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Short Paper

^{14}C chronology for ice retreat and inception of Champlain Sea in the St. Lawrence Lowlands, Canada

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Abstract

AMS radiocarbon cross-dating of plant debris and marine shells trapped in a lake basin on Mount St. Hilaire (Québec, Canada) provides a direct assessment of a reservoir effect totaling *ca*. 1800 ^{14}C years during the early stage of Champlain Sea. Pollen-based extrapolation of bottommost ages on terrestrial plant macrofossils in sediments of this lake, and of another lake nearby support an estimate of 11,100 ± 100 ^{14}C yr B.P. for marine invasion in the Central St. Lawrence River Lowlands. Results indicate a 400–1000 years younger regional chronology of ice retreat, now congruent with the one inferred from the New England varve chronology. This is a summary of a longer paper to be published in French.

Keywords: ^{14}C chronology; Pleistocene–Holocene transition; Glacial Lake Candona; Champlain Sea; Deglaciation; Glacial meltwater influx

Marine shells are abundant in sediments from postglacial seas of glacio-isostatic origin. Theoretically, they represent appropriate material for dating marine and glacial episodes at the Pleistocene–Holocene transition. However, local marine reservoir effects are often unknown, or variable through time and with the species dated (Björck et al., 2003; England et al., 2003; Hutchinson et al., 2004; Ridge et al., 2001; Sutherland, 1986; Wastegård and Schoning, 1997). In the St. Lawrence River Lowlands (Canada), the chronology of ice retreat was based mainly on shell dates from Champlain Sea and Goldthwait Sea shore deposits (until the question of local marine ^{14}C reservoir correction has been investigated more thoroughly) (Occhietti et al., 2004). We report here on one such ^{14}C reservoir correction obtained from a rare paleogeographical setting. Palynologically controlled radiocarbon ages from early terrestrial plant debris in lake sediments prompt revision of the regional chronology of ice retreat. Full assessment of existing chronological data for the St. Lawrence River Lowlands is presented in a longer paper to be published in French (Occhietti and Richard, in press).

Mount St. Hilaire, the highest (411 m) of the Monteregian Hills (Cretaceous intrusions in Ordovician sedimentary rocks) in the St. Lawrence Lowlands, east of Montréal (Fig. 1a), was an island in the proglacial, then postglacial, Champlain Sea (Fig. 1b). Two bedrock basins located, respectively, above and under the altitudinal limit of marine waters (ca. 190–200 m: David, 1972; Parent and Occhietti, 1988) accumulated ca. 10 m of postglacial sediments (Fig. 1b). The Hemlock Carr basin (a 5 ha, tree-covered swamp formerly a lake; altitude: 243 m; 45° 33′ 24″ N, 73° 08′ 27″ W) drains a 62 ha watershed. Reservoir Hertel (31 ha; altitude: 173 m; 45° 32′ 45″ N, 73° 09′ 08″ W) was expanded from a lower (169 m), smaller (15 ha), natural lake by artificial damming since 1750 A.D.; it drains the central depression (373 ha). Sediments from Hemlock Carr were collected with a Russian sampler, and those from Lake Hertel with a Livingstone sampler; both penetrated to the underlying till (Fig. 1c). Lasalle (1966) compiled pollen diagrams for the same sites and obtained basal ^{14}C ages on bulk, lacustrine

