Northeast Friends of the Pleistocene 2017

June 9-11, 2017

Middle and Late Wisconsinan events and stratigraphy in southern Québec – A new pre-LGM marine incursion

Fieltrip leaders:

- Michel Parent (Geological Survey of Canada, Québec, QC)
- Hugo Dubé-Loubert (Ministère de l'Énergie et des Ressources naturelles, Val d'Or, QC)

Collaborators :

- Pierre J.H. Richard, Université de Montréal, Montréal, QC
- Guillaume Légaré-Couture, INRS- Centre Eau, Terre, Environnement, Québec, QC
- J.P. Guilbault, Museum of Paleontology and Evolution, Montréal, QC

The 80th Annual Reunion of the Friends of the Pleistocene, head-quartered at Mont St-Hilaire (Gault Nature Reserve, McGill University) in southern Québec, Canada, is co-sponsored by the Geological Survey of Canada and the Ministère de l'Énergie et des Ressources naturelles du Québec.

Program - 80th Annual meeting of the NE Friends of the Pleistocene (June 9-11, 2017)

Middle and Late Wisconsinan events and stratigraphy in southern Québec – A new pre-LGM marine incursion

Day 1: Friday, June 9th

18:30 – Meeting and ice-breaker at the Gault House (Gault Nature Reserve, McGill University) on Mont Saint Hilaire. Instructions to participants and distribution of guidebooks.

Day 2: Saturday, June 10th (by bus)

Site 1 – Mont St-Hilaire slope. Typical fossil shell assemblages in Champlain Sea littoral deposits.

Site 2 – La Présentation. Post Champlain Sea alluvial sand sheet. Sablière Luc Beauregard

Site 3 – St-Jude. Lake Lampsilis rhythmites. Landslide of May 10th 2010 (4 casualties)

Site 4 – Bridge over Yamaska River. Presentation and discussion of sonic drillholes RS-4 et RS-2

Site 5 – St-Nazaire d'Acton – SE-trending striae on SW-trending roches moutonnées.

Site 6 – St-Dominique – Readvance till overlying esker and subaqueous outwash sediments.

18:00 – Gault House - Conference by Dr. Pierre J.H. Richard on the stratigraphic and paleoecologic record of Lac Hertel, a key site for the regional deglacial history.

19:00 - Annual banquet of the NE Friends of the Pleistocene

Day 3 (half day): Sunday, June 11th (by bus)

Site 7 – St-Césaire – Readvance till overlying esker and subaqueous outwash. Lake Candona varves. Champlain Sea fossil assemblages.

(Site 8 – Optional - West Brome - Lake Candona delta at 210 mASL).

Site 9- Abercorn – Lake Vermont rhythmites

1. Introduction

The 2017 fieldtrip, which is held in the St. Lawrence Lowlands of southern Québec for the first time since 1982 when Pierre LaSalle, Peter David and Michel Bouchard had hosted the 45th annual FOP fieldtrip in St-Hyacinthe and Drummondville (LaSalle et al., 1982). This fieldtrip includes visits to a series of 8 or 9 sites that will provide participants with an opportunity to discuss current concepts and issues on Late Quaternary stratigraphy and events in the St. Lawrence Valley and in the adjacent Appalachian piedmont and uplands (Fig. 1). At one of these sites, we will present and discuss the sediment record of four sonic boreholes drilled in 2010.

At the time of the 1982 meeting, the early radiocarbon age (> 12 500 BP) of the Champlain Sea incursion and associated deglacial events, most notably the ice-flow reversal in the Appalachians and the development of a calving bay in the St. Lawrence Valley, were controversial issues. The 1982 guidebook actually presented some evidence that questioned the calving bay model (Gadd, 1988) but the 1982 findings had not been fully integrated into a regional model and did not really challenge the calving bay model.

Now that the existence of a large proglacial lake preceding the Champlain Sea (Glacial Lake Candona) has been reinstated in the southern St. Lawrence Lowlands deglaciation framework (Parent and Occhietti, 1988; Rodrigues, 1992) and that late glacial ice-flow re-orientations have been ascribed to the development of ice-streams (Parent and Occhietti, 1999; Ross et al., 2006), other uncertainties in the regional Late Quaternary record have emerged as a result of new findings from fieldwork and drilling conducted in the context of regional hydrogeologic surveys (Dubé-Loubert et al., 2014; Carrier et al., 2013; Parent et al., 2014).

