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S.H. Richard

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Foreword

At the time of his death S.H. Richard was preparing a summary of the late Quaternary history of the western basin of the Champlain Sea. The summary included a list of more than 100 radiocarbon age determinations on marine and freshwater macrofossils obtained from the Geological Survey of Canada Dating Laboratory and IsoTrace Laboratory, University of Toronto. The report had not progressed to the point where it could be published, but the radiocarbon ages are an important body of data representing a lasting contribution of S.H. Richard to the deciphering of the late Quaternary history of the western basin of the Champlain Sea. The radiocarbon ages are presented here along with a brief summary of Richard's interpretation.

Avant-propos

Au moment de son décès, S.H. Richard préparait un sommaire de l'histoire géologique du bassin ouest de la mer Champlain au cours de la fin du Quaternaire. Ce document comprenait une liste de plus de 100 âges radiométriques déterminés par datation au carbone radioactif de macrofossiles marins et d'eau douce. M. Richard avait obtenu ces données du Laboratoire de datation de la Commission géologique du Canada et du IsoTrace Laboratory de l'Université de Toronto. Le rapport n'était pas assez avancé pour être publié comme tel; par contre, les âges radiométriques forment un important ensemble de données. Par cette remarquable contribution, S.H. Richard aide à mieux faire connaître l'histoire géologique du bassin ouest de la mer Champlain au cours de la fin du Quaternaire. On trouvera dans le présent document les âges obtenus par datation au carbone radioactif ainsi qu'un bref résumé des interprétations de M. Richard.

R.J. Fulton et C.G. Rodrigues

SERGE HENRY RICHARD
(1932-1987)

On 3 October 1987, Serge Henry Richard of the Geological Survey's Terrain Sciences Division died suddenly during a geological excursion in the Ottawa area. We have not only lost a colleague but also a friend. Here are some of the highlights of his professional career.

Henry first obtained his *licence ès lettres* in geography at the University of Laval in 1954. From 1954 to 1957, he pursued his studies at the Laboratoire de géographie physique of the University of Paris, under the direction of Professor Pierre Birot. During his university years, Henry was fortunate in having summer employment related to his field of studies. As early as 1950, he worked as field assistant on H.W. McGerrigle's field party from the Québec Department of Mines and in 1951, on H.C. Cooke's field party. In 1954, he was introduced to Quaternary geology field work at the Geological Survey of Canada as an assistant to Eric Henderson and later worked with Owen Hughes. In 1952 and from 1955 to 1957, he undertook various tasks related to the preparation of the Atlas of Canada under the authority of the former Geographical Branch of the Department of Mines and Surveys.

Le 3 octobre 1987, Serge Henry Richard, de la Division de la science des terrains de la Commission géologique du Canada, décédait subitement au cours d'une excursion géologique dans la région d'Ottawa. Plus qu'un chercheur, nous avons perdu un ami dont voici les principales étapes de sa vie professionnelle.

Henry a d'abord obtenu une licence ès lettres en géographie à l'Université Laval en 1954. De 1954 à 1957, il poursuivait ses études au Laboratoire de géographie physique de l'Université de Paris, sous la direction du professeur Pierre Birot. Au cours de ses années d'étude à l'université, Henry a toujours pu profiter d'un emploi d'été en rapport avec ses études. Ainsi dès 1950, il travaillait comme assistant sur le terrain au ministère des Mines du Québec dans l'équipe de terrain de monsieur H.W. McGerrigle, puis en 1951, dans celle de monsieur H.C. Cooke. En 1954, il s'initiait sur le terrain à la géologie du Quaternaire en assistant monsieur Éric Henderson, puis monsieur Owen Hughes de la Commission géologique du Canada. En 1952, puis de 1955 à 1957, il a participé à divers travaux reliés à la préparation de l'Atlas du Canada sous l'autorité de l'ancienne Direction de la géographie du ministère des Mines et relevés techniques.

Henry began his professional career in 1975, at the Geographical Branch. From 1957 to 1959, he worked with R.J. Gadja on problems related to postglacial isostatic rebound. His work has been used, for example, in the preparation of Ferrand and Gadja's article entitled "Isobases on the Wisconsin Marine Limit in Canada", which has since become a classic. In 1959, he undertook his first surficial geology mapping project. He worked in Saskatchewan until 1964, particularly in the Wynyard area. His research in this area served as the basis for his master's thesis which he obtained in 1964 from the University of Laval. In 1966, Henry joined the Geological Survey of Canada. His first task was airphoto interpretation of the northern regions of Manitoba (Operation Winisk). From 1967 to 1970, he continued mapping surficial deposits in western Canada, this time in Alberta. In 1970 the Survey gave him responsibility for systematic, large-scale mapping of the Ottawa area, a task which continued to the time of his death. During those years, he completed detailed mapping of the region extending from Arnprior in the west to Montréal Island to the east, and from St. Lawrence River in the south to Sainte-Agathe in the north.

Henry knew this region thoroughly, and was often called upon to share this knowledge, not only with his colleagues from the Survey and from various universities, but also with consultants and municipal planners. All are agreed on the high quality and great utility of the many fine maps he made. Henry also published numerous reports on the Outaouais region, especially in the Geological Survey's Current Research series. He also contributed to several guide books on the Ottawa area. Of particular interest is the field trip guidebook prepared for the 12th Congress of the International Union for Quaternary Research (INQUA), held in Ottawa in August 1987. Researchers from more than 40 countries were thus able to appreciate first hand the quality of his contribution.

Two days before his death Henry and I met to discuss his research and future projects. As always, he was cheerful and enthusiastic. He had planned a wide series of studies and, as always, conveyed his insatiable thirst for knowledge and understanding. After all those years, he was still as excited as ever by his research, and the very day of his death, took delight in animated discussions with his colleagues.

In the years to come, the maps he made will help keep his memory alive in the minds of all those who consult them. We will also vividly remember his warmth, his smile, and his readiness to help. We will remember a colleague and friend.

Henry a commencé sa carrière professionnelle en 1957, à la Direction de la géographie. De 1957 à 1959, il a travaillé avec monsieur R.J. Gajda à étudier les problèmes reliés au soulèvement isostatique post-glaciaire. Ses travaux ont entre autres servi à la préparation de l'article de Farrand et Gajda, intitulé "Isobases on the Wisconsin Marine Limit in Canada", devenu depuis un classique. En 1959, il entreprenait ses premiers travaux de cartographie sur les formations en surface. C'est ainsi qu'il a travaillé en Saskatchewan jusqu'en 1964, et plus particulièrement dans la région de Wynyard. Ses recherches sur cette région lui ont d'ailleurs servi à faire sa thèse de maîtrise qu'il a soutenu avec succès à l'Université Laval, en 1964. En 1966, Henry entrait au service de la Commission géologique du Canada. Sa première tâche fut d'étudier les régions du nord du Manitoba à l'aide de photographies aériennes (opération Winisk). De 1967 à 1970, il a poursuivi son travail de cartographie des formations en surface dans l'Ouest canadien, en Alberta, cette fois. En 1970, la Commission lui confia la responsabilité des travaux de cartographie systématique à grande échelle de la région d'Ottawa. Il y travaillait d'ailleurs encore au moment de son décès. Au cours de ces années, il a dressé la carte détaillée de la région qui s'étend de Arnprior, à l'ouest, jusqu'à l'île de Montréal, à l'est, et du Saint-Laurent, au sud, jusqu'à Sainte-Agathe, au nord. Henry connaissait à fond cette région, et aussi bien ses collègues de la Commission et des différentes universités que les experts-conseils et les planificateurs municipaux faisaient appel à sa vaste expérience. Tous, d'ailleurs, s'entendent pour reconnaître la qualité et la grande utilité des très belles et nombreuses cartes qu'il a dressées. Henry a également publié de nombreux rapports sur la région de l'Outaouais, surtout dans le cadre de la publication "Recherches en cours" comme il a contribué à la préparation de plusieurs livrets guides sur la région d'Ottawa. Notons plus particulièrement le livret guide préparé à l'occasion de la tenue du congrès de l'Association internationale pour l'étude du Quaternaire (INQUA) à Ottawa, en août 1987. Les chercheurs de plus de quarante pays ont pu remarquer et apprécier la qualité de sa contribution.

Deux jours avant son décès, je rencontrais notre cher ami et collègue Henry pour discuter de ses recherches et de ses projets. Comme à son habitude, il était souriant et enthousiaste. Il avait planifé toute une série de travaux et j'ai senti comme toujours sa soif d'apprendre et de comprendre. Après toutes ces années, il était encore aussi passionné par ses recherches et, le jour même de son décès, il prenait plaisir à discuter de façon animée avec ses collègues.