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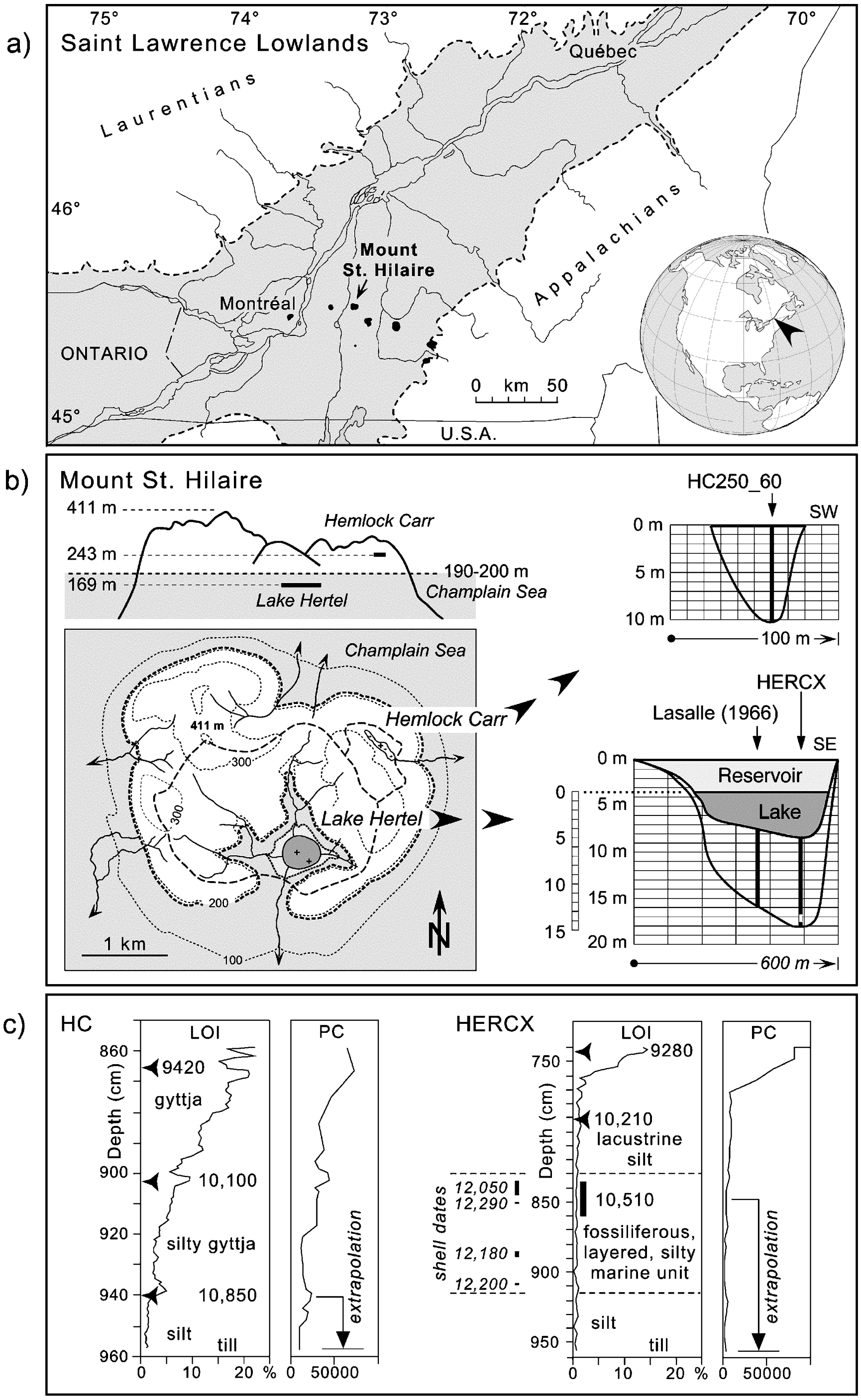

Figure 1. (a) Location map of Mount St. Hilaire among the Monteregian Hills (black) east of Montréal in the St. Lawrence Lowlands (shaded); (b) location of Hemlock Carr and Lake Hertel with their watershed (dashed lines), their altitudinal setting (dotted contour lines in meters) relative to the limit of Champlain Sea (gray shade outside thick dotted line on map, and on cross-section above), and location of the sediment cores (right: marine sediments are shown in white on core HERCX); (c) sediment type, depth of AMS radiocarbon dates in conventional ^{14}C years B.P., loss on ignition (% LOI) and pollen concentration (PC, in grains cm^{-3}) of the basal sediments of Hemlock Carr (left) and Lake Hertel (right). The pollen-based chronological extrapolation zone is indicated (see text). The entire marine unit spans ca. 330 years.

sediments. Our study uses AMS radiocarbon dating of terrestrial plant debris and includes pollen concentration assessments (Benninghoff, 1962) along with continuous, centimetric loss on ignition (LOI) analyses (Dean, 1974) for organic matter content (Fig. 1c).

A previously undetected fossiliferous marine deposit is present under Lake Hertel's sediments (Figs. 1b and c). Four conventional ages between 12,290 and 12,050 ^{14}C yr B.P. were obtained from marine shells and Foraminifera (Table 1, Fig. 1c). Considering the age of 10,510 ± 40 ^{14}C yr B.P.