These new findings include:

- Multiple sites showing the presence of a possible post-LGM 'readvance till' overlying glaciofluvial and/or glaciolacustrine sediments. The age of this readvance remains unconstrained by stratigraphic data or by radiocarbon dating and its outer limit remains to be established. At this time, we believe this till may have been emplaced during the Lake Candona episode, but this has yet to be confirmed. In practice, it brings back to surface the Fort-Covington and Malone tills issue (Clark and Karrow, 1983).
- Pre-LGM fossiliferous marine sediments, overlying alluvial sands AMS-radiocarbon-dated at 31 270 ± 200 years BP and 33 250 ± 240 years BP. The fossil content and age of these sediments indicate that a relatively long Middle Wisconsinan interstadial event, characterized by normal drainage conditions and followed by a relatively short-lived marine incursion, preceded the Late Wisconsinan glacial advance across the region.

2. General geological and surficial contexts

Four physiographic and hydrogeological contexts can be defined in the study area (Figure 1). The **St. Lawrence Platform** is underlain by flat-lying sedimentary rocks of Cambrian and Ordovician age. They mainly consist of red and black shale, dolostone and limestone. The platform unconformably overlies igneous and metamorphic rocks of the Grenville Province (Precambrian basement). The regional hydrogeological context requires that the platform be

divided into two subregions: the **southern platform** which is mainly underlain by an assemblage of glacial sediments and thin Champlain Sea sediments (Fig. 2), and the **northern platform** where the glacial sediments are buried under a thick blanket of Champlain Sea clay and sand (Figs. 2 and 3). In the study area, **Appalachian** rocks, also Cambro-Ordovician in age, mainly consist of deformed low-grade metasedimentary rocks (sandstone, mudstone, limestone) but also include a few volcanic units. These rocks were intensely deformed, faulted and fractured mostly during the Taconian orogeny, and to a lesser extent during the Acadian orogeny. The Appalachians are composed of two zones: the External zone (corresponding to the Piedmont physiographic region) and the Internal zone (corresponding to the Uplands physiographic region). Rocks of the External zone in Quebec are slightly less metamorphosed than those of the Internal zone. Logan's Line, a major fault zone, separates the St. Lawrence Platform from the Appalachians. **Post-orogenic intrusive rocks** in Quebec correspond mainly to Cretaceous alkaline intrusives of the Monteregian Hills. Although these late intrusives are of limited areal extent, they constitute a separate context because they show distinctive characteristics compared to the other contexts and because they play a distinct and key role in the regional hydrogeology of the study area.

