candona* assemblages. Thus, pre-A deposits, if they were synchronous throughout the basin, would show an east-west salinity gradient. Unfortunately, there is no way of establishing synchroneity of all pre-A intervals throughout the basin. The present author tends to follow the argument of Rodrigues (1988) according to whom *Candona* could not have come to the basin otherwise than from inland sources (they could not survive marine water) which implies deglaciation and the presence of a lake in the southern parts of the basin, in opposition to the notion that the early Champlain Sea opened through quick calving and was entirely surrounded by glaciers (Thomas, 1977). The existence of a lake in turn implies that ice blocked the Québec City strait. According to Parent and Occhietti (1988), that ice block extended as far west as the north-central Champlain Sea (St-Maurice lobe of Parent and Occhietti, 1988, Fig. 9). It is only when it melted away that the pre-A phase of the eastern Champlain Sea began. Therefore, *some* of the western Champlain Sea's pre-A must be older than its eastern equivalent. One would tend to believe that the fully lacustrine pre-A of the western region occurs systematically beneath the brackish pre-A as reported by Rodrigues *et al.* (1987) at Casselman. However, as reported by Guilbault (1989) at Île Perrot, *Candona*-only assemblages can occur above *Candona*-foraminifera assemblages. The latter cannot precede the initial breakup of the eastern ice block. Thus, some western *Candona*-only assemblages must be posterior to the melting of the ice block. The complexity of the pre-A interval is well illustrated by the results of Hunt and Rathburn (1988) who report, from Lake Champlain cores, a thick interval (assemblages C_1 and C_2) correlatable with the present pre-A but whose fauna, although scarce, suggests either high salinity (*Islandiella* spp.) or freshwater (*Candona*); furthermore, the earlier assemblage (C_2) contains no freshwater ostracodes while the following one (C_1) does.

It is probable that the pre-A interval, after the opening of the Québec City inlet, was predominantly a time of brackish to fresh water, where hyposalinity was maintained by a much greater influx of freshwater over marine water. East of St-Ambroise-de-Kildare, some salinity remained at all times whereas west of that site, saltwater incursions must have been sporadic, interspersed with freshwater intervals. Occasionally, salinity may have been high. This interpretation is compatible with the scenario of Parent and Occhietti (1988) according to whom the area between Québec City and Lake

St. Lawrence (Upham, 1895, reinstated by Rodrigues, 1992; Lake Candona of Parent and Occhietti, 1988) was abruptly deglaciated through calving. That area roughly coincides with the brackish, *Cassidulina reniforme* dominated pre-A. The mixed foraminifer-*Candona* assemblages of the central and western Champlain Sea remain unexplained however. Nonmarine ostracodes of cold or temperate climates are known to be intolerant of even low-salinity marine (chloride rich) waters (Forester and Brouwers, 1985) and their close association with zone A foraminifera, as in Hunt, and Rathburn's (1988) C_1, must have required peculiar hydrographic conditions. Hunt and Rathburn (1988) suggested three explanations for this: (1) sediment mixing, (2) rapidly fluctuating salinity conditions and (3) very low salinities that would be compatible with all species present. The present author does not believe in (1) because the extreme fragility of *Candona* makes *postmortem* transport without damage unlikely, neither does he believe in (3) because the salinity requirements of *Candona* and *Islandiella* spp. are incompatible. There remains rapidly fluctuating salinities, which could bring, in succession and on a seasonal basis, conditions suitable for *Islandiella* and then, for *Candona*. An explanation could be that the strait at Québec City was not broadly open and that ice movement closed it for more or less long intervals. At such an early phase of Champlain Sea development, relative sea level must have been high and had the Québec City strait been wide open, salinity at the site of Montréal would have been permanently high. It is an unavoidable conclusion that the strait must have been partially obstructed and the obstructing agent that most naturally comes to mind is an ice lobe. Variations in the size of the obstructing ice mass may have been the cause of the recorded changes in biofacies within the pre-A interval, but in order to explain seasonal saltwater incursions, a wedge type of estuarine circulation (such as proposed by Rodrigues, 1992) appears more appropriate. If we assume the Québec City strait to be for the most part obstructed, the appearance of a saltwater wedge appears unavoidable. That wedge could move over considerable distance from season to season, bringing a sharp change in salinity for any site along its path. Areas beyond the reach of the wedge would be permanently fresh.

Zone A

Zone A, representing conditions closest to normal marine, is the most widespread zone in the eastern Champlain Sea (Table II and III and Fig. 2). The only species present in significant numbers in zone A samples collected near the St-Narcisse ice front are indicator species, that is, *Cassidulina reniforme, Islandiella helenae* (rarely *Islandiella norcrossi*) and *Elphidium excavatum* plus, locally, *Virgulina schreibersiana*. The number of species per sample is usually less than 10. At far-from-ice localities that number is usually above 10 and closer to 20 or more. In addition to the indicator species listed above, a sizable number of *Haynesina orbiculare, Astrononion gallowayi* and *Virgulina concava* are observed plus, mostly around Québec City, *Cibicides lobatulus*. There is also a large number of minor species which are rare or absent in near-ice position. The only minor form that seems more frequent near the ice front is *Silicosigmoilina groenlandica*.

The number of species is expectably lower near the ice front because the assemblages from that area contain much lower foraminifer numbers. In order to have a more representative expression of diversity, one must turn to diversity indices. Fisher α-index values (Fig. 13) vary considerably in zone A but samples collected near the St-Narcisse Moraine show on the average lower α-index values than others collected far from it. The "far from ice" material includes some diamicton samples from Pointe St-Nicolas, Bourret and St-Antoine-de-Tilly that may have been deposited near ice fronts other than the St-Narcisse Moraine. These samples are few (12), some have high, others low diversity and if they were removed from the diagrams, the general trend would not be changed. This trend suggests that during zone A, a north-south environmental gradient existed in the sense that living conditions for foraminifera were less favourable close to the ice front than a few tens of kilometres offshore or even than some more westerly localities.

Figure 14 shows Walton's faunal diversity indexes for the various sites positioned according to their distance west from Québec City. The values given are averages for a given zone at a given site. Five trendlines are deduced from linking the points on the diagram. Trendlines I and III both represent deep offshore environments ("far from ice") and one can think of joining them by interpolation. The resulting trendline would show a general westward decrease in diversity in addition to passing above trendline IV. This last trendline regroups sites situated close to the St-Narcisse ice front ("near-ice" position). Thus, in addition to a westward diversity decrease, Walton's faunal diversities show the same near-ice diversity decrease as the Fisher α-index. The low diversities of trendline V indicate less favourable conditions for these two sites, either due to an earlier ice readvance, or because that material was redeposited from the area of trendline IV.