(Table 1) on terrestrial plant debris enclosed in the marine sediments, the total reservoir effect on shells is ~1780 ^{14}C years; the local reservoir effect is thus 1370^{14}C years after a standard reservoir correction of −410 years. This local effect is due to a combination of factors: (1) input of bedrock-derived, dissolved carbon from glacial meltwaters; (2) stratification of meltwaters over marine waters (Hillaire-Marcel, 1981); (3) enhanced non-equilibration of the marine waters with the atmospheric ^{14}C due to seasonal ice; (4) confinement of the ancient marine bay (Fig. 1b) on a partly carbonate bedrock. Finally, the feeding habit of the dated marine organisms (e.g., bottom feeders vs. suspension feeders) may influence the radiocarbon age (Dyke, 2004; Dyke et al., 2003a; England et al., 2003). Our cross-dating confirms the old carbon enrichment of marine shells living in top waters during the early Champlain Sea episode (Rodrigues, 1988, 1992).

The local reservoir effect during the entire Champlain Sea episode is expected to be variable through time (e.g., 350 years between wood and shells from late Champlain Sea sediments in the Québec City area; Occhietti et al., 2001a) and with location, as well as being different for the various organisms dated; finding reservoir corrections for Champlain Sea shell ages throughout the episode thus seems an intractable task (Dyke, 2004). Fortunately, combination of pollen analyses of sediments, and AMS-dating of early postglacial terrestrial plant debris in Lake Hertel and at Hemlock Carr provides an alternative for deglaciation chronology because of the strategic location of the two sites (Fig. 1b).

The AMS age of 10,850 ± 40 ^{14}C yr B.P. (Table 1, Fig. 1c) on lowest terrestrial plant debris at Hemlock Carr prompts us to reject the basal age of 12,570 ± 220 ^{14}C yr B.P. (GSC-419) obtained by Lasalle (1966). The discrepancy may be due to carbonates derived from surrounding rocks; marl deposits are present nearby in the basin. Taking into account the time represented by the pollen grains accumulated in the 18.5-cm-thick deposits beneath the dated layer (Fig. 1c), the minimum age for ice retreat around Hemlock Carr is estimated at 11,250 ± 150 ^{14}C yr B.P. The

Table 1
Chronological data on Hemlock Carr and Lake Hertel

Depth[a] (cm)	Age, ^{14}C yr B.P.[b]	Organisms AMS dated	δ^{13}C (‰)	Laboratory number
Hemlock Carr (core HC250_60-1)				
865–867	9420 ± 40	*Dryas integrifolia* *Saxifraga stellaris* *Vaccinium uliginosum* *Salix* dwarf *Betula glandulosa* *Picea mariana* type *Betula papyrifera* *Pinus strobus*	−27.2	Beta-176151
902–903	10,100 ± 40	*Salix herbacea* *Dryas integrifolia* *Oxyria digyna*	−27.1	Beta-176152
939–940	10,850 ± 40	*Salix herbacea* *Dryas integrifolia* *Senecio* sp.	−27.7	Beta-176153
Lake Hertel (water depth: 8,6 m)				
742–743	9280 ± 90	*Picea* or *Larix* wood	—	TO-8734
788–793	10,210 ± 60	*Dryas integrifolia* *Salix herbacea* cf. *Potentilla*, cf. *Cerastium*, cf. Polygonaceae shrub twig, leaf fragments	−28.3	Beta-178841
835–845	*12,050 ± 80*	*Elphidium* cf. *excavatum*	—	TO-10248
850–851	*12,290 ± 40*	*Macoma* sp.	−0.5	Beta-178100
836–860[c]	10,510 ± 60	*Dryas integrifolia* *Salix herbacea, Salix* sp. cf. *Saxifraga* *Shepherdia canadensis* Brassicaceae *Carex, Juncus*	−28.6	Beta-179065
885–889	*12,180 ± 40*	*Macoma* sp.	−2.4	Beta-177292
908–909	*12,200 ± 80*	Portlandia arctica	—	TO-10249

[a] Depth from surface (Hemlock Carr) or water-sediment interface (Lake Hertel).
[b] Radiocarbon ages on marine organisms shown in *italics.*
[c] 13 basal cores were necessary to find the dated plant debris.

extrapolated time span is given by the cumulative pollen concentration (PC) in the corresponding sediments (268,290 grains) divided by the pollen accumulation rate (PAR; 1100 grains cm^{-2} ^{14}C yr^{-1}) calculated for the immediately overlying sediments (Fig. 1c). This gives a minimum duration because the amount of pollen produced by the corresponding vegetation earlier in the succession should be lower (see King, 1985). The extrapolated time span is similar in a twin basal core with different clastic sediment accumulation rates (Occhietti and Richard, in press). The estimated error (± 150 yr) is obtained by using a minimum and a maximum estimate for the PAR, considering the fact the pollen assemblages indicate an initial cold desert landscape succeeded by tundra (see species dated, Table 1). As a temporary nunatak, the upper part of Mount St. Hilaire was deglaciated a few centuries before the surrounding St. Lawrence Lowlands (Figs. 1b and 2).