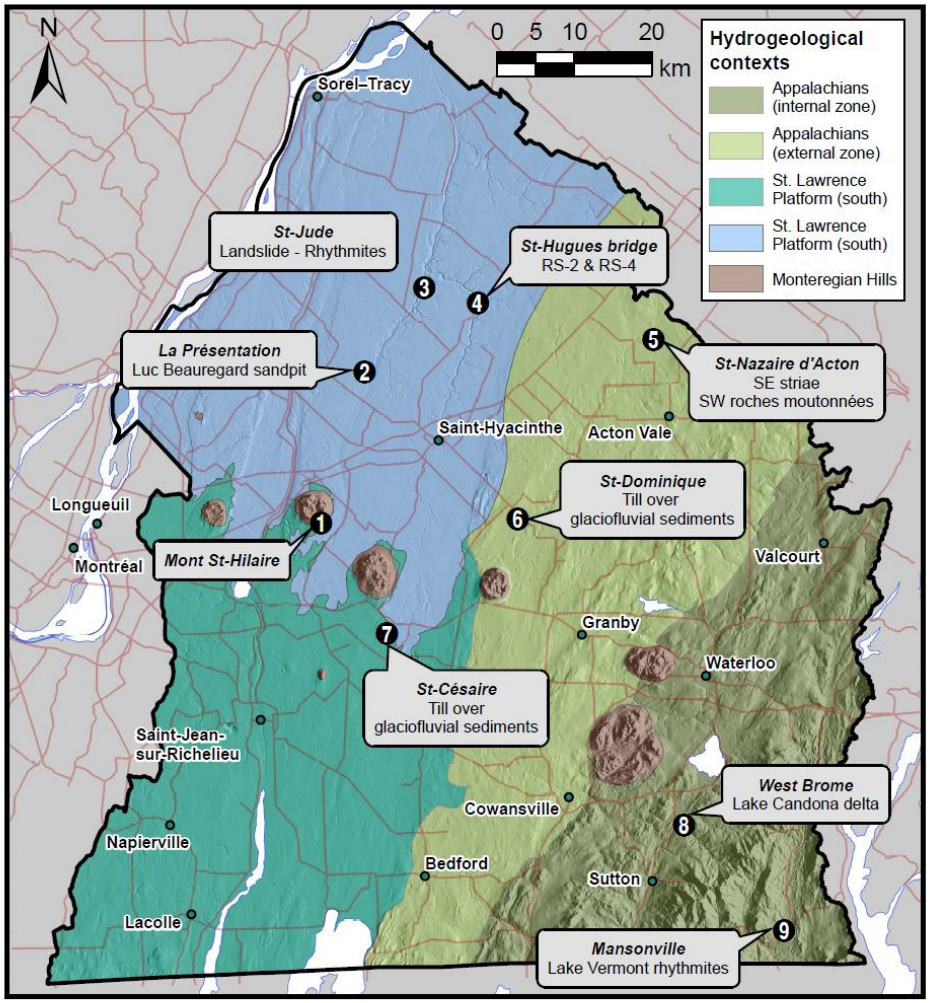

Figure 1: Simplified map showing regional physiographic contexts and location of fieldtrip stops.