Au cours des années à venir, les cartes qu'Henry a dressées contribueront à préserver son souvenir dans l'esprit de tous ceux qui consulteront ces documents. Nous garderons également un vif souvenir de sa chaleur, de son sourire et de sa grande disponibilité, le souvenir d'un ami.

Jean-Serge Vincent
Geological Survey of Canada
Commission Géologique du Canada

CONTENTS

RADIOCARBON DATES FROM THE WESTERN BASIN OF THE CHAMPLAIN SEA

Abstract

The late S.H. Richard accumulated a large body of radiocarbon ages related to events in the western basin of the Champlain Sea. As interpreted by Richard, 1) ages greater than 12 ka are evidence that the Champlain Sea entered the Ottawa area via a calving bay while ice remained in the upper reaches of St. Lawrence River valley, 2) ice contact deposits and till containing marine shells with ages ranging from 11.0 to 11.3 ka indicate a late readvance into the Champlain Sea, and 3) ages of freshwater shells and Holocene marine materials indicate that the Champlain Sea regressed from the area at the beginning of Holocene.

Résumé

Le regretté S.H. Richard avait accumulé un nombre considérable d'âges obtenus par datation au carbone radioactif relativement à des événements qui se sont produits dans le bassin ouest de la mer Champlain. L'interprétation de ces données avait amené M. Richard à tirer les conclusions suivantes: 1) le fait qu'on ait obtenu des âges de plus de 12 000 ans montre que la mer Champlain a envahi la région d'Ottawa par une baie qui s'était ouverte par vêlage du front glaciaire, pendant que les glaces couvraient encore la partie supérieure de la vallée du fleuve Saint-Laurent; 2) la présence de till renfermant des coquilles marines et de dépôts de contact glaciaire dont l'âge varie entre 11 000 et 11 300 ans témoigne d'une nouvelle avancée tardive dans la mer Champlain et 3) l'âge de coquilles d'eau douce et de sédiments marins holocènes indique que la mer Champlain s'est retirée de la région au début de l'Holocène.

INTRODUCTION

S.H. Richard spent much of his career mapping and conducting Quaternary research in the Ontario-Quebec region near Ottawa (Appendix 1 lists maps prepared by S.H. Richard and Appendix 2 lists other publications in which he was involved). His work in the Ottawa area was conducted from 1970-1987 and one of his main goals was to develop a radiocarbon chronology for the Champlain Sea. Tables 1 to 3 list radiocarbon ages obtained largely through his work and Fig. 1 shows locations of dated sites. This report assembles all of these dates as an inventory and also contains a brief summary of the interpretations that S.H. Richard placed on these ages. In order to put these interpretations in perspective, it is first necessary to provide some background on late glacial events of the Ottawa region.

LATE GLACIAL EVENTS OF THE OTTAWA REGION

The most widely studied and controversial late glacial event of the Ottawa region was invasion by marine waters. The name given to the body of marine water that occupied the isostatically depressed Central St. Lawrence Lowland at the end of the last glaciation is the Champlain Sea (Elson, 1969). Even though discussions about the Champlain Sea have been in the literature for more than a century, many unanswered questions remain concerning the relationship of the Champlain Sea to other late glacial events. The two main problems are the relationship between retreat of the Laurentide Ice Sheet and development of the Champlain Sea and the interrelationship between the Champlain Sea and lakes in the Great Lakes basin.

Early geologists reported varved clay lying between glacial and marine sediments in the vicinity of Ottawa. As a consequence of these occurrences, and others in adjacent areas, Leverett and Taylor (1915) proposed that a glacial lake (Lake Frontenac) occupied the lowland between the Adirondack Mountains and Ottawa during retreat of the last ice sheet. This lake apparently formed through amalgamation of glacial Lake Iroquois, in the Lake Ontario basin to the west, with glacial Lake Vermont, in the valley of Lake Champlain to the east. The two glacial lakes joined when the Laurentide Ice Sheet retreated from the northern margin of the Adirondack Mountains and the lake expanded, in contact with the ice front, as the ice receded to the north. Prest (1970), showed this lake on one of his ice retreat maps as "Belleville-Fort Ann Phase". According to the deglaciation model of Prest, the Ottawa region was deglaciated by a south to north retreat of the ice front; breaching of an ice dam in the Québec City area permitted drawdown of the glacial lakes south of the dam, and allowed marine waters from the Gulf of St. Lawrence, to the north, to occupy the isostatically depressed Lake Champlain valley, upper St. Lawrence Valley, and lower Ottawa Valley. This model of ice retreat and sequence of events was further supported by Anderson et al (1985) and Naldrett (1988a) who correlated varved lake deposits in the Ottawa area with sediments in the Great Lakes basin and Lake Champlain valley. Their correlations were based largely on occurrence of the ostracode *Candona subtriangulata* in sediments in each area, and partly on the nature of the sediments and assumptions about the nature of local deglaciation. One piece of evidence that contradicts this interpretation is occurrence of marine fossils in what apparently are ice contact sediments in the Ottawa area (cf. Naldrett, 1988b). If the Laurentide ice margin had retreated from the lower Ottawa Valley in contact with a lake, then ice contact deposits in the area would be glaciolacustrine in origin and could not contain marine fossils.

Prest (1970) used his model of deglaciation and the radiocarbon ages available at that time to place an age of about 11.8 ka on invasion of the Ottawa area by the Champlain Sea. Several older radiocarbon ages that have been obtained since 1970 (Romanelli, 1975; Richard,1978a; Rodrigues and Richard, 1983) suggested that the Champlain Sea might have arrived at Ottawa before 12 ka. Interestingly these older ages came from the northern part of the basin, not the southern part, which should have been the first area invaded by marine waters if the ice margin had been retreating from south to north. Gadd (1980) suggested that this contradiction could be explained by having marine waters enter the area via a calving bay. This was an extension of the "working hypothesis" used earlier (Gadd, 1975) to explain reversal of ice flow during deglaciation of the Appalachian region of southern Quebec. Extension of this calving bay into Ottawa Valley could bring marine water into the Ottawa area while ice continued to occupy upper St. Lawrence River valley and while high level lakes remained in the Lake Ontario basin.

The calving bay hypothesis provided a mechanism for getting marine water into the northern part of the western basin of the Champlain Sea before invading the south; explained how a glacial lake could be retained in the basin of Lake Ontario at the same time marine water occupied the area around Ottawa; and as ice in the Ottawa area would have been retreating in the sea, explained the presence of marine fossils in ice contact deposits. There are, however, two major problems with this explanation: it does not explain the lacustrine sediments which lie between glacial and marine deposits in the vicinity of Ottawa and there is no physical evidence to indicate that a calving bay passed through the area. A calving bay would have tapped the internal drainage system of the ice causing west to east meltwater flow; all current flow indicators in glaciofluvial deposits, however, indicate general north to south meltwater flow. Also there is no widespread evidence that ice in the western basin of the Champlain Sea was lifted off its bed; dropstones are not common in marine deposits and the subaqueous fan model posed for deposition of the glaciofluvial deposits requires grounded ice. A further point against this hypothesis for deglaciation of the Ottawa region is that Chauvin et al. (1985) claimed that the calving bay which caused the ice flow reversal in the Eastern Townships did not follow St. Lawrence Valley upstream from Québec.

Possible explanations of the contradictory evidence that do not require a calving bay are: 1) the old radiocarbon ages are erroneous and 2) the shell-bearing "glaciomarine" sediments are not ice contact deposits. Marine shells have been shown to give radiocarbon ages that are too old (Mangerud, 1972; Mangerud and Gulliksen, 1975). During early stages of invasion, the Champlain Sea would have contained large quantities of "old" carbon derived from glacial meltwaters. Animals that lived in those waters would be expected to provide ages more closely related to the radiocarbon age of the water than to that of the atmosphere of that time. The marine sediments that have been referred to as ice contact deposits consist mainly of slumped and contorted sand, gravel, and silt and diamicton. Rather than being of glacigenic origin, the disruption of these sediments may have been due to slumping and upward movement of water caused by melting of buried, stagnant ice or by ploughing and churning caused by the drag of ice bergs and by the scouring action of pressure ridge keels of seasonal ice. Both explanations are highly plausible because these sediments occur on ridges cored by sediments of unquestioned ice contact origin which probably contained buried ice blocks and the ridges stood as topographic highs on the sea bed and so would have been the focus of ice scouring.