The higher diversities of trendline II seem related to reduced water depth. All three sections are either at higher altitude or at sites that formed shoals in the Champlain Sea. It is remarkable that, contrary to a "normal" open shelf situation, diversities in deeper parts of the Champlain Sea are less than in shallower waters. For example, diversities in zone EH are higher than in trendline II; also, zone EA is more diverse than zone B. As the basin was far from the open ocean and connected to it only through a narrow channel, it is difficult to apply to it the same rules as to an open shelf where water masses and their nutrients can move freely. We must assume that shallow waters were less saline than deep waters: this is a hydrographic necessity. Low dissolved oxygen concentration is not a likely cause of lower bottom diversity as there is no sill at the basin's entrance. The strong seasonal water stratification, on the other hand, would have favoured low oxygen content especially with the large volumes of freshwater flowing into the basin in summer in late Champlain Sea time. However, this would not apply to the period of deposition of zone A when relative sea level was higher and circulation easier. The shallow waters may nevertheless have been comparatively favourable environments

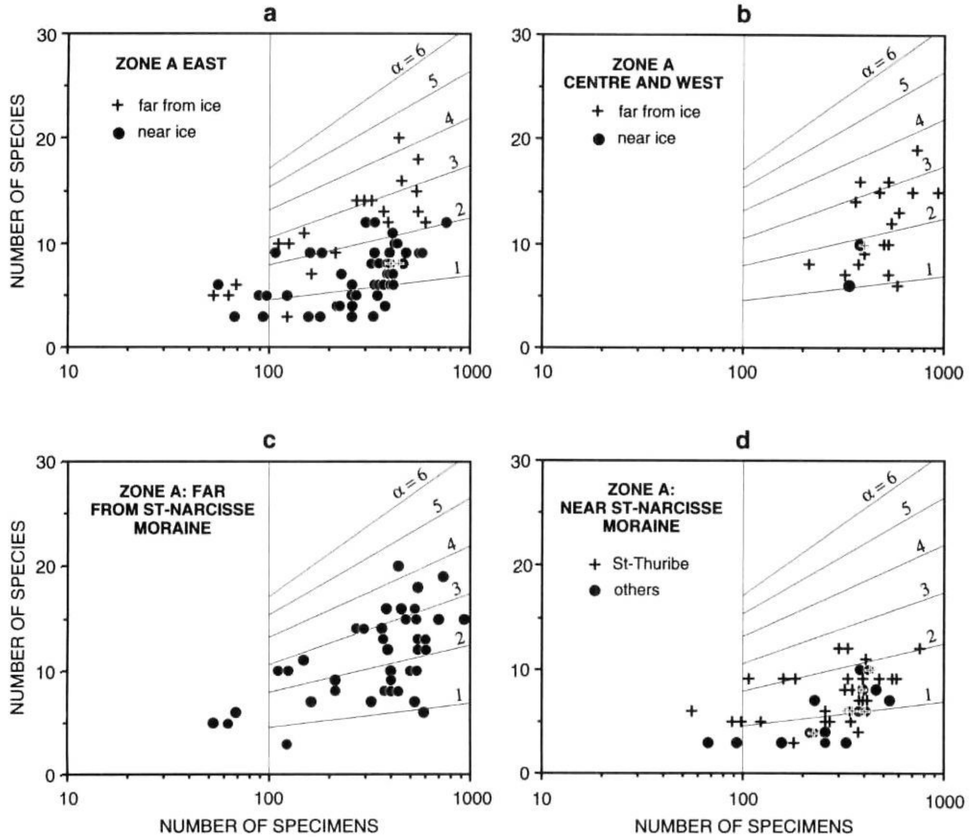


FIGURE 13. Fisher α-index diagrams for zone A for a) the eastern Champlain Sea area, b) the western and central Champlain Sea area (studied by Guilbault, 1989), c) localities far from the St-Narcisse ice front, east, centre and west included and d) all near-St-Narcisse localities. St-Thuribe is represented differently because of the great number of samples from that site.

Diagrammes de Fisher α-index pour la zone A dans a) la partie orientale du bassin de la Mer de Champlain, b) les parties centrale et occidentale du bassin de la Mer de Champlain (étudiées par Guilbault, 1989), c) les sites éloignés du front glaciaire de St-Narcisse, régions est, centre et ouest confondues et d) les sites proches de la Moraine de Saint-Narcisse. Saint-Thuribe est représentée différemment à cause du grand nombre d'échantillons provenant de ce site.

especially in terms of food supply because of the combined effect of wind-induced nearshore upwelling, higher summer temperatures and sunlight. De Vernal *et al.* (1989) reported a large influx of dinoflagellate cysts in the shallow, late Champlain Sea at St-Césaire. They conclude to a high productivity and believe this is the result of long summers during that phase; during the main saline phase however, productivity appears to have been much lower. Nevertheless, high productivity does not necessarily mean high diversity. The high diversities recorded in the shallower parts of zone A and in zone EH are probably the consequence of the other factors: summer temperature and sunlight which made these environments attractive to a greater number of species.

The moderate east-to-west decline in Walton's faunal diversity or the strong contrast in both Walton's faunal diversity and α-index between zones A and B (Fig. 15a and b) may intuitively be correlated with differences in salinity. On the other hand, the cause for the lower diversities near the ice front is not obvious. The reasons for this may include reduced or variable salinity although the presence of high percentages of *Islandiella helenae* excludes salinities lower than approximately 25 ‰. This is not surprising as meltwater flowing out of the glacier must have spread at the surface while bottom waters remained quite saline. However, the difference between 25 ‰ and the 30 to 32 ‰ values such as probably existed elsewhere in the eastern Champlain Sea would be sufficient to significantly affect faunal composition.

Another factor that could have caused unfavourable conditions is the high sedimentation rate or the high turbidity related to it: the relatively great thickness of zone A near the St-Narcisse ice front (Fig. 2) could be interpreted as resulting from the ice front being a source of sediment at the time when zone A assemblages were living there. Phases of fast sedimentation would conceivably have buried assemblages and forced recolonization. As a consequence, only quick colonizers or efficient burrowers could have survived in significant numbers.

Diamictons probably correlative with those at St-Étienne-des-Grès and Marchand have been dated at sites not investigated in this study and yielded ages of 11,100 ± 90 BP (GSC-2045) and 11,300 ± 160 BP (GSC-1729) (both by Occhietti, 1980); they underlie the material of the St-Narcisse Moraine (*ibid.*). Considering that the few radiometric ages on zone A basinwide fall between 10.6 and 11.3 ka BP (Table V) and that the age for the buildup of the Moraine (see Geological Setting) falls within that range, it is reasonable to assume that zone A and the formation of the St-Narcisse Moraine are at least in part synchronous. It is probable that the underlying diamictons fit within the same interval.