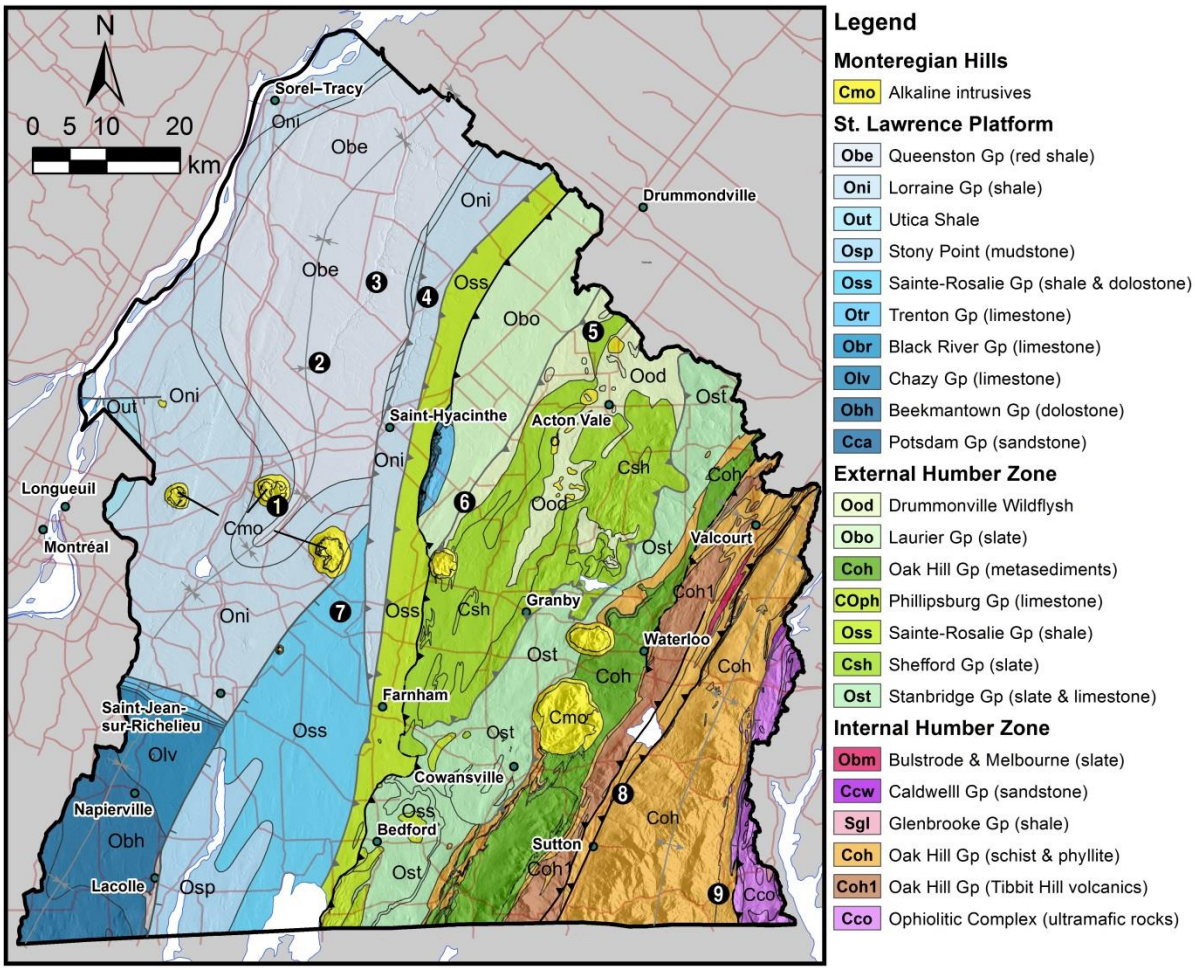

Figure 2: Generalized bedrock geology map (modified from Slivitsky and St-Julien, 1987; Globensky, 1987)

The surficial geology map presented in Figure 3 is a generalized version of the 1:50 000 maps prepared by Dubé-Loubert et al. (2014). As shown in Figure 3, till is the most extensive Quaternary unit in the study area. In the northern part of the **St. Lawrence Lowlands**, the regional till is generally covered by a 20 to 30 m thick blanket of marine muds that were deposited in the Champlain Sea, an arm of the Atlantic Ocean that inundated the isostatically depressed St. Lawrence Valley up to almost 200 m ASL. This post-glacial sea existed for almost 2 000 years at the end of the last deglaciation.

The marine unit locally overlies fine-grained varves that had been deposited during the preceding Glacial Lake Candona episode (Figure 4) (Parent and Occhietti, 1988 and 1999). Lake Candona shorelines lie about 40 to 60 m above Champlain Sea shorelines and have been observed on the Appalachian Piedmont and valleys as well as in the Lake Champlain and Upper St. Lawrence valleys. In the southern part of the St. Lawrence lowlands, the marine clay unit is thinner and much more discontinuous.

Here, except in local mud-filled bedrock lows, the surficial units are relatively thin (< 10 m) and consist of a mosaic of wave-reworked till and littoral sands and gravels. Regionally, the marine muds grade upward into freshwater muds that were deposited in Lake Lampsilis (Figure 5), a body of freshwater water that replaced marine waters as relative sea level fell below about 60 m in the Québec City region. Continued uplift led to further emergence and to the deposition of a discontinuous blanket of alluvial sands by the Proto-St. Lawrence River. This offlap fluvial unit increases in thickness near the modern St. Lawrence River and Lake St-Pierre.