The following summary indicates how the late S.H. Richard used the radiocarbon data base he built up for the western basin of the Champlain Sea to interpret the late glacial and early postglacial history of the Ottawa area. This summary comes from published and unpublished reports, and many hours of discussion both in the office and the field.

INTERPRETATION OF AGES OLDER THAN 12 ka

Materials with ^{14}C ages greater than 12 ka have been found mainly southwest and north of Ottawa and come from littoral and nearshore sediments at or near marine limit (Fig. 1 and 2). Richard's interpretation was that these ages indicate the time of first deglaciation and of marine invasion of northern and western reaches of the western basin of the Champlain Sea. He noted that these fossils seemed to indicate deglaciation of only two relatively small parts of the basin and reasoned that this suggested that other parts remained under a glacier cover at this time. To get marine waters into the Ottawa area without their occupying the southern part of the Champlain Sea basin, he suggested that the invasion took place along Ottawa River valley while ice remained in southern parts of the basin; he felt this was accomplished through a calving bay, as was suggested by Gadd (1980).

Richard suggested that if a calving bay had not operated in that area, then there might be a problem with the radiocarbon ages, and the shells might be older than the age of deposition of the enclosing sediments. He did not elaborate further on this but referred to Karrow et al. (1975), Karrow (1981), and Anderson et al. (1985) who suggested alternative explanations of these possibly anomalous radiocarbon ages.

INTERPRETATION OF AGES BETWEEN 12 AND 11 ka

Richard interpreted this group of ages as documenting continuing ice retreat and marine invasion of the western basin of the Champlain Sea. If the ice front had retreated from south to north, through the western basin of the Champlain Sea, he reasoned that marine shells should be oldest in the south and youngest in the north. Using a deglaciation model developed by Stuiver and Borns (1975) for the coast of Maine, he calculated that it would have taken 500 to 600 years for the ice front to retreat from the Adirondack Mountains to the Laurentian Highland. Because this time difference is not apparent in the radiocarbon ages (compare ages at sites 4, 5, and 8 in the north with those of sites 6, 7, and 14 in the south; Fig. 3, Tables 1 and 3), he concluded that the ages did not support a regular south to north retreat of the ice. In addition, he noted that most deposits containing shells that fall in this age range were not ice contact in nature and could not be related to ice marginal features. This seemed to suggest that the Champlain Sea did not progressively invade the area from the south as the ice retreated.

In the course of his work Richard mapped and named a series of sand and gravel features (dominantly ridges) that are scattered throughout the western basin of the Champlain Sea (Fig. 4). Even though marine littoral and beach sediments occur as surface veneers on these features, the cores of the ridges consist of ice contact deposits which have been referred to as subaqueous fans (Rust and Romanelli, 1975; Richard, 1977; Cheel, 1982; Sharpe, 1987, 1989; Rust, 1989). In parts of some of these features marine shells and

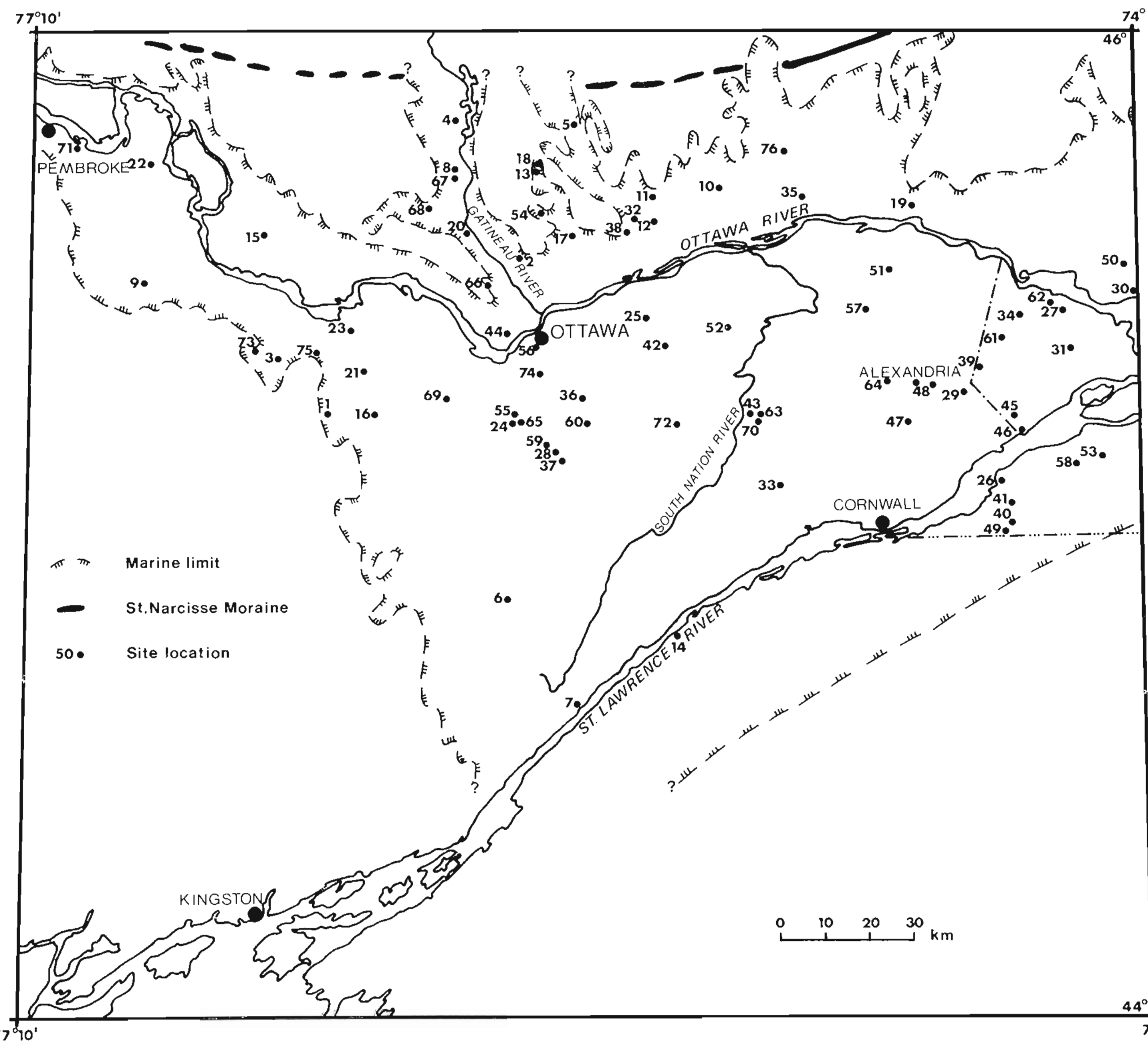

Figure 1. Locations of sites where radiocarbon ages listed in Tables 1-3 were obtained.