At Pointe St-Nicolas, zone A contains an exceptionally high percentage of *Astrononion gallowayi* (up to 8.9%) and occasionally of *Cibicides lobatulus* (up to 6.7%) in the 11.2 to 11.3 ka BP-year-old *Balanus hameri*-bearing stony clays. At St-Nicolas, *A. gallowayi* reaches 7.1% of one of the samples (no. 24) of zone A. These samples have *C. reniforme* and *I. helenae* as predominant species and according to the methodology used here, should be included in zone A. For two of the Pointe St-Nicolas samples however (12 and 15), where the percentage of *A. gallowayi* is equal to or greater than that of *I. helenae*, incorporation into zone A is not obvious. The

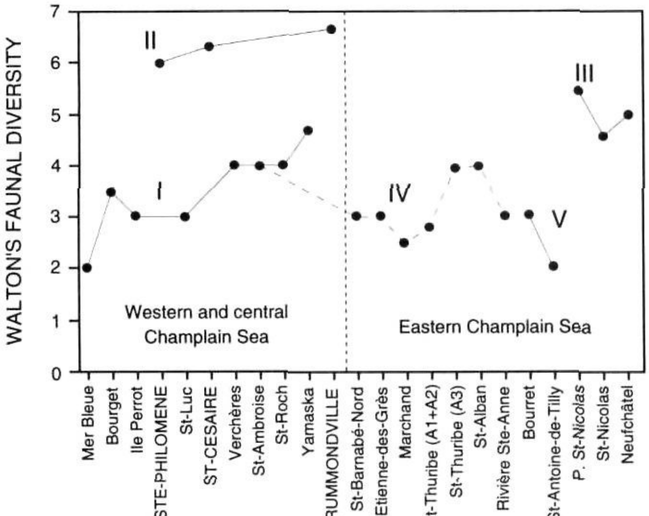


FIGURE 14. Walton faunal diversities for zone A. The diversity values are averages of all zone A samples at a given site. Data points have been joined according to their region of origin. Trendline I includes deep water, low altitude occurrences in the central and western basin while trendline III regroups similar sites in the Québec City area. Trendline II (locality names in capital letters) represents shallower water (but deeper than zone EH). Trendline IV (dashed lines to distinguish it from trendline I) includes all deep water localities near the St-Narcisse ice front while trendline V occurrences are associated with ice-rafted sediments situated far from that ice front. St-Ambroise (de Kildare) may be considered the "near-ice" as well as the "far from ice"; therefore it is connected to two different trendlines.

Diversités fauniques de Walton en zone A, comparaison entre les régions est et ouest. Les valeurs de diversité illustrées sont les moyennes de tous les échantillons de zone A à un site donné. Les points ont été reliés d'après leur région d'origine. La ligne I inclut les sites d'eau profonde et de basse altitude du bassin central et occidental tandis que la ligne III regroupe des sites similaires dans la région de Québec. La ligne II (noms en majuscules) représente des eaux moins profondes, mais quand même plus profondes que la zone EH. La ligne IV (en tireté pour la distinguer de la ligne I) inclut toutes les sites d'eau profonde proches du front glaciaire de Saint-Narcisse, tandis que les échantillons de la ligne V sont associés à des sédiments de délestage bien qu'éloignés de ce front glaciaire. Saint-Ambroise peut tout aussi bien être considérée « proche » que « loin » du glacier et de ce fait est reliée à deux lignes différentes.

Pointe St-Nicolas and St-Nicolas material is interesting to compare with some western Champlain Sea results of Rodrigues *et al.* (1987) and Rodrigues (1988). At Watterson Corners near Ottawa, Rodrigues (1988) dated *Balanus hameri* plates at 11,200 ± 110 BP (GSC-4070 OF, outer fraction) and 11,300 ± 110 BP (GSC-4070 IF, inner fraction). The associated foraminiferal assemblage is characterized by *Astrononion gallowayi, Cassidulina reniforme* and *Cibicides lobatulus* (foraminiferal association FA3); *Islandiella helenae* is not reported. Rodrigues (1988) reports a similar assemblage from Rivière-Beaudette (SW of Montréal) with a ^{14}C age of 11,000 ± 90 BP (GSC-3702). He interprets his FA3 as indicating high salinity, the same as for the *Islandiella helenae* assemblage (his FA1, the present zone A). The FA3 assemblage should not be included in zone A because of the difference in faunal composition, but it could nevertheless indicate high salinities. Rodrigues *et al.* (1987) report from Navan, near Ottawa, an 11,000 ± 90 BP year old (GSC-3706), *Balanus hameri*-rich assemblage with a microfauna intermediate between the FA3 of Rodrigues (1988) and the present zone A (both *I. helenae* and *A. gallowayi* frequent): the Navan sample may be compared with the anomalous Pointe St-Nicolas samples 12 and 15 mentioned above. The present writer prefers to include these "intermediate" samples in zone A as long as no new zone anterior to A is created.

Cassidulina reniforme is not an indicator of high salinity, and *C. lobatulus* is less determined in its distribution by salinity than by the fact it needs a hard surface on which to cling: its presence is expectable considering these samples are all more or less stony. The distribution of *Astrononion gallowayi* may be related to salinity. A search of the literature concerning modern occurrences of that species (31 references consulted, *A. gallowayi* reported present in 26) showed that it is not as freshwater-tolerant as, for example, *Elphidium excavatum*. It is absent in estuaries, present in small numbers (less than approximately 3%) in shallow bays (Scott *et al.*, 1980, for Chezzetcook Inlet) but will reach higher relative abundances only in open shelf or upper slope situations. It is thus suggestive of near-normal marine salinity. The presence of an 11,300 year old *Astrononion gallowayi* assemblage (FA3 of Rodrigues, 1988) in the Ottawa Valley suggests that zone A was preceded by another high salinity phase. Its limited occurrence could mean it was very short-lived or that it was a period of slow sedimentation.

Save for the absence of *Melonis zaandamae*, there is a resemblance between Watterson Comers and the upper part of interval C of Vilks *et al.* (1990) in the Gulf of St. Lawrence, which in turn represents the late part of a high salinity phase in that region. Similarly, the present zone A is very close to interval B of Vilks *et al.* (1990). Comparable conditions may have developed in both areas, both being physically connected. The age reported by Vilks *et al.* (1990) for the bottom of interval B (11,480 ± 290 BP, TO-1848) would mean, if errors are disregarded, that the lower salinity phase began in the Gulf earlier than in the Champlain Sea, which is difficult to imagine. More attention will have to be given to this problem.