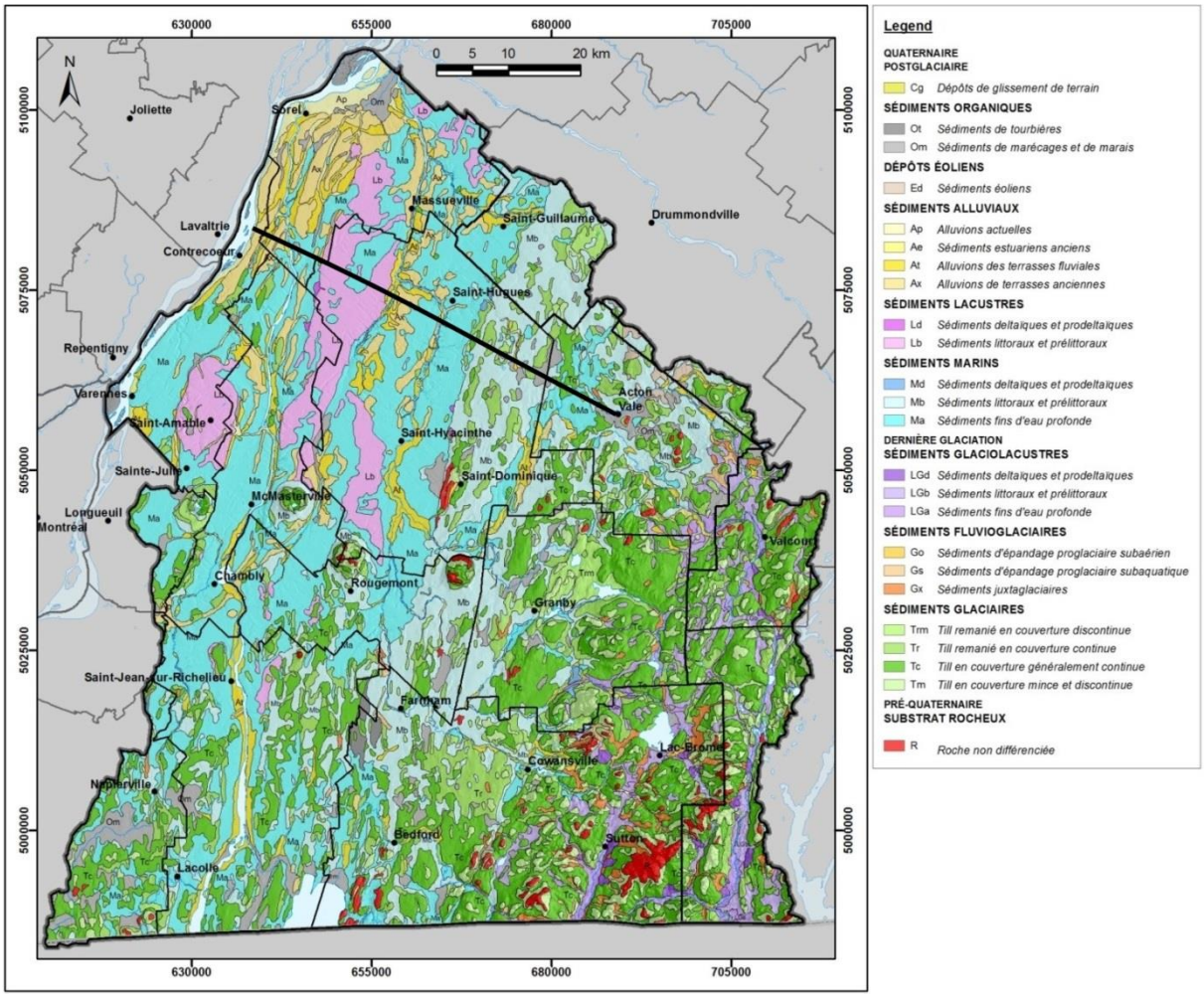

Figure 3: Surficial geology map (generalized at a scale of 1:500 000 from detailed 1:50 000 map sheets) (Dubé-Loubert et al., 2014). Approximate location of the schematic cross-section of Figure 4 is shown by a black line.

In the **External zone (Appalachian Piedmont)**, the Quaternary sediment cover is thin and rock outcrops are quite common. The top 1 to 2 meters of the surface till were vigorously reworked and winnowed by waves and currents of the Champlain Sea and are therefore coarser and more permeable than the underlying compact till. Littoral sands and gravels along with reworked tills are the most widespread surficial unit of the Piedmont. Champlain Sea muds are restricted to the

main valleys, such as the Yamaska and Rivière Noire valleys. In the **Internal zone (Appalachian Uplands)**, the till cover is generally thin and discontinuous on topographic highs and rock outcrops are abundant. In mountainous terrains, such as in the Sutton Hills, coarser melt-out till commonly cover bedrock or compact basal till. Glaciofluvial sands and gravels occur almost exclusively in valleys where glacial meltwaters were concentrated. Glaciolacustrine sediments, including varved silt and littoral/deltaic sand, are common in the main Appalachian valleys (e.g., Upper Missisquoi and Sutton).

Figure 4 presents a schematic cross-section between the St. Lawrence River and the Appalachian uplands in the northern part of the Richelieu-Yamaska region. In addition to the distribution of Champlain Sea and post-Champlain Sea sediments, the cross-section presents a schematic view of the architecture of the underlying glacial and non-glacial sediments. Archival well data together with new borehole data and multiple CPT soundings show a nearly continuous till sheet. A cored borehole (RS-02) has intersected a body of subaqueous outwash sand which is overlain by thin till and overlies a thick till unit. A similar stratigraphic context can also be observed near St-Césaire at Stop #5. Borehole RS-04 intersected plant-bearing alluvial sands between two till units. Selected plant debris from the alluvial sand were dated at 31 270 ± 200 years BP (Beta-343397). This alluvial unit thus predates the Last glacial maximum (LGM) but appears as significantly younger than the classical St-Pierre Sediments (Gadd, 1971; Lamothe, 1989; Occhietti, 1990).