Table 1. Radiocarbon ages for *Macoma balthica* and *Macoma calcarea*

Dated Material	Site: Number	Site: Name	Elevation[1] (m a.s.l.)	Laboratory Number	Age (years BP): Uncorrected	Age (years BP): Corrected[2]	$\delta^{13}C$ (‰)	Comment	Collector	Reference
	1	Clayton	167	GSC-1859	12 800 ± 220			Pebbly sand near marine limit	S.H. Richard	Richard, 1974
				GSC-2151OF	12 800 ± 100	12 800 ± 100	-0.2	Material from same level as	S.H. Richard &	Richard, 1978a
				GSC-2151 IF	12 700 ± 100	12 700 ± 100	0.2	GSC-1859	W. Blake, Jr.	Richard, 1978a
				TO-245		12 180 ± 100		Material from same collection as GSC-2151		Fulton & Richard, 1987
	2	Cantley	194	GSC-1646	12 200 ± 160			Silty sand near marine limit	R. Romanelli	Lowdon & Blake, 1973; Romanelli, 1975
			195	GSC-3844	11 800 ± 170			Pebbly mud near marine limit	S.H. Richard	Rodrigues & Richard, 1985
	3	White Lake	170	GSC-3110OF	12 100 ± 100	12 100 ± 100	-0.6	Pebbly sand near marine limit	S.H. Richard	Rodrigues & Richard, 1983
				GSC-3110MF	12 200 ± 100	12 200 ± 100	-0.5			Rodrigues & Richard, 1983
				GSC-3110 IF	12 100 ± 100	12 100 ± 100	-0.5			Rodrigues & Richard, 1983
	4	Martindale	176	GSC-1772	11 900 ± 160			From transition zone between laminated silty clay and overlying gravelly sand	R. Romanelli	Lowdon & Blake, 1973; Romanelli, 1975
	5	Val-des-Bois	182	GSC-2769	11 900 ± 100	11 800 ± 100	-1.8	Sand at marine limit	S.H. Richard	Lowdon & Blake, 1980; Richard, 1980
	6	Merrickville	118-120	GSC-3523	11 800 ± 100	11 800 ± 100	-0.7	Pebbly sand overlying bedrock	C.G. Rodrigues & S.H. Richard	Blake, 1984; Rodrigues & Richard, 1986
	7	Maitland	103	GSC-1013	11 800 ± 210			Sand	E.P. Henderson	Lowdon & Blake, 1970
	8	Farrellton	180	GSC-3812	11 700 ± 100	11 700 ± 100	-1.4	Clay near marine limit	S.H. Richard	Rodrigues & Richard, 1985
	9	Douglas	120	GSC-3872	11 700 ± 120	11 700 ± 120	3.6	Sandy clay clasts at base of sand unit	C.G. Rodrigues, S.H. Richard, & R.J. Fulton	Rodrigues & Richard, 1985
	10	Saint-Sixte	145	GSC-2863	11 600 ± 200	11 500 ± 200	-4.8	Sand overlying marine clay	S.H. Richard	Lowdon & Blake, 1980; Richard, 1980
Macoma balthica (Linne)	11	Buckingham	127	GSC-4359	11 600 ± 190	11 500 ± 190	0.8	Sand	S.H. Richard	This report
	12	Mayo	185	GSC-2878	11 500 ± 210	11 500 ± 210	-0.6	Clay in bedrock depression	S.H. Richard	Lowdon & Blake, 1980; Richard, 1980
	13	Val-Paquin	195-198	GSC-3865	11 500 ± 130	11 500 ± 130	1.7	Clay near marine limit	S.H. Richard	Rodrigues & Richard, 1985
	14	Sparrowhawk Point	83	GSC-3788	11 400 ± 100	11 300 ± 100	2.7	Sand overlying marine clay	C.G. Rodrigues & S.H. Richard	Rodrigues & Richard, 1985
	15	Shawville	170	GSC-3670	11 300 ± 190	11 400 ± 190	+1.7	Boulder gravel underlain by sand	R.J. Fulton, S.H. Richard, & W.W. Shilts	Blake, 1983
	16	Almonte	154	GSC-1672	11 200 ± 160			Sandy gravel	S.H. Richard	Lowdon & Blake, 1973; Richard, 1975b
	17	Perkins	178-180	GSC-3835	11 200 ± 100			Sand overlying marine clay	S.H. Richard	Rodrigues & Richard, 1985
	18	Lucerne	175	GSC-3997	11 200 ± 130	11 200 ± 130	+0.7	Clay near marine limit	S.H. Richard	Fulton & Richard, 1987
	19	Calumet	160	GSC-2703	11 100 ± 120			Sand at marine limit	S.H. Richard	Lowdon & Blake, 1980; Richard, 1980
	20	Wakefield	139	GSC-4056	11 100 ± 120	11 100 ± 120	1.4	Stratified sand	R.J. Fulton, C.G. Rodrigues,& D.G. Fulton	Fulton & Rodrigues, 1987
	21	Antrim	134	GSC-4201	11 100 ± 90	11 100 ± 90	-1.4	Shell bed with pebbly sand matrix	C.G. Rodrigues	This report
	22	Westmeath	158	GSC-1664	11 100 ± 110	11 000 ± 160	-1.6	Clayey sand	P.J. Howarth	Lowdon & Blake, 1979
	23	Galetta	100	GSC-4168	10 900 ± 130	10 800 ± 130	-1.6	Pebbly sand at top of marine sequence	C.G. Rodrigues	This report
	24	Twin Elm	100	GSC-588	10 880 ± 160			Sand	R.J. Mott, J. Terasmae, & T.W. Anderson	Mott, 1968; Lowdon & Blake, 1970
	25	Navan	95	GSC-3743OF	10 700 ± 100	10 700 ± 100	-1.7	Shell bed with pebbly sand	R.J. Fulton &	Rodrigues & Richard, 1986
				GSC-3743 IF	10 800 ± 90	10 800 ± 90	-1.8	matrix near top of marine sequence	C.G. Rodrigues	Rodrigues & Richard, 1986
	26	Cazaville	55	GSC-2423	10 600 ± 140			Sand	S.H. Richard	Richard, 1978a; Lowdon & Blake, 1979
	27	Hudson	70	GSC-4133	10 600 ± 110	10 600 ± 110	1.9	Gravelly sand	S.H. Richard	This report
	28	Kars	98	GSC-4350	10 600 ± 100	10 600 ± 100	-1.6	Clay	S.H. Richard	This report
	29	Glennevis	79	GSC-119 OF	10 460 ± 160			Sand overlying marine clay	J.J.L. Tremblay	Dyck & Fyles, 1964
				GSC-119 IF	10 740 ± 170					Dyck & Fyles, 1964
	30	La Trappe	70	GSC-4251	10 300 ± 140	10 300 ± 140	-0.8	Pebbly sandy gravel	S.H. Richard	This report
Macoma calcarea (Gmelin)	31	Saint-Lazare-de-Vaudreuil	82	GSC-3614	10 600 ± 100	10 600 ± 100	-1.1	Pebbly sandy clay	S.H. Richard	Blake, 1983

OF - outer fraction MF - middle fraction IF - inner fraction

[1] Elevation interpreted from 1:50,000 scale topographic maps with contour intervals of 25 or 50 feet

[2] Corrected age is normalized to a base of $\delta^{13}C = 0‰$ (PDB)

GSC - Geological Survey of Canada. GSC ages are reported at 95.5% probability (2σ criterion)

TO - IsoTrace (University of Toronto). TO ages are reported at 68% probability (1σ criterion)

Table 2. Radiocarbon ages for *Hiatella arctica, Mya* spp., and *Lampsilis* spp.