As to the samples of St-Nicolas, Pointe St-Nicolas and Navan, which contain a fair proportion of *Islandiella helenae*, they may represent intermediate conditions between the late interval C and interval B of Vilks *et al.* (1990). The ^{14}C ages of both types of assemblages (with and without *I. helenae*) are overlapping: 11.0 to 11.3 ka BP. Both may indeed have been synchronous. There is therefore a potential for defining a new high salinity zone in the Champlain Sea in pre-A time, provided that more occurrences of it are discovered.

In the easternmost Champlain Sea, Québec City area included, zone A began no later than 11.34 ka BP and lasted until after 10.6, possibly up to near 10.2 ka BP (Table V). In the Ottawa Valley it may have lasted barely from 11 to 10.8 ka BP (see chronology in Guilbault, 1989). The existence of zone A as early as 11.34 ka BP in the vicinity of Québec City (Pointe St-Nicolas) brings the question of why these high salinity faunas did not fully occupy the central and western Champlain Sea at a time when the basin was at its deepest and the strait at Québec City presumably at its broadest (the

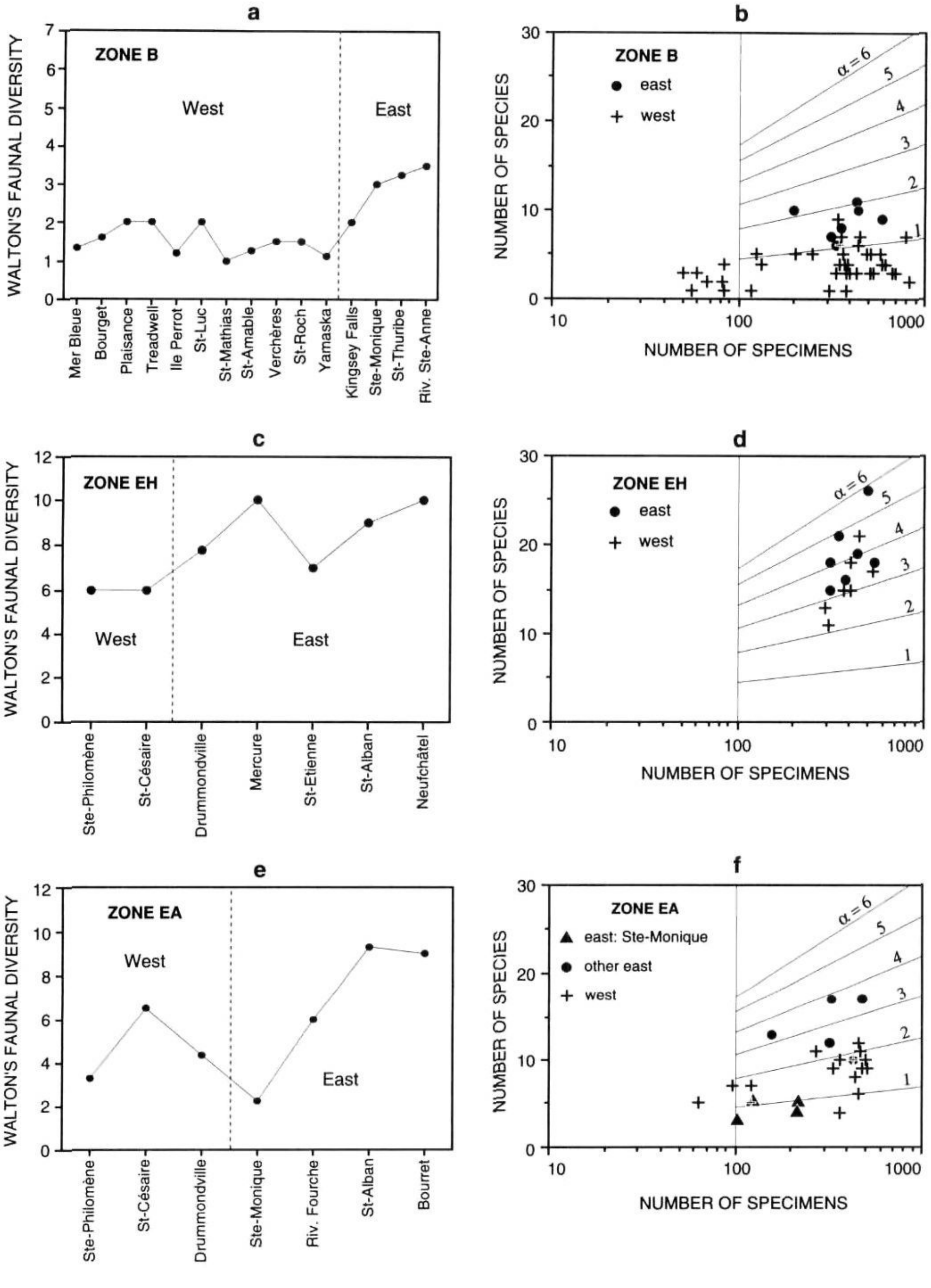


FIGURE 15. Walton faunal diversities and Fisher α-index diagrams for zones B, EH and EA, eastern and western areas included. "West" is meant to include the central Champlain Sea area of Guilbault (1989). Walton faunal diversity graphs are conceived the same way as Figure 14.

Diagrammes de diversité faunique de Walton et de Fisher α-index pour les zones B, EH et EA, régions est et ouest confondues. Le terme «west» comprend la partie centrale de la Mer de Champlain d'après Guilbault (1989). Les diagrammes de diversité faunique de Walton sont conçus de la même manière qu'à la figure 14.

Watterson Corners fauna may be regarded as exceptional, representing a short duration event). The probable answer has already been put forward in the discussion of the pre-A phase: the (recurring?) glacial readvance proposed by LaSalle *et al.* (1977) could have had an important restricting effect regardless of whether the ice was fully or just partially grounded. Another possibility is that ice sheet melting was taking place at a faster rate in pre-A and early A times, limiting the access of marine water into the basin. As discussed later, it is unlikely that an increase in discharge could affect significantly the salinities in the deep parts of the basin.

Zone B

Zone B is much less well represented in the eastern Champlain Sea than in the central and western parts of the basin. Also, the few occurrences are noticeably different from those in the west. The dominance of *Elphidium excavatum* is less strong and the diversity is higher (Table II and III). A plot of Walton's faunal diversity or of Fisher's α-index (Figs. 15a and b) for zone B shows a clear contrast between east and west. In zone B there seems to be a return to pre-A conditions in the sense that the low salinities observed over the whole basin are accompanied by a strong east-west salinity gradient. This is expectable due to the progressive restriction of the strait in the Québec City region. Zone B is the result of that gradual restriction and therefore should not occur eastward of a certain point. Its occurrence at the base of the delta at Rivière Ste-Anne may be a local occurrence of a B-type facies due to a local freshwater input: the early Rivière Ste-Anne. A similar explanation may apply to the St-Thuribe occurrence of zone B. On the other hand, at Ste-Monique-de-Nicolet, zone B is likely to be part of the large contiguous occurrence of the zone covering the central and western Champlain Sea. The case of Kingsey Falls is not conclusive. In summary, it may be that contiguous zone B does not extend much further east than Trois-Rivières.