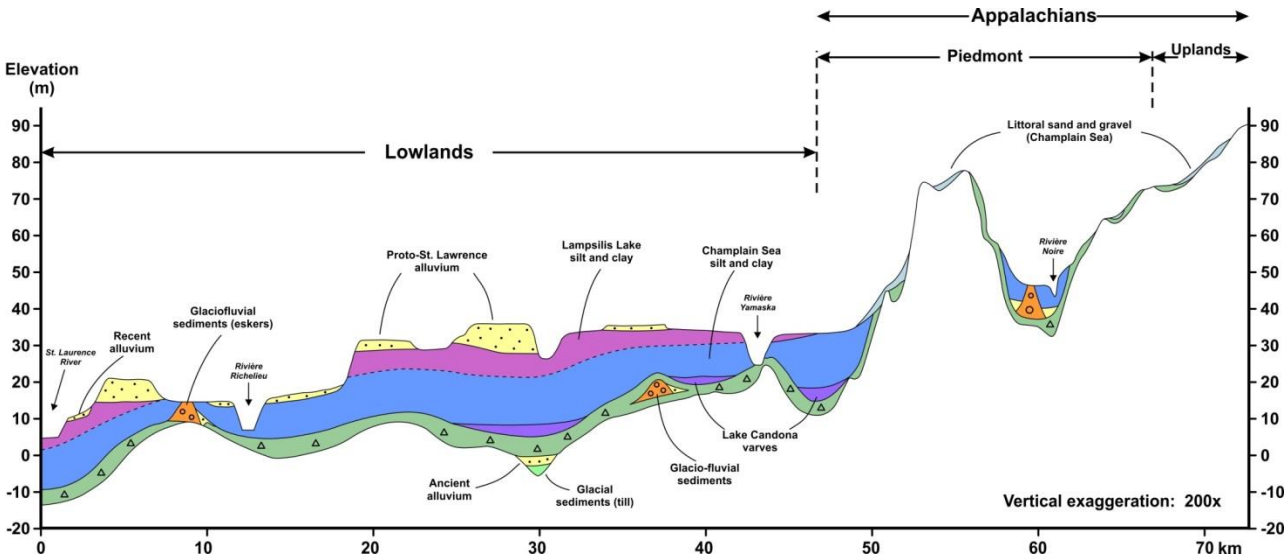

Figure 4: Schematic cross-section showing representative Quaternary units in the northern part of the study area.

3. Late Wisconsinan deglaciation

Ice retreat pattern in south-central Québec and adjacent regions (Fig. 5) were compiled by Richard and Occhietti (2005) on the basis of earlier work by various authors (Gadd et al., 1972; Parent, 1987; Occhietti et al., 2001; Ridge et al., 1999, 2012). Figure 5 depicts the general northward ice-retreat pattern that characterized Late Wisconsinan deglaciation and it also shows the areal extent of water bodies that occupied the St. Lawrence Valley, namely **Glacial Lake Candona** and the ensuing Champlain Sea. The Ulverton-Tingwick Moraine (UT) is a fairly small moraine that was formed near the end of the Lake Candona episode while the slightly older Mont Ham Moraine (MH) was emplaced during the final (Sherbrooke) phase of Glacial Lake Memphremagog (Parent and Occhietti, 1999; McDonald, 1968). The Cherry River/East-Angus Moraine (CR-EA) was emplaced near the beginning of the Sherbrooke phase while the Dixville-Ditchfield Dx-Dt) and Frontier (Fr) moraines were emplaced in earlier proglacial lakes that have yet to be dated or firmly correlated with the regional framework of deglacial events.