Dated Material	Site Number	Site Name	Elevation[1] (m a s.l.)	Laboratory Number	Age (years BP) Uncorrected	Age (years BP) Corrected[2]	$\delta^{13}C$ (‰)	Comment	Collector	Reference
	32	Buckingham	180	GSC-2763	11 400 ± 140	11 400 ± 140	+1.9	Pebbly clay near marine limit	S.H. Richard	Lowdon & Blake, 1980, Richard, 1980
	33	Newington	100	GSC-2108	11 200 ± 100			Compact diamicton	S.H. Richard	Richard, 1975b, Lowdon & Blake, 1979
	34	Rigaud	160	GSC-2296	11 200 ± 90	11 200 ± 90	+1.7	Pebbly sand near marine limit	S.H. Richard	Richard, 1978b; Lowdon & Blake, 1979
	35	Montebello	167	GSC-2590	11 100 ± 120	11 100 ± 120	+2.3	Gravelly sand near marine limit	S.H. Richard	Lowdon & Blake, 1980; Richard, 1980
	36	Manotick	107	GSC-4166	11 100 ± 130	11 100 ± 130	+1.5	Deformed sand and gravel	B.R. Rust	Rust, 1987
			110	GSC-4173	10 500 ± 120	10 500 ± 120	+0.3	Sand and gravel unconformably overlying deformed sand and gravel	B.R. Rust	Rust, 1987
	37	Kars	98	GSC-2312	10 900 ± 100	10 900 ± 100	+1.7	Silty sandy clay	T.M. Cronin	Cronin, 1976; Lowdon & Blake, 1976
	20	Wakefield	135	GSC-4088	10 800 ± 110	10 800 ± 110	-0.2	Sandy and silty clay overlain by marine sand	R.J. Fulton, C.G. Rodrigues,	Fulton & Rodrigues, 1987
				GSC-4213	10 700 ± 110	10 700 ± 110	+0.5	From same unit as and 0.3 m above material used for GSC-4088	& D.G. Fulton C.G. Rodrigues	Rodrigues, 1989
Hiatella arctica (Linne)	38	Riviere-du-Lievre	146	GSC-2621	10 700 ± 100	10 700 ± 100	+1.1	Base of silt and clay unit underlain by stratified sand and gravel	J-S. Vincent	Lowdon & Blake, 1978
	31	Saint-Lazare-de-Vaudreuil	84	GSC-2265	10 600 ± 130	10 600 ± 130	+1.1	Pebbly clayey sand	S.H. Richard, R.J. Fulton, & E.B. Owen	Lowdon & Blake, 1979
	39	Sainte-Justine-de-Newton	74	GSC-2391	10 500 ± 110	10 500 ± 110	+1.5	Pebbly sandy clay underlain by till	S.H. Richard & R.J. Richardson	Richard, 1978a, Lowdon & Blake, 1979
	40	Beaver Crossing	67	GSC-2453	10 500 ± 80	10 500 ± 80	+1.6	Sand and gravel	S.H. Richard	Lowdon & Blake, 1979
	41	Cazaville	72	GSC-3882OF	10 300 ± 90	10 300 ± 90	0.1	Gravelly sand overlying till	S.H. Richard	Rodrigues & Richard, 1985
				GSC-3882 IF	10 400 ± 90	10 500 ± 90	+1.2			Rodrigues & Richard, 1985
	42	Bearbrook	68	GSC-3907OF	10 300 ± 110	10 200 ± 110	-0.8	Shell bed with pebbly sand matrix at top of marine sequence	C.G. Rodrigues & S.H. Richard	Rodrigues & Richard, 1986
				GSC-3907 IF	10 200 ± 90	10 200 ± 90	+0.3			Rodrigues & Richard, 1986
	43	Saint-Albert	73	GSC-4315	10 100 ± 120	10 200 ± 120	+2.0	Sand overlying marine clay	S.H. Richard	This report
	44	Deschênes	94	GSC-2189	10 100 ± 130	10 100 ± 130	+1.3	Sand overlying marine clay	S.H. Richard	Richard, 1978a, Lowdon & Blake, 1979
	45	Rivière-Beaudette	56	GSC-3741	11 100 ± 100	11 100 ± 100	2.2	Horizontally bedded sandy clay overlain by crossbedded sand	S.H. Richard	Rodrigues & Richard, 1985; Blake, 1986
	46	Rivière-Beaudette	58	GSC-3809	10 900 ± 100	10 900 ± 100	-2.7	Pebbly sand near top of marine sequence	S.H. Richard & C.G. Rodrigues	Rodrigues & Richard, 1985, Blake, 1986
Mya arenaria Linne	47	Glenroy	80	GSC-3845	10 800 ± 100	10 700 ± 100	2.7	Clayey sand overlying marine shell bed	C.G. Rodrigues & S.H. Richard	Rodrigues & Richard, 1985
	48	Glen Norman	83	GSC-4477	10 500 ± 190	10 500 ± 190	+0.2	Pebbly sand at top of marine sequence	S.H. Richard	This report
	39	Sainte-Justine-de-Newton	76	GSC-3475	10 600 ± 100	10 500 ± 100	-0.9	Pebbly sand at top of marine sequence	S.H. Richard	Blake, 1982, Rodrigues & Richard, 1985
	49	Sainte-Agnès-de-Dundee	57	GSC-4228	10 100 ± 180	10 100 ± 180	-1.5	Pebbly sandy gravel	S.H. Richard	This report
Mya truncata Linne	39	Sainte-Justine-de-Newton	75	GSC-2261	10 200 ± 100	10 300 ± 100	+1.5	Pebbly sand from middle part of marine sequence	W. Blake, Jr. & E.B. Owen	Richard, 1978a; Lowdon & Blake, 1979
	50	Saint-Joseph-du-Lac	96	GSC-4159	9860 ± 80	9880 ± 80	+1.5	Pebbly sand overlying pebbly sandy clay	S.H. Richard & C.G. Rodrigues	Rodrigues, 1989
Lampsilis sp.	9	Douglas	120	GSC-3852	11 400 ± 400		6.3	Base of sand unit underlain by clay	S.H. Richard, C.G. Rodrigues, & R.J. Fulton	Rodrigues & Richard, 1985
Lampsilis radiata (Gmelin) s.l.	51	Vankleek Hill	61	GSC-3235	10 300 ± 90			Sand and gravel in an abandoned channel	S.H. Richard	Lowdon & Blake, 1981; Rodrigues & Richard, 1983
Lampsilis sp.	52	Bourget	53	GSC-1968	10 200 ± 90			Sand and gravel in an abandoned channel	N.R. Gadd	Gadd, 1976; Lowdon & Blake, 1976
Lampsilis siliquoidea (Barnes)	53	Saint-Stanislas-de-Kostka	47	GSC-2414	9750 ± 150			Sand overlying marine clay	S.H. Richard	Richard, 1978a, Lowdon & Blake, 1979

OF- outer fraction IF-inner fraction
1 Elevation interpreted from 1:50 000 scale topographic maps with contour interval of 25 or 50 feet
2 Corrected age is normalized to a base of $\delta^{13}C$ = 0‰ (PDB)
GSC - Geological survey of Canada. GSC ages are reported at 95.5% probability (2σ criterion)

Table 3. Radiocarbon ages for pelecypods, cirripeds, whale bone, and algae

Dated Material	Site Number	Site Name	Elevation[1] (m a.s.l.)	Laboratory Number	Age (years BP) Uncorrected	Age (years BP) Corrected[2]	$\delta^{13}C$ (‰)	Comment	Collector	Reference
Portlandia arctica (Gray)	14	Sparrowhawk Point	75	GSC-4044	11 900 ± 140	11 900 ± 140	+0.3	Clay underlying "varved" silt and clay	C.G. Rodrigues & S.H. Richard	Rodrigues, 1987
			76	GSC-3767	11 900 ± 100	11 900 ± 100	+0.2	Base of clay overlying "varved" silt and clay	C.G. Rodrigues & S.H. Richard	Rodrigues & Richard, 1985
	20	Wakefield	139	TO-112R		11 760 ± 120		Bouldery silty clay overlying sand and gravel	R.J. Fulton	Fulton & Richard, 1987
	54	Saint-Pierre-de-Wakefield	161	GSC-3834	11 800 ± 150	11 700 ± 150	-1.1	Clay near marine limit	S.H. Richard	Rodrigues & Richard, 1985
	55	Twin Elm	105	GSC-3641	11 200 ± 200	11 200 ± 200	2.8	Interbedded pebbly clay and gravel	S.H. Richard	Blake, 1983
	56	Ottawa	64	GSC-623	10 720 ± 150			Bedded silty clay overlying till	N.R. Gadd	Lowdon et al., 1967
	57	Saint-Bernardin	62	TO-649		10 660 ± 100		Interbedded clay and sand	S.H. Richard	This report
	58	Saint-Stanislas-de-Kostka	42	GSC-3853	10 500 ± 210	10 500 ± 210	0.4	Clay overlain by sand containing freshwater pelecypods	S.H. Richard & C.G. Rodrigues	Rodrigues & Richard, 1985
	76	Notre-Dame-de-la-Paix	145	TO-797		10 160 ± 100		Clay overlain by sand	S.H. Richard	This report
Balanus hameri (Ascanius)	59	Watterson Corners	93	GSC-4070OF GSC-4070 IF	11 200 ± 110 11 300 ± 110	11 200 ± 110 11 300 ± 110	-1.1 0.8	Cobbly pebbly sand at base of marine sequence	S.H. Richard & C.G. Rodrigues	Rodrigues, 1989 Rodrigues, 1989
	60	Hebert Corners	93	GSC-4113-1[3] GSC-4113-2[3]	11 200 ± 110 11 200 ± 110	11 200 ± 110 11 200 ± 110	0.0 +0.8	Cobbly pebbly sand at base of marine sequence	S.H. Richard & C.G. Rodrigues	Rodrigues, 1989
	61	Tres-Saint-Redempteur	80	GSC-4258	11 200 ± 150	11 200 ± 150	0.6	Pebbly sandy clay at base of marine sequence	S.H. Richard	This report
	62	Rigaud	28	GSC-4132	11 100 ± 130	11 100 ± 130	-0.7	Pebbly clay at base of marine sequence	S.H. Richard	Rodrigues 1989
	46	Riviere-Beaudette	56	GSC-3702	11 000 ± 90	11 000 ± 90	+1.4	Pebbly clay at base of marine sequence	S.H. Richard & C.G. Rodrigues	Rodrigues & Richard, 1985, Blake, 1986
	25	Navan	93	GSC-3706	11 000 ± 90	11 000 ± 90	+1.4	Pebbly clay lens in pebbly sandy diamicton	S.H. Richard	Blake, 1984, Rodrigues & Richard, 1986
	63	Crysler	69	GSC-4043	10 900 ± 90	10 900 ± 90	0.9	Pebbly clay at base of marine sequence	C.G. Rodrigues & S.H. Richard	Rodrigues, 1989
	64	Dornie	106	GSC-4468	10 900 ± 120	10 900 ± 120	-0.9	Pebbly clay at base of marine sequence	S.H. Richard	This report
	65	Twin Elm	97	GSC-4052	10 800 ± 110	10 800 ± 110	+0.7	Pebbly sand underlain by marine pebbly clay and "varved" silt and clay	C.G. Rodrigues & S.H. Richard	Rodrigues, 1989
	42	Bearbrook	67	GSC-3983OF GSC-3983 IF	10 700 ± 130 10 800 ± 90	10 700 ± 130 10 800 ± 90	0.9 -0.2	Pebbly sandy clay underlain by marine pebbly clay and "varved" silt and clay	C.G. Rodrigues	Rodrigues et al., 1987 Rodrigues & Richard, 1986
Balanus crenatus Bruguiere	64	Dornie	97	GSC-4235	10 500 ± 170	10 500 ± 170	1.6	Gravel and sand near top of marine sequence	S.H. Richard	This report
Hiatella arctica and *Macoma balthica*	66	Meach Lake	170	GSC-842	11 600 ± 150			Sand overlying clay	J.T. Buckley	Lowdon & Blake, 1970
Macoma sp.	67	Lascelles	166	GSC-1612	11 500 ± 150			Gravel	N.R. Gadd	Lowdon & Blake, 1975
Macoma sp.	68	Mahon Lake	167	GSC-982	11 300 ± 180			Gravel in stream bed cut in clay	J.T. Buckley	Lowdon & Blake, 1970
Pelecypod shells (*Hiatella arctica*?)	69	Stittsville	130	GSC-2448	11 300 ± 120			Deformed sand and silt	N.R. Gadd, R.J. Fulton, and others	Gadd, 1978, Lowdon & Blake, 1979
Macoma balthica and *M. calcarea*	70	Crysler	70	GSC-2614	11 000 ± 100	10 900 ± 100	2.1	Sand	S.H. Richard	Lowdon & Blake, 1980
Pelecypod shells	71	Pembroke	139	GSC-90	10 870 ± 130			Stratified sand and clay overlying sand and gravel	J. Terasmae	Dyck & Fyles, 1963
Pelecypod shells	24	Twin Elm	104	GSC-587	10 620 ± 200			Crossbedded sand near top of marine sequence	R.J. Mott, J. Terasmae, & T.W. Anderson	Mott, 1968; Lowdon & Blake, 1970
Macoma balthica and *M. calcarea*	72	Russell	70	GSC-1553	10 000 ± 300			Sand	S.H. Richard	Lowdon & Blake, 1973
Marine algae (kelp)	24	Twin Elm	98	GSC-570	10 800 ± 150			From sand layers	R.J. Mott, J. Terasmae, and T.W. Anderson	Mott, 1968, Lowdon & Blake, 1970
Balaena mysticetus Linne	73	White Lake	170	GSC-2269[4]	11 400 ± 90	11 500 ± 90	13.5	Sand near marine limit	A. Jones	Lowdon & Blake, 1979
Bones of white whale (beluga)	74	Ottawa	91	GSC-454[4]	10 420 ± 150			Sand	G.B. Roland	Dyck et al., 1966
Delphinapterus leucas Pallas	75	Pakenham	107	GSC-2418[4]	10 250 ± 80	10 400 ± 80	13.6	Clay	P. Cannon	Lowdon & Blake, 1979