The AMS age of 10,210 ± 60 ^{14}C yr B.P. (Table 1, Fig. 1c) on terrestrial plant debris at Lake Hertel invalidates the age of 10,880 ± 260 ^{14}C yr B.P. (GSC-482) obtained by Lasalle (1966) from palynologically correlative bulk lacustrine sediments (Fig. 1b). Taking into account the time represented by the pollen grains accumulated in the 104-cm-thick deposits beneath the layer that yielded the basal age of 10,510 ± 40 ^{14}C yr B.P. on terrestrial plants (Fig. 1c: 367,328 cumulated grains; PAR = 1446 grains cm^{-2} ^{14}C yr^{-1}), the minimum age of the lowermost sediments is estimated at 10,850 ± 100 ^{14}C yr B.P. The estimated error

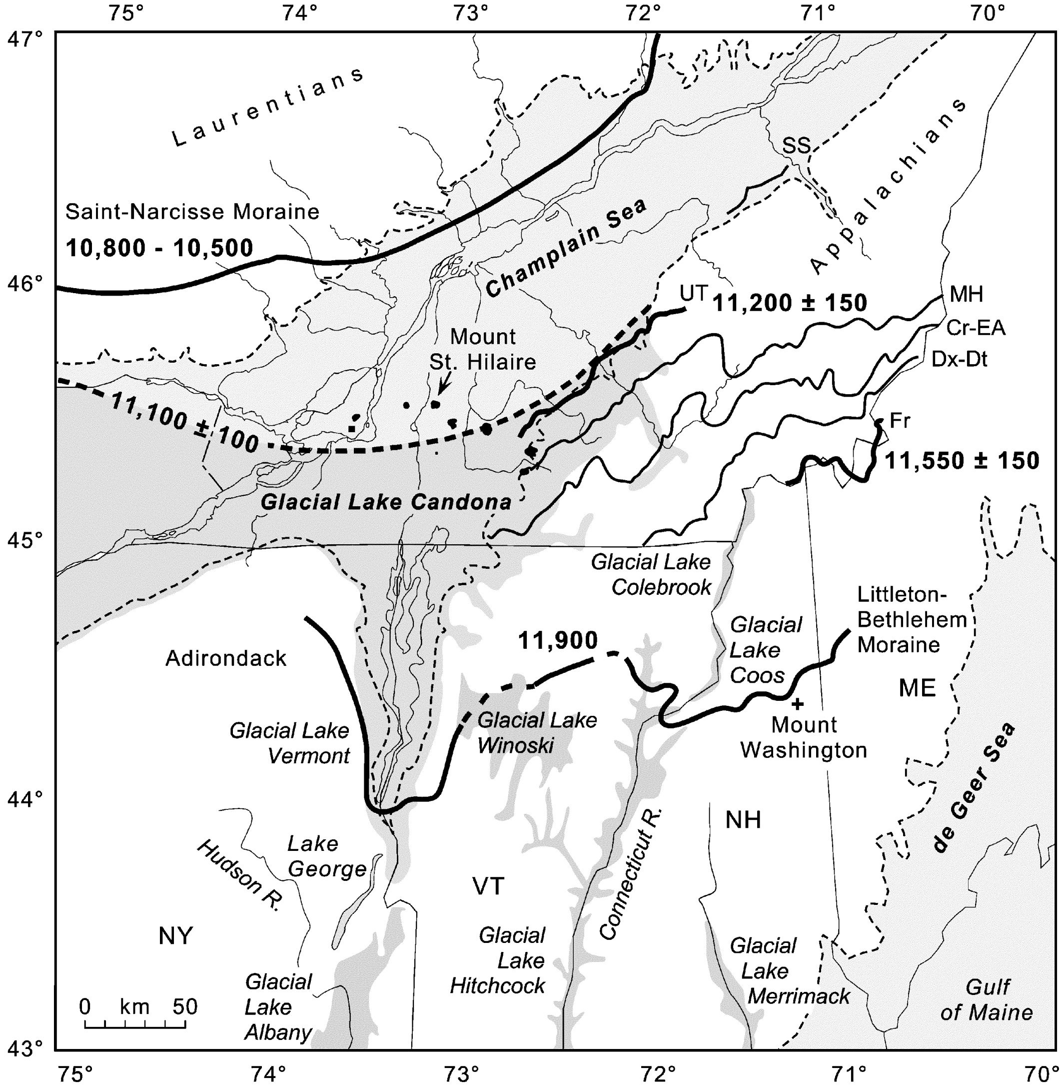

Figure 2. Chronology of ice retreat in south-central Québec and northern New-England, in conventional ^{14}C years B.P. Ages are given for Littleton-Bethlehem Moraine (LB) (Ridge et al., 2001), Frontier Moraine (Fr), Ulverton-Tingwick Moraine (UT), Saint-Narcisse Moraine (heavy lines), and for the estimated position of the ice-front at the onset of Champlain Sea (dashed heavy line) with estimated error (also given for UT and Fr). Other major morainic belts (light lines) in the Québec Appalachians include Saint-Sylvestre (SS), Mount Ham (MH), Cherry River-East Angus (Cr-EA), and Dixville-Ditchfield (Dx-Dt). Extent of Glacial Lake Candona (dark shading), maximal (diachronous) extent of Champlain Sea (light shading and dashed contour line), and position of the moraines in Québec modified after Occhietti et al. (2001b). Glacial lakes, de Geer Sea (maximal extent), and moraines in New England modified after Ridge et al. (1999, 2001). Conterminous States are identified by their code letters.

is smaller here due to more uniform tundra pollen assemblages and concentration throughout the sedimentary interval (Fig. 1c).

Since Mount St. Hilaire was located some 30–40 km north of the position of the ice front when Champlain Sea invaded the St. Lawrence Lowlands (Fig. 2), and applying an estimated rate of ice retreat of 250 m/yr (Occhietti et al., 2004), the age of the regional invasion of Champlain Sea is thus estimated at 11,100 ± 100 ^{14}C yr B.P. The event consequently occurred towards the end of the Allerød. This age also dates the end of proglacial