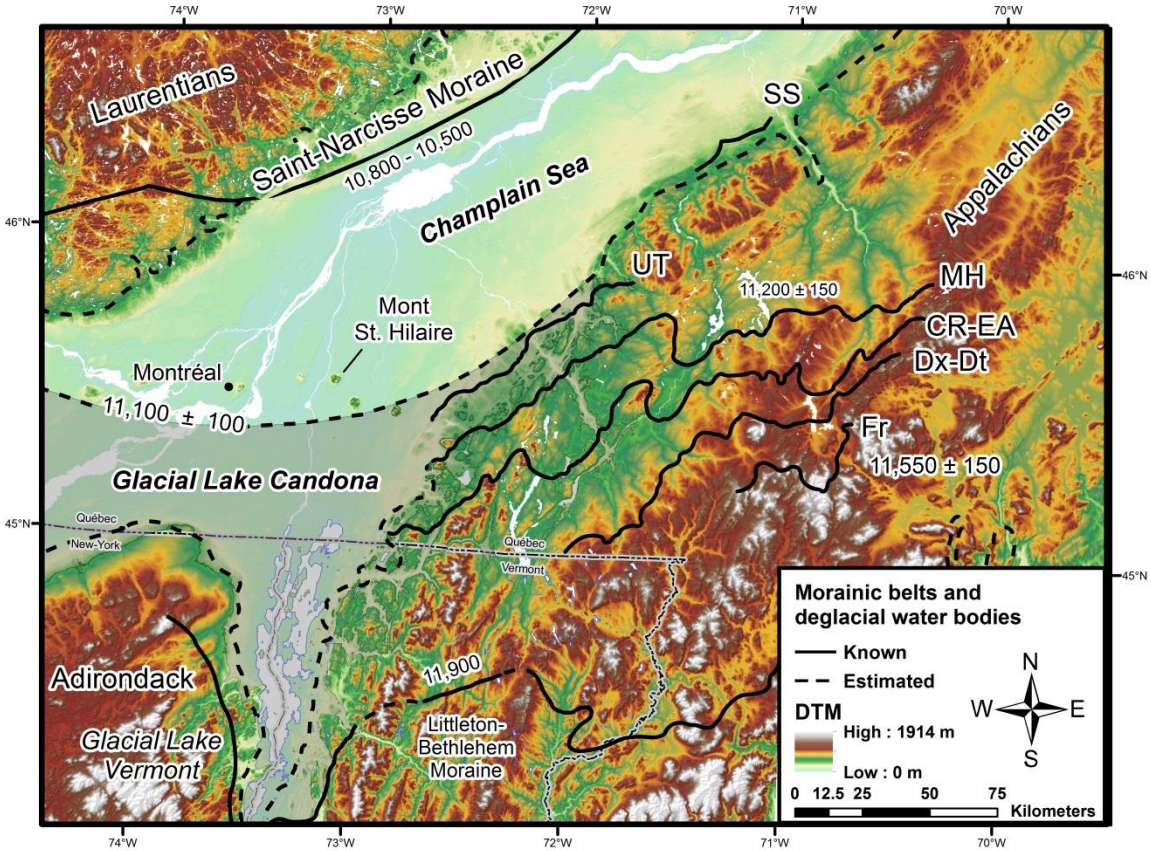

Figure 5: Ice retreat pattern and chronology (Conventional ^{14}C years BP) south-central Québec and adjacent New England (from Richard and Occhietti, 2005) The outline of the Ulverton-Tingwick (UT) , Mont Ham (MH), Cherry River-East-Angus (CR-EA) and Dixville-Ditchfield (Dx-Dt) moraines are after Parent (1987). The Frontier Moraine (Ft) is after Shilts (1981) while the Littleton-Bethlehem Moraine is after Ridge et al. (1999).

The areal extent of Glacial Lake Candona, which resulted of the coalescence of three earlier glaciolacustrine water bodies (Vermont, Iroquois and Memphremagog) in the southern part of the St. Lawrence Valley (Fig. 6). The lake was named by Parent and Occhietti (1988) after its characteristic fossil, *Candona subtriangulata,* an ostracod species that thrived in cold glaciocustrine waters. Since Lake Candona was a relatively short-lived water body, lasting slightly more than about 100 years in southern Québec, as recorded by the Danville Varves (Parent and Occhietti, 1999), its reconstructed water plane records an almost isochronous glacial isostatic tilt of about 1m/km. Lake Candona drained southward through the Fort Ann outlet to the Hudson River during its maximum extent. The exact mechanism and the pathway of its final discharge into the Goldthwait/Champlain Sea have yet to be documented.