OF - outer fraction IF - inner fraction
1 Elevation interpreted from 1:50 000 scale topographic maps with contour intervals of 25 or 50 feet
2 Corrected age is normalized to a base of $\delta^{13}C = 0$‰ (PDB)
3 GSC-4113-1 acid leach treatment, GSC-4113-2 no acid leach treatment
4 Collagen fraction used for dating. Carbonate fraction of material used for GSC-454 yielded an age of 105 ± 0.65% of standard (Dyck et al., 1966)
GSC - Geological Survey of Canada, GSC ages are reported at 95.5% probability (2σ criterion)
TO - IsoTrace (University of Toronto), TO ages are reported at 68% probability (1σ criterion)

mammal bones occur in faulted, folded, and tilted sand, silt, clay, and diamicton (Richard, 1977; Sharpe, 1987; Naldrett, 1988b). Richard interpreted the disruption of the fossiliferous stratified sediments as glacial tectonic in origin and noted that the fauna present is the same as that found near the margin of present day glaciers. These observations and conclusions led him to the conclusion that these sediments were deposited in marine water at an ice margin. Shells from "ice contact" sediments in these ridges have provided radiocarbon ages ranging from 11.0 to 11.3 ka (see sites 25, 36, and 69 of Tables 1, 2, 3; Fig. 3).

As noted above, Richard used the occurrence of fossiliferous nearshore and beach sediments to the north and west of Ottawa as proof that the Champlain Sea invaded that area more than 12 ka ago. "Ice contact" deposits 11 to 11.3 ka old, south of Ottawa, however, suggest that ice was in the central part of the basin until 11 ka. Rather than questioning the validity of one of these apparently conflicting pieces of information, Richard accepted both and interpreted the fossiliferous "ice contact" sediments as deposits of a readvance that took place after the Champlain Sea was established in this area. In addition, Richard used marine shells which occur in diamicton, interpreted as till (Richard, 1975a, b, 1976, 1978a, b), as further evidence that a readvance occurred into the Champlain Sea. The age provided for the one dated site where shell fragments were collected from the matrix of a compact diamicton interpreted as till is 11 200 + 100 BP (GSC-2108; 33 of Table 2). Richard noted that Terasmae (1965) had also suggested a late, but undated, readvance in this area and that the ice advance which he hypothesized as occurring in the western basin of the Champlain Sea would have taken place at about the same time as the Valders, the Younger Dryas, and the St. Narcisse advances.

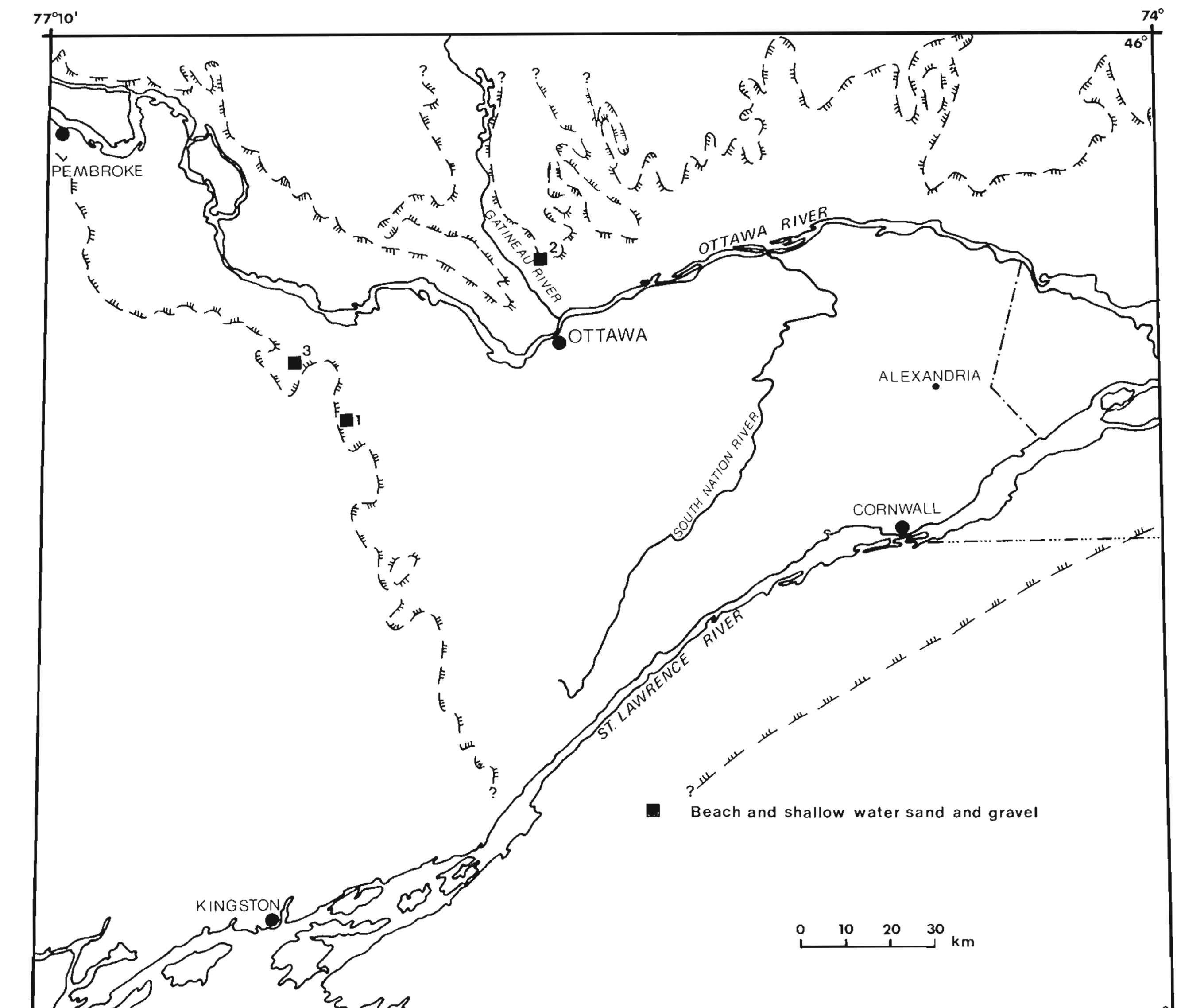

Figure 2. Location of sites with shells dated as older than 12 ka.