Lake Candona (Fig. 2), that is, the ultimate glaciolacustrine phase resulting from the coalescence of Glacial Lakes Iroquois, Vermont and Memphremagog (Parent and Occhietti, 1988). Our estimated age is in agreement with the age of 11,150 ^{14}C yr B.P. proposed for this event by Anderson (1988), from the palynological study of a section exposing the lacustrine to marine transition, correlated with radiocarbon-dated lake sediments in eastern Ontario. It is also consistent with the radiocarbon dating of the New England varve chronology (Ridge et al., 1999, 2001).

A new chronology of ice retreat is thus proposed for southern Québec (Fig. 2). We accept the age of 11,900 ^{14}C yr B.P. for the Littleton-Bethlehem Moraine in New Hampshire (Ridge et al., 1999). The age of the Frontier Moraine is estimated at 11,550 ± 150 ^{14}C yr B.P., and that for the Ulverton-Tingwick Moraine is set at 11,200 ± 150 ^{14}C yr B.P. This chronology is 400 ± 100 years younger than what is proposed in the most recent synthesis on the chronology of ice retreat at the continent scale (Dyke et al., 2003b), and ca. 1000 years younger than the still widely cited Dyke and Prest (1987) chronology. At the regional scale, the chronology proposed by Parent and Occhietti (1999) and Occhietti et al. (2001b) is now viewed as being ca. 900 years too old, and the most recent one (Occhietti et al., 2004), ca. 550 years too old.

Glacial Lake Candona covered about 30,000 km^2, including Lake Post-Iroquois, glacial Lake Vermont, glacial Lake Memphremagog, and a deglaciated portion of the St. Lawrence Valley (Fig. 2). Drainage of Lake Candona at its northeastern edge caused a lowering of the water plane of 30 to 50 m (Parent and Occhietti, 1988), and a sudden freshwater influx of the order of 3000 km^3 in the North Atlantic Ocean, just before the invasion by the Champlain Sea. Our age estimation of 11,100 ± 100 ^{14}C yr B.P. for this event, a century or two before the end of the Allerød, should help refine the hypotheses relating such a drainage to the change in thermohaline circulation in the North Atlantic Ocean (Boyle, 2000), and to the intra-Allerød Killarney (cold) episode (Levesque et al., 1993).

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