Zone C

This is essentially a central Champlain Sea zone; within the eastern area, it occurs only at St-Léon-le-Grand west of Trois-Rivières. The presence of morphotype C specimens of *E. excavatum* at Ste-Monique-de-Nicolet suggests zone C may be present in deeper water sediments in the same area, but it probably does not extend east of Trois-Rivières. This agrees with the idea that zone C developed at a time when relative sea level was quite low and only the low-lying plain southwest of Trois-Rivières was submerged. There is not enough diversity in zone C to speculate on diversity variations.

Zones EH and EA

The shallow water zones show a westward decrease in diversity but the significance of the data is reduced because of the limited number of localities. For instance, Cronin (1976) has reported from eastern Ontario a very EH-like assemblage with at least 41 species. If that assemblage was plotted on the diagram of Figure 15c, the trend would probably become a slow westward decrease in diversity, as in the case of zone A; on the Fisher α-index diagam (Fig. 15d), it would probably be located within the present cloud of points. This indicates good circulation of saltwater at the time of zone EH.

In the case of zone EA (Figs. 15e and f) the trend is more evident if Ste-Monique-de-Nicolet is neglected. That occurrence of EA is transitional with the deep water sequence and in particular with the monospecific zone C; it comprises the four "east: Ste-Monique" samples on Figure 15f. As in the case of zone B, zone EA shows a stronger diversity gradient than zones representing periods of greater marine influence. Zone EA near Montréal probably coexisted with zones B and C whereas in the east, where zone B did not extend, it must have been the neighbour of the more saline late zone A and probably have been more saline itself.

It is remarkable that the EH-EA sequence remains recognizable throughout the Champlain Sea despite varying local conditions. Zone EA has been described from the central Champlain Sea by Guilbault (1989) as a low-diversity, low-salinity assemblage with abundant *Elphidium albiumbilicatum*, overlying zone EH. At St-Alban, Rivière à la Fourche and Bourret, zone EA is about as diverse as zone EH, suggesting comparable salinity conditions. Both zones can nevertheless be distinguished on the basis of their most important character, the relative frequency of *Elphidium hallandense* and *E. albiumbilicatum*. In consequence, there has to be factors other than salinity, areally more widespread, affecting the distribution of elphidiid species. Independently of diversity indices that can be hard to apply to very low diversity assemblages, it is clear that zone EA has a more diverse aspect than the contemporaneous late zone B and zone C. The latter show a very high abundance of one species whereas in zone EA there is a more "balanced" representation of three forms: *Elphidium excavatum, Haynesina orbiculare* and *E. albiumbilicatum*. This higher diversity — or lower dominance — is difficult to interpret as meaning more open marine conditions. In a given marine basin, the more saline and denser waters should be expected at the bottom and the less saline waters at the surface. This should hold even in the setting considered here where all waters are hyposaline. The reason for the higher diversity in zone EA could be that the shallow waters of the late Champlain Sea did reach a fairly high temperature during the summer as suggested by the extensive presence of the mollusk *Mya arenaria* which does not live today north of southernmost Labrador (Lubinsky, 1980). Cronin (1977) also found temperate ostracodes in some late Champlain Sea deposits. The warm summers coupled with upwelling may have generated high productivities in shallow waters; de Vernal *et al.* (1989) recognized this at St-Césaire where they observed high numbers of dinoflagellate cysts in the latest Champlain Sea sediments. The conclusion could be that the shallow late Champlain Sea was a more favourable environment, at least for some species, than the contemporaneous deep waters, the contrast being even more accentuated than in the previously discussed case of zones A and EH. The Champlain Sea distribution of *E. albiumbilicatum* agrees with the fact that the richest and most extensive modern occurrence of that species is in the shallow waters of the Baltic Sea (Lutze, 1965, 1974), a cold-temperate, hyposaline environment that is well supplied in organic matter, both terrestrial and marine.

STRATIGRAPHY-HYDROGRAPHY RELATIONSHIPS

The Champlain Sea west of Trois-Rivières at the time of zone A was probably not a saltwater-wedge type of estuary where the saltwater front moves back and forth with seasons over a large portion of the basin. The volume of the basin and the amount of freshwater flowing into it with all likelyhood did not allow this and furthermore, the zone A species could not have survived such a salinity regime. Wedge-type circulation must have been limited to areas close to freshwater inlets.

As relative sea level went down, the volume of the basin decreased as well as the saltwater influx, and one of two possible successions of events must have occurred. The first alternative is that the whole basin from Trois-Rivières westward became gradually very hyposaline at all depths (though less so at the bottom). This is suggested by the numerous stages of salinity decrease: AB, lower B, upper B (about lower B and upper B, see Guilbault, 1989, quoting ostracode data communicated by T.M. Cronin) and C which seem to imply smooth change. The other alternative is that a wedge-type estuarine circulation developed in the west where discharge from the Great Lakes was pouring in. That wedge would have shifted seasonally over a wider and wider area and eventually migrated eastward towards Québec City. The geographic distribution of zones at any given time could be related to the movements of the wedge. The area swept annually by the wedge could have been inhabited, for example, by zone B, or lower B, or lower B plus AB, or by any succession of faunal stages except A and post-C. It is not possible to tell which faunal stage or set of stages correspond to which hydrographic condition because of lack of really comparable modern equivalent and because other factors than hydrography (sedimentation, nutrient supply) may be also involved. This "migration" model leads to a time-transgressive distribution of zones (Fig. 16a) resulting from the progressively greater freshwater influence. The other alternative, where the whole basin becomes progressively brackish, would on the contrary lead to synchronous zonal boundaries (Fig. 16b). It is not possible to decide between both alternatives with the present data, but the matter could probably be settled with radiocarbon dating of widely spaced and well-sampled boreholes. Datings should concentrate on the top of zone A or the AB transition, as less saline facies might generate an error due to old carbonate.

Between Trois-Rivières and Québec City, there is a different succession where zone A lasts until decreasing sea level brings shallow water zones EH and EA. Locally, freshwater inlets generated B-like conditions especially on the north shore following the retreat of the ice from the St-Narcisse position. These occurrences of zone B (for instance at Rivière Ste-Anne) may not be connected with the main body of the zone located to the SW.