Additional insight into Richard's use of radiocarbon ages in determining the pattern of deglaciation is given by his interpretation of marine and terrestrial ages in the Laurentian Highlands. He noted that the oldest ages on terrestrial materials (bog bottom dates) from the Laurentian Highlands at the northern edge of the western basin of the Champlain Sea are between 11 and 10 ka (cf. Anderson, 1987). Radiocarbon ages on shells in marine sediments in valleys which extend many kilometres into the uplands, however, are about 800 radiocarbon years older than this (see 2, 4, 5, 8 of Table 1). On the basis of this evidence, he felt that during deglaciation this area must have appeared similar to parts of present day Baffin Island with ice capping uplands but with fiords extending long distances inland to tidewater glaciers. It is unfortunate that Richard's work did not progress to the point where he felt he had sufficient evidence to warrant plotting paleogeographic maps depicting ice retreat.

INTERPRETATION OF AGES YOUNGER THAN 11 ka

The majority of ages in this group are on shells collected from "shallow water and intertidal sediments" that are well below the limit of submergence and are not related to ice contact deposits (Fig. 5). Most of these samples were collected to date low-level shorelines and to provide ages for paleoecological suites of fossils that he collected in conjunction with C.G. Rodrigues (Rodrigues and Richard, 1983, 1985, 1986). These ages were interpreted as documenting a systematic shoaling and eastward regression of the sea, and the suite of fossils were interpreted as indicating that the marine waters underwent a progressive warming and decrease of salinity. The radiocarbon ages indicate that the sea left the Ottawa area about 10.1 ka (44 of Table 2) and receded from the eastern edge of the area after 9.9 ka (50 of Table 2).

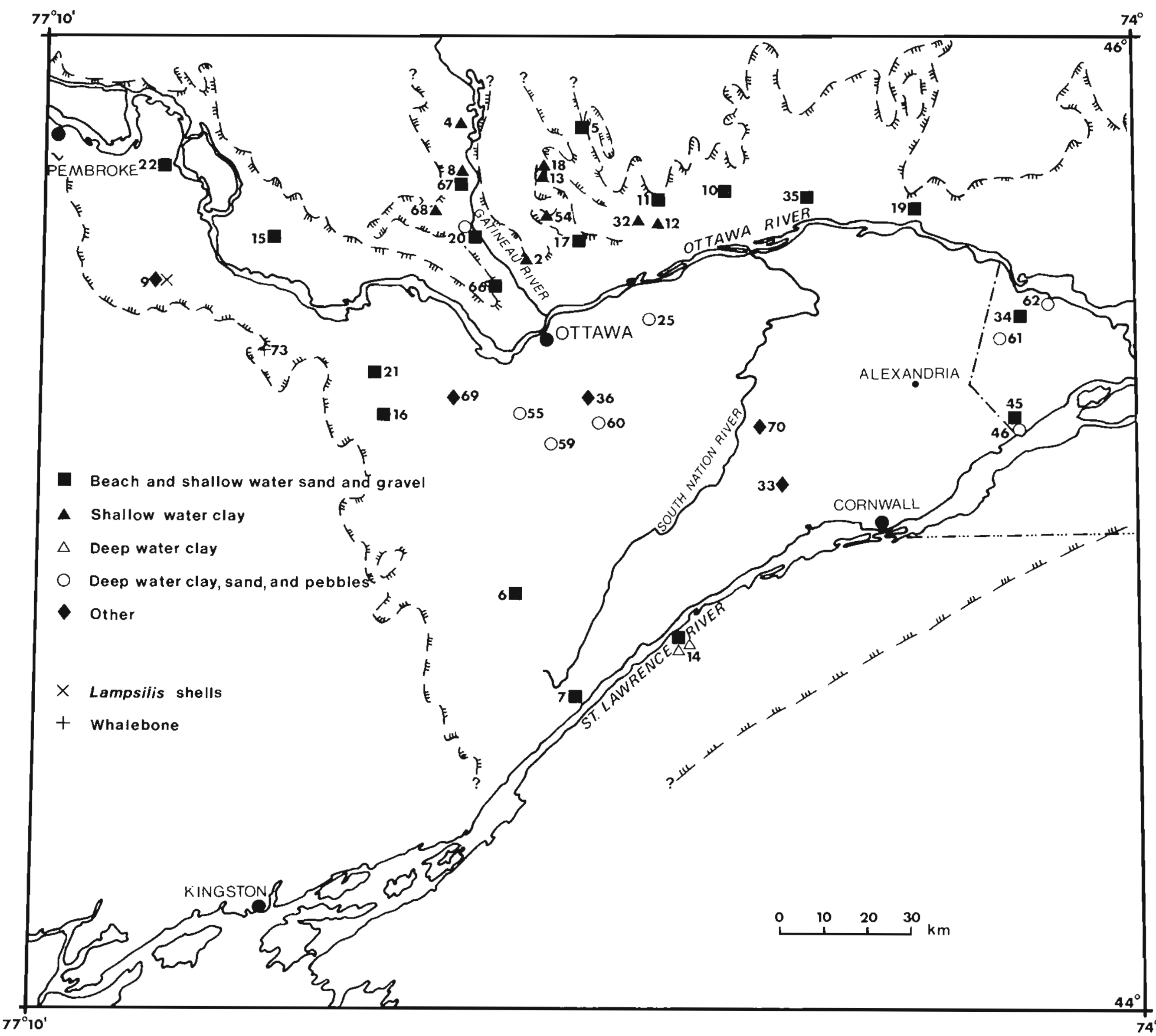

Figure 3. Location of sites with shells or other organic materials dated between 12 and 11 ka.

The chronology of regression provided by marine shells is at variance with that indicated by freshwater shells. Freshwater shells, Lampsilis sp., suggest that the sea had retreated from the vicinity of Douglas by 11.4 ka (9 of Table 2 and Fig. 3), the vicinity of Vankleek Hill by 10.3 ka (51 of Table 2 and Fig. 5), and from Saint-Stanislas-de-Kostka by 9.8 ka (53 of Table 2 and Fig. 5). The Douglas date is further out of line with the marine ages than are the other ages and is said to relate to a time when a freshwater layer was present in the western part of the sea basin (Rodrigues and Richard, 1985); the Vankleek Hill age is for shells collected from a high level terrace of Ottawa River; and the Saint-Stanislas-de-Kostka date is for fossils collected from sand deposited in Lampsilis Lake (Elson, 1962).

SUMMARY OF RADIOCARBON AGE INTERPRETATIONS

S.H. Richard's main conclusions on the Quaternary history of the western basin of the Champlain as based on radiocarbon ages are as follows:

(1) The radiocarbon ages range from 12.8 to 9.8 ka and this time span defines the duration of the Champlain Sea in its western basin.

(2) Three shell collections give ages ranging from 12.8 to 12.1 ka representing the earliest phase of ice retreat and marine inundation. The location of sites from which the dated materials were obtained indicates initial marine incursion occurred in Ottawa Valley before ice retreated from the upper St. Lawrence Valley.