CORRELATION WITH THE GREAT LAKES AND THE NORTH ATLANTIC

The diversion of Lake Agassiz discharge has been proposed by Rooth (1982), supported by Broecker *et al.* (1989) and opposed by Fairbanks (1989) as a cause for the climatic deterioration in the North Atlantic region during Younger Dryas time through the formation of a brackish ocean-wide surface layer. That phenomenon would have lasted from 11 up till 10 ka BP (Broecker *et al.*, 1989). Lewis and Anderson (1989) propose a history of the glacial Great Lakes where Lake Agassiz waters drained eastward between 11 and 10.1 ka BP due to glacial retreat in the Lake Superior Basin; earlier, discharge took place toward the Mississippi. From 11 to 10.5 ka (Main Algonquin phase), these waters entered the Champlain Sea in the Upper St. Lawrence region whereas in the subsequent post-Algonquin phase (10.5 to 10.1 ka BP), they came through the newly cleared North Bay outlet into the Ottawa Valley. From 10.1 to 9.6 ka BP, Lake Agassiz water flowed southward into the Mississippi basin and consequently meltwater influx into the Champlain Sea was much reduced.

Such variations in the influx of freshwater may have affected Champlain Sea salinity. The chronologies given above however do not correlate with the succession found in the Champlain Sea benthos. In the western and central Champlain Sea, the transition to zone B takes place shortly after 10.8 ka BP (Guilbault, 1989). There is no evidence for a sharp and huge influx of freshwater at 11 to 10.8 ka BP which is the period of optimal salinity. Where the sampling interval is narrow enough, such as at Verchères (Guilbault, 1989, Fig. 11), the A to B transition is not sharp but smooth and gradual, which seems to exclude a sharp, massive and durable increase in freshwater influx. At 10.1 ka BP, when the freshwater influx must have reduced drastically according to Lewis and Anderson (1989), there is no evidence for an increase in salinity. Even in the central parts of the basin, near Montréal, where the clay sedimentation is monotonous and correlation from site to site easy, the trend is one of continuous, uninterrupted decrease in salinity until foraminifera

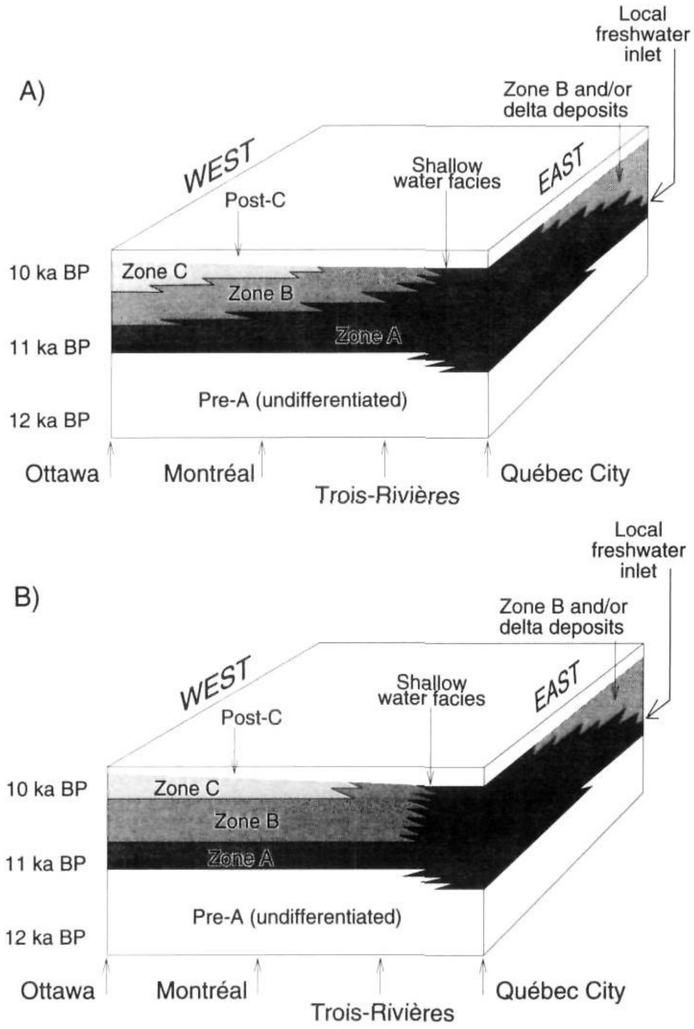


FIGURE 16. Possible time-stratigraphic correlations for the deep-water zones along an east-west cross-section following the main axis of the basin from Québec City to Ottawa. "Local freshwater inlet" may be a meltwater river coming from the retreating ice margin. Time scale is approximate. A) Time-transgressive zones resulting from the progradation of a freshwater prism. B) Time-parallel zones resulting from the whole basin becoming gradually less saline.

Corrélations chronostratigraphiques possibles pour les zones d'eau profonde suivant une coupe parallèle à l'axe principal du bassin, de Québec à Ottawa. « Local freshwater inlet » pourrait être une rivière d'eau de fonte provenant du front glaciaire. L'échelle chronologique est approximative. A) Zones diachrones résultant de la progradation d'un prisme d'eau douce. B) Zones synchrones résultant de la dessalure graduelle de l'ensemble du bassin.

disappear altogether. Early and late Champlain Sea shell dates are questionable, because they come from hyposaline environments and thus may contain a hard-water (old carbonate) error of many centuries (Rodrigues, 1988); the dates of Lewis and Anderson (1989) on undifferentiated organic matter may not be totally reliable either (Lewis, pers. comm.) and thus dating discrepancies can be expected between both areas. However, shell dates on high salinity material from 10.8 to 11.0 ka BP should not be biased and the absence of noticeable freshening during that period suggests an absence of diversion.

We should now ask ourselves if the absence of evidence of hyposalinity in the benthic fauna necessarily means that no diversion has taken place. Lewis and Anderson (1989) could not estimate the Lake Algonquin discharge during the Main Algonquin phase (Broecker *et al.*, 1989, talk of 30,000 m^3/sec *above* normal Lake Algonquin discharge; Teller, 1990, computes 58,000 m^3/sec for the St. Lawrence and Hudson Valleys combined) but even assuming it was many tens of thousands of cubic metres per second, one may wonder if it was enough, considering the width of the Québec City strait (approximately 60 km when relative sea level was at the 120 m contour line), to do more than somewhat thicken the *seasonal superficial brackish water layer or make it less* saline, leaving the deep Champlain Sea as saline as before. If we assume the seasonal brackish water layer to have been 20 m thick as in the modern Gulf of St. Lawrence, that gives a cross-sectional area of the order of one million square metres for freshwater to exit. Even allowing for dilution by saltwater, this leaves a tremendous capacity for evacuating freshwater, as great as what Lewis and Anderson (1989) envisaged for a flood situation (hundreds of thousands of m^3/sec). Therefore, changes in the base flow must have little effect on a large portion of the Champlain Sea. Floods would have been very short and their traces in the deep Champlain Sea record would probably be undetectable with the sampling density used here. It seems likely that the change in baseflow would produce a sudden eastward displacement of the saltwater wedge, if one existed at the time of the diversion. However, the absolute error on radiocarbon dating is probably too large to detect such a shift. The shallow water change from zone EH to zone EA, in the region of Montréal, can be thought of as resulting from an increase in the amount of freshwater spreading at the surface of the sea. However, as mentioned above, dating on hyposaline EA material is most probably affected by old carbonate error and may be inaccurate. Even if datings on EA were accurate, nothing could prove that the salinity change is not due to another factor, such as the restriction of the Québec City strait, or accelerated melting of the Laurentide Ice Sheet due to climate improvement. The absence of any return to saltier water anywhere suggests that the Marquette cutoff has left no detectable trace in the Champlain Sea, either because it took place after retreat of marine water or because it did not involve large enough amounts of water to leave an obvious trace. In conclusion, it does not appear possible to make a clear correlation with the Great Lakes on the basis of the present data. That does not prevent an important amount of freshwater to have been evacuated through the Champlain Sea, as de Vernal *et al.* (1993) report, in the Gulf of St. Lawrence, a period of moderate freshening of surface water coinciding with Champlain Sea time. That period, however, lasted longer than the time interval considered by Broecker *et al.* (1989).

ACKNOWLEDGMENTS

I wish to thank the following persons whose contribution was vital in the genesis of this paper. I must first of all thank Prof. R. W. Feyling-Hanssen and Lekt. Karen Luise Knudsen of the Geological Institute, Aarhus University, without whose advice this study, including the paper of Guilbault (1989), would have been impossible. The manuscript was critically read and improved by Michel A. Bouchard (Université de Montréal), Bruce H. Corliss (Duke University), Cyril G. Rodrigues (University of Windsor), Charles T. Schafer and Gustavs Vilks (both Atlantic Geoscience Centre). Pierre LaSalle and Denis-Jacques Dion (ministère de l'Énergie et des Ressources du Québec) and Serge Occhietti (UQAM) introduced me to interesting sections. Jette Gissel Nielsen of the University of Aarhus and Michel Demidoff of the Université de Montréal drafted most of the figures.

REFERENCES

Anderson, T.W., 1988. Late Quaternary Pollen Stratigraphy of the Ottawa Valley – Lake Ontario Region and its Application in Dating the Champlain Sea, p. 207-224. *In* N.R. Gadd, ed., The Late Quaternary Development of the Champlain Sea Basin. Geological Association of Canada, Special Paper 35.

Broecker, W.S., Kennett, J.P., Flower, B.P., Teller, J.T., Trumbore, S., Bonani, G. and Wolfli, W., 1989. Routing of meltwater from the Laurentide Ice Sheet during the Younger Dryas cold episode. Nature, 341: 318-321.

Cronin, T.M., 1976. An Arctic foraminiferal fauna from Champlain Sea deposits in Ontario. Canadian Journal of Earth Sciences, 13 (2): 1678-1682.

——— 1977. Champlain Sea Foraminifera and Ostracoda: a systematic and paleoecological synthesis. Géographie physique et Quaternaire, 31 (1-2): 107-122.

——— 1979a. Late Pleistocene benthic foraminifera from the St. Lawrence Lowlands. Journal of Paleontology, 53 (4): 781-814.

——— 1979b. Foraminifer and ostracode diversity in the Pleistocene Champlain Sea of the St. Lawrence Lowlands. Journal of Paleontology, 53 (2): 233-244.

de Vernal, A., Goyette, C. and Rodrigues, C.G., 1989. Contribution palynostratigraphique (dinokystes, pollen et spores) à la connaissance de la mer de Champlain: coupe de Saint-Césaire, Québec. Canadian Journal of Earth Sciences, 26 (12): 2450-2464.

de Vernal, A., Guiot, J. and Turon, J.-L., 1993. Late and Postglacial paleoenvironments of the Gulf of St. Lawrence: Marine and terrestrial palynological evidence. Géographie physique et Quaternaire, 47(2), in press.

Elson, J.A., 1969. Late Quaternary marine submergence of Québec. Revue de géographie de Montréal, 23 (3): 247-258.

Fairbanks, R.G., 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature, 342: 637-642.

Feyling-Hanssen, R.W., 1964. Foraminifera in Late Quaternary deposits from the Oslofjord area. Norsk Geologisk Undersøkelse, 225: 383 p.

Fisher, R.A., Corbet, A.S. and Williams, C.B., 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. Journal of Animal Ecology, 12: 42-58.

Forester, R.M. and Brouwers, E.M., 1985. Hydrochemical parameters governing the occurrence of estuarine and marginal marine ostracodes: an example from south-central Alaska. Journal of Paleontology, 59 (2) 344-369.

Gadd, N.R., 1971. Pleistocene geology of the central St. Lawrence Lowland. Geological Survey of Canada, Memoir 359. 153 p.

——— 1986. Lithofacies of Leda Clay in the Ottawa Basin of the Champlain Sea. Geological Survey of Canada, Paper 85-21, p. 1-44.

——— ed., 1988. The Late Quaternary Development of the Champlain Sea Basin. Geological Association of Canada, Special Paper 35. 312 p.

Gadd, N.R., LaSalle, P., Dionne, J.-C., Shilts, W.W. and McDonald, B.C., 1972. Quaternary Geology and Geomorphology, Southern Québec. Guidebook, field Excursions A44-C44, XXIV International Geological Congress, Montréal. 70 p.

Guilbault, J.-P., 1980. A stratigraphic approach to the study of the Late-Glacial Champlain Sea deposits with the use of foraminifera. Licentiat Thesis, Aarhus Universitet. University Microfilms no. 82-28, 762.

——— 1989. Foraminiferal distribution in the central and western parts of the late Pleistocene Champlain Sea basin, Eastern Canada. Géographie physique et Quaternaire, 43 (1): 3-26.

Hillaire-Marcel, C., Occhietti, S. and Vincent, J.-S., 1981. Sakami Moraine, Quebec: A 500-km-long moraine without climatic control. Geology, 9: 210-214.

Hunt, A.S. and Rathburn, A.E., 1988. Microfaunal Assemblages of Southern Champlain Sea Piston Cores. p. 145-154 *In* N.R. Gadd, ed., The Late Quaternary Development of the Champlain Sea Basin. Geological Association of Canada, Special Paper 35.

LaSalle, P., 1984. Quaternary stratigraphy of Quebec: A review, p. 155-171. In R.J. Fulton, ed., Quaternary stratigraphy of Canada — A Canadian Contribution to IGCP Project 24, Geological Survey of Canada, Paper 84-10.