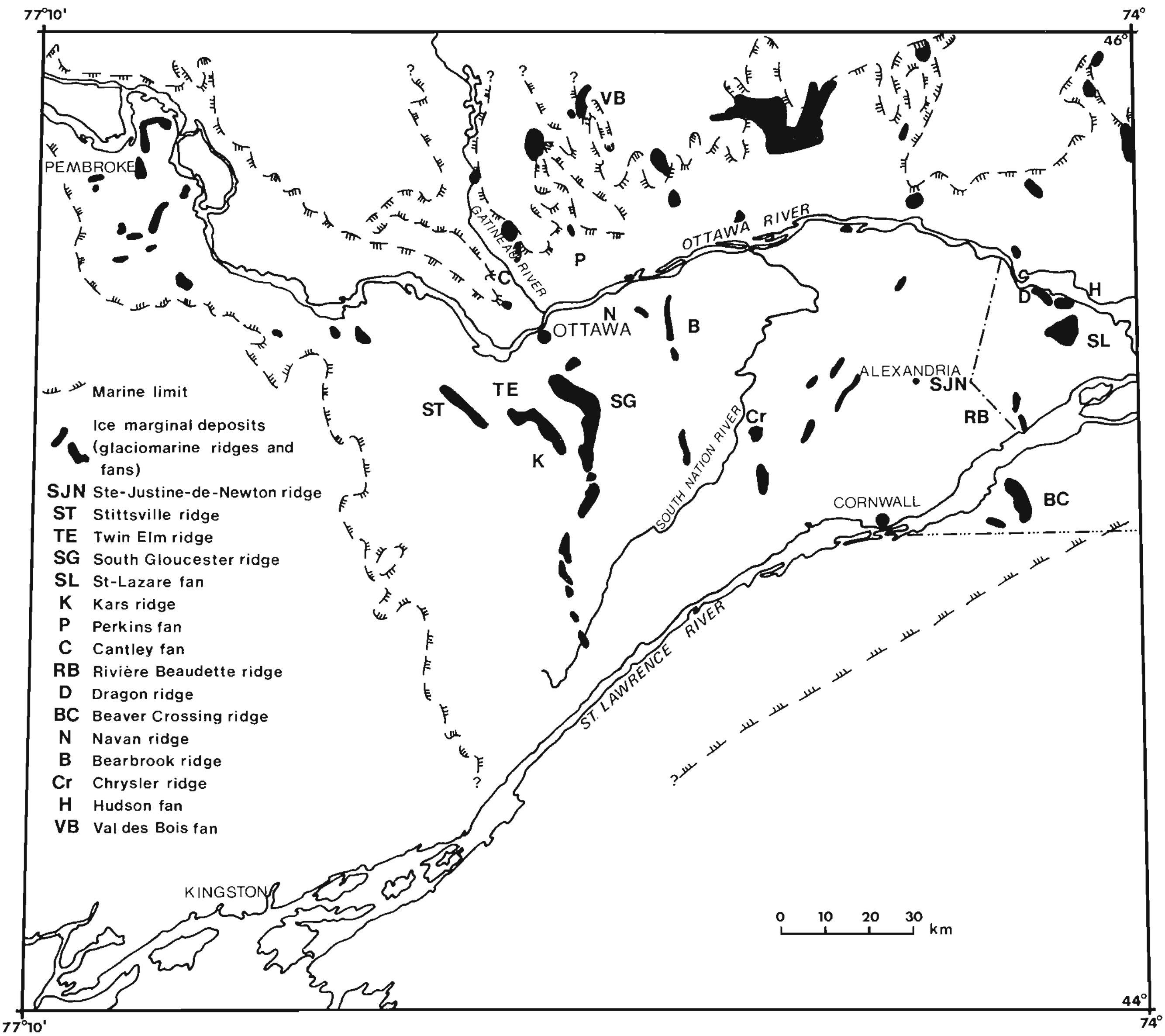

Figure 4. Distribution of ice contact glaciofluvial deposits in the western basin of the Champlain Sea.

(3) The old shell ages are all as old as, or older than, the earliest radiocarbon ages obtained on terrestrial materials from glacial Lake Iroquois sediments in the eastern Great Lakes basin. If both sets of ages are accurate and reliable, the two water bodies were synchronous.

(4) Radiocarbon ages ranging from 12 to 11 ka document continuing ice retreat and marine inundation. They show that the marine waters reached their maximum limit at about the same time, (11.9 to 11.7 ka) along the northern, southern, and western margins of the basin.

(5) A number of radiocarbon ages falling between 11.3 and 11.0 ka come from glaciomarine sediments. Unless the 12.8 to 12.1 ages from the northern and western margins of the basin are erroneous, this implies a partial reoccupation of the marine embayment by glaciers.

(6) Ages ranging from 10.9 to 9.8 ka relate to a late phase of the marine submergence when falling water levels were producing major changes in the size, depth, and configuration of the regressing Champlain Sea.

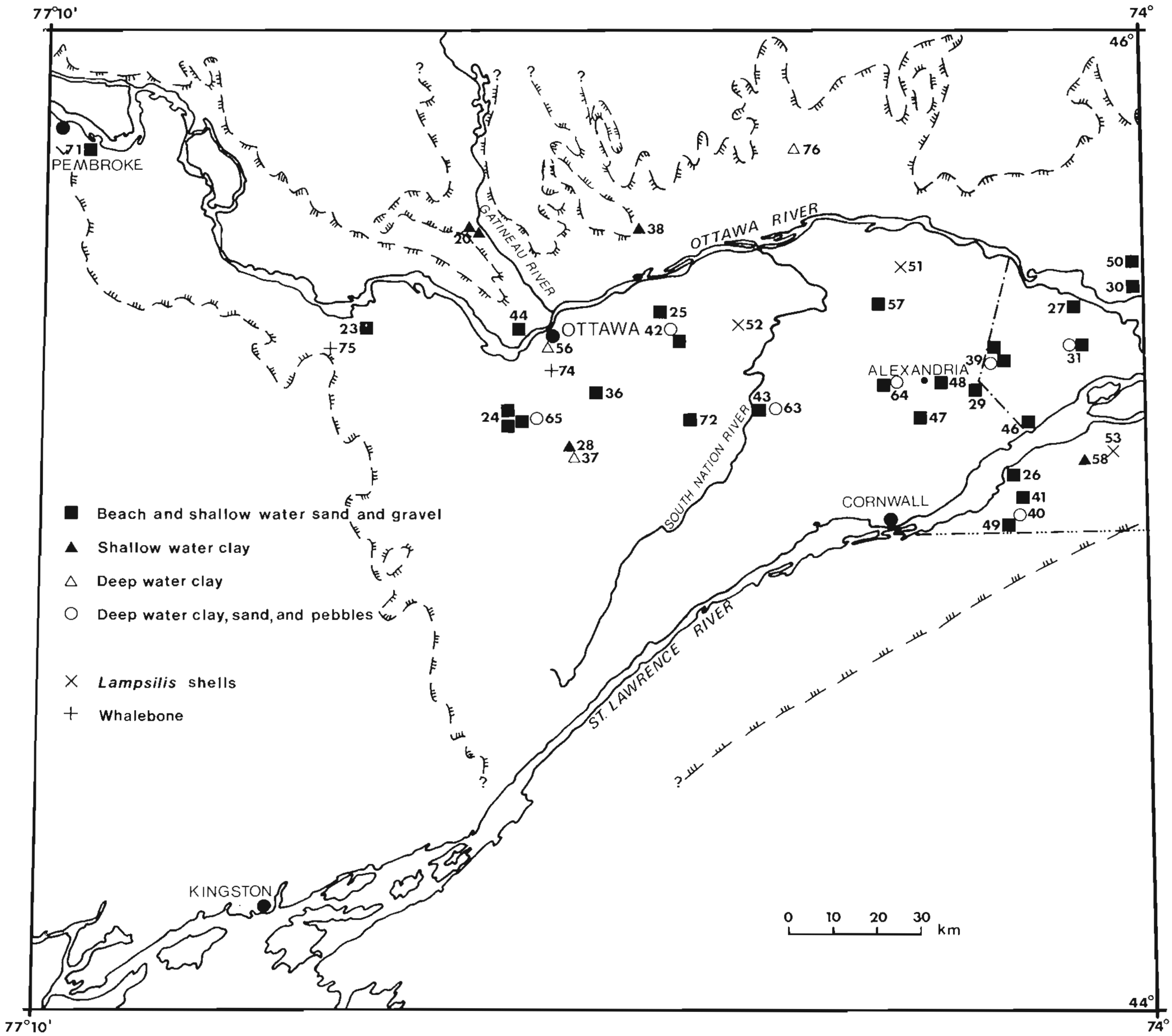

Figure 5. Location of sites with shells and other materials dated as younger than 11 ka.

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