——— 1987. The Quebec City area, p. 52-71. *In* M. Lamothe, ed., Pleistocene stratigraphy in the St-Lawrence Lowland and the Appalachians of southern Québec: a field guide. Collection Environnement et Géologie, 4.

——— ed., 1989. Guidebook for field excursions. Friends of the Pleistocene 52nd Annual Reunion, Québec City, Québec, Canada, May 19-21, 1989.

LaSalle P. and Elson, J.A., 1975. Emplacement of the St-Narcisse Moraine as a Climatic Event in Eastern Canada. Quaternary Research, 5: 621-625.

LaSalle, P., Martineau, G. and Chauvin, L., 1977. Morphologie, stratigraphie et déglaciation dans la région de Beauce – Monts Notre-Dame – Parc des Laurentides. Ministère des Richesses naturelles du Québec, Exploration géologique, DPV-516, 74 p.

Lewis, C.F.M. and Anderson, T.W., 1989. Oscillations of levels and cool phases of the Laurentian Great Lakes caused by inflows from glacial Lakes Agassiz and Barlow-Ojibway. Journal of Paleolimnology, 2 (2): 99-146.

Lortie, G. and Guilbault, J.-P., 1984. Les Diatomées et les Foraminifères des sédiments marins post-glaciaires du Bas Saint-Laurent (Québec): une analyse comparée des assemblages. Naturaliste canadien, 111: 297-310.

Lowdon, J.A. and Blake, W., 1979. Geological Survey of Canada Dates XIX. Geological Survey of Canada, Paper 79-7, 58 p.

Lubinsky, I., 1980. Marine bivalve molluscs of the Canadian central and eastern Arctic: faunal compositions and zoogeography. Canadian Bulletin of Fisheries and Aquatic Sciences, no. 207, 111 p.

Lutze, G.F., 1965. Zur Foraminiferen-Fauna der Ostsee. Meyniana, 15: 75-142.

——— 1974. Foraminiferen der Kieler Bucht (Westliche Ostsee): 1. "Hausgartengebiet" des Sonderforschungbereiches 95 der Universität Kiel. Meyniana, 26: 9-22.

Murray, J.W., 1973. Distribution and Ecology of Living Benthic Foraminiferids. Heinemann Educational Books Ltd., London, 274 p.

Occhietti, S., 1976. Dépôts et faits quaternaires du Bas St-Maurice, Québec (2e partie). Geological Survey of Canada, Paper 76-1C: 217-220.

——— 1977. Stratigraphie du Wisconsinien de la région de Trois-Rivières – Shawinigan, Québec. Géographie physique et Quaternaire, 31 (3-4): 307-322.

——— 1980. Le Quaternaire de la région de Trois-Rivières – Shawinigan, Québec. Contribution à la paléogéographie de la vallée moyenne du St-Laurent et corrélations stratigraphiques. Université du Québec à Trois-Rivières, Paléo-Québec, 10, 227 p.

Occhietti, S. and Hillaire-Marcel C., 1977. Chronologie ^{14}C des événements paléogéographiques du Québec depuis 14 000 ans. Géographie physique et Quaternaire, 31: 123-133.

Parent, M., 1987. The Asbestos-Valcourt and Sherbrooke area, p. 102-140. *In* M. Lamothe, ed., Pleistocene stratigraphy in the St-Lawrence Lowland and the Appalachians of southern Québec: a field guide. Collection Environnement et Géologie 4.

Parent, M. and Occhietti, S., 1988. Late Wisconsinan deglaciation and Champlain Sea invasion in the St. Lawrence Valley, Québec. Géographie physique et Quaternaire, 42 (3): 215-246.

Rodrigues, C.G., 1987. Late Pleistocene invertebrate macrofossils, microfossils and depositional environments of the Western Basin of the Champlain Sea, p. 16-23. *In* R.J. Fulton, ed., Quaternary Geology of the Ottawa Region, Ontario and Quebec. Geological Survey of Canada, Paper 86-23, p. 1-47.

——— 1988. Late Quaternary Invertebrate Faunal Associations and Chronology of the Western Champlain Sea Basin, p. 155-176. *In* N.R. Gadd, ed., The Late Quaternary Development of the Champlain Sea Basin. Geological Association of Canada, Special Paper 35.

——— 1992. Successions of invertebrate microfossils and the late Quaternary deglaciation of the central St. Lawrence Lowland, Canada and United States. Quaternary Science Reviews, 11: 503-534.

Rodrigues, C.G., Gadd, N.R. and Richard, S.H., 1987. Excursion B. Invertebrate paleontology and lithostratigraphy of Champlain Sea sediments. Quaternary of the Ottawa Region and guides for day excursions. INQUA 87 Canada, XIIth International Congress, p. 25-36.

Rooth, C., 1982. Hydrology and Ocean Circulation. Progress in Oceanography, 11: 131-149.

Samson, C., Barette, L., LaSalle, P. and Fortier, J., 1977. Quebec Radiocarbon Measurements I. Radiocarbon, 19 (1): 96-100.

Savoie, L. and Richard, P., 1979. Paléophytogéographie de l'épisode Saint-Narcisse dans la région de Sainte-Agathe, Québec. Géographie physique et Quaternaire, 33 (2): 175-188.

Scott, D.B., Schafer, C.T. and Medioli, F.S., 1980. Eastern Canadian estuarine foraminifera: a framework for comparison. Journal of Foraminiferal Research, 10 (3): 205-234.

Teller, J. T., 1990. Volume and Routing of Late-Glacial Runoff from the Southern Laurentide Ice Sheet. Quaternary Research, 34 (1): 12-23.

Thomas, R.H., 1977. Calving bay dynamics and ice sheet retreat up the St. Lawrence Valley system. Géographie physique et Quaternaire, 31 (3-4): 347-356.

Upham, W., 1895. Late glacial or Champlain subsidence and reevaluation of the St. Lawrence River basin. American Journal of Science, Third Series, 49: 1-18.

Vilks, G., MacLean, B. and Rodrigues, C.G., 1990. Late Quaternary high resolution seismic and foraminiferal stratigraphy in the Gulf of St. Lawrence. *In* Current Research Part B, Geological Survey of Canada, Paper 90-B: 49-58.

Vilks, G., Wagner, F.J.E. and Pelletier, B.R., 1979. The Holocene marine environment of the Beaufort Shelf. Geological Survey of Canada, Bulletin 303, p. 1-43.

Wagner, F.J.E., 1970. Faunas of the Pleistocene Champlain Sea. Geological Survey of Canada, Bulletin 181, 104 p.

Walton, W.R., 1964. Recent foraminiferal ecology and paleoecology, p. 151-237. *In* J. Imbrie and N.D. Newell, eds., Approaches to Paleoecology. Wiley and Sons, New York.