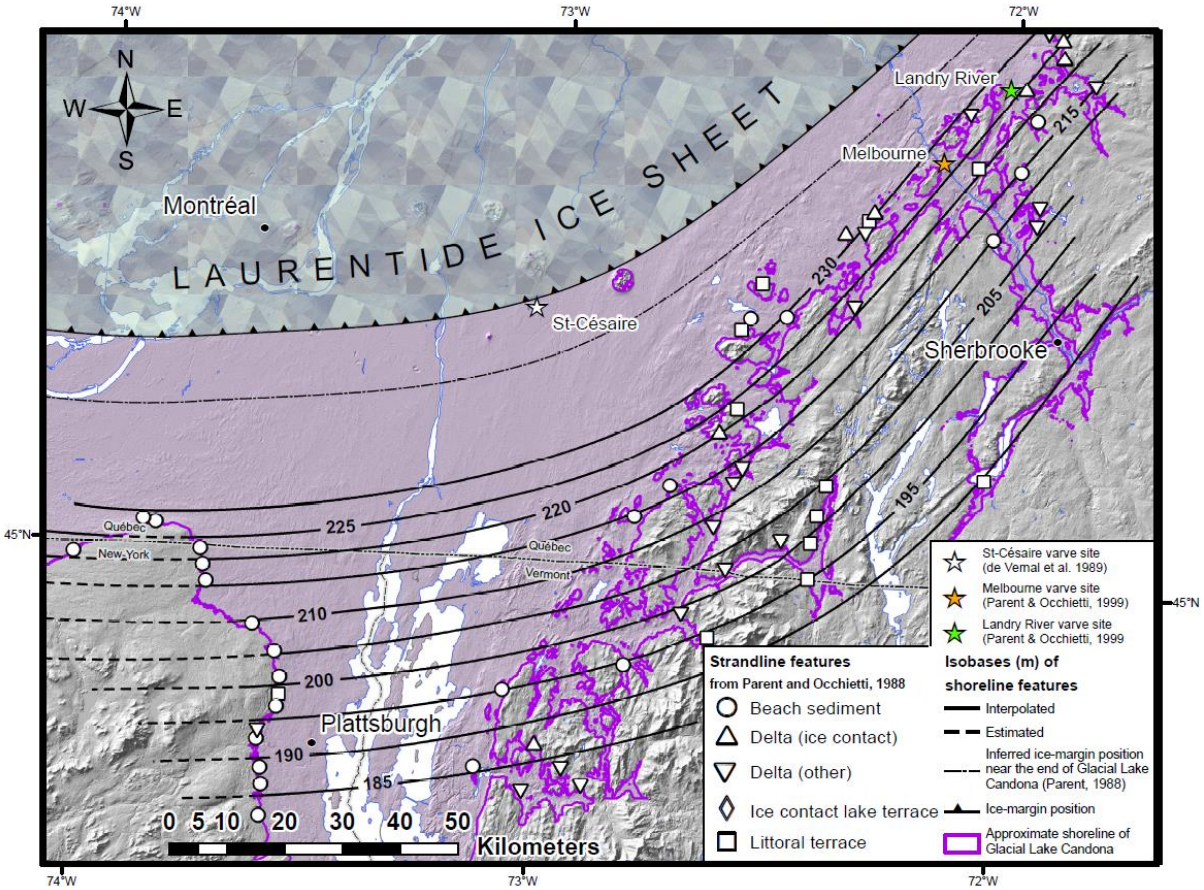

Figure 6: Glacial Lake Candona at or near its maximum extent in south-central Quebec, eastern Ontario and northern New-England (from Parent, 1987; Parent and Occhietti, 1988). Also shown are the Landry River, St-Césaire and Melbourne varve sites.

When Lake Candona discharged to sea level, water levels in the St. Lawrence and Lake Champlain valleys fell by about 55 m, hence from 230 m ASL along the edge of the Appalachian piedmont (Fig. 6) down to about 175 m ASL (Fig. 7), which is the local elevation of the marine limit.

As the upper **Champlain Sea** shoreline features are slightly younger than the Lake Candona features and the associated ice-front position lies further north, their tilt is slightly less (0.9 m/km) than that recorded by Lake Candona strandlines.

The regression of the Champlain Sea was rapid and largely controlled by glacial isostatic uplift as it took place in a context of globally rising sea level. By about 9800 years BP, waters in the marine basin had been replaced by a successor freshwater lake, called **Lake Lampsilis** on the basis of the characteristic freshwater shell observed in littoral and sublittoral sediments below about 60 mASL (Elson, 1969; Parent et al., 1997). The possible occurrence of standstills, or even minor transgressions, during the Champlain Sea regression has been alluded to occasionally in the literature, but firm evidence for such events has yet to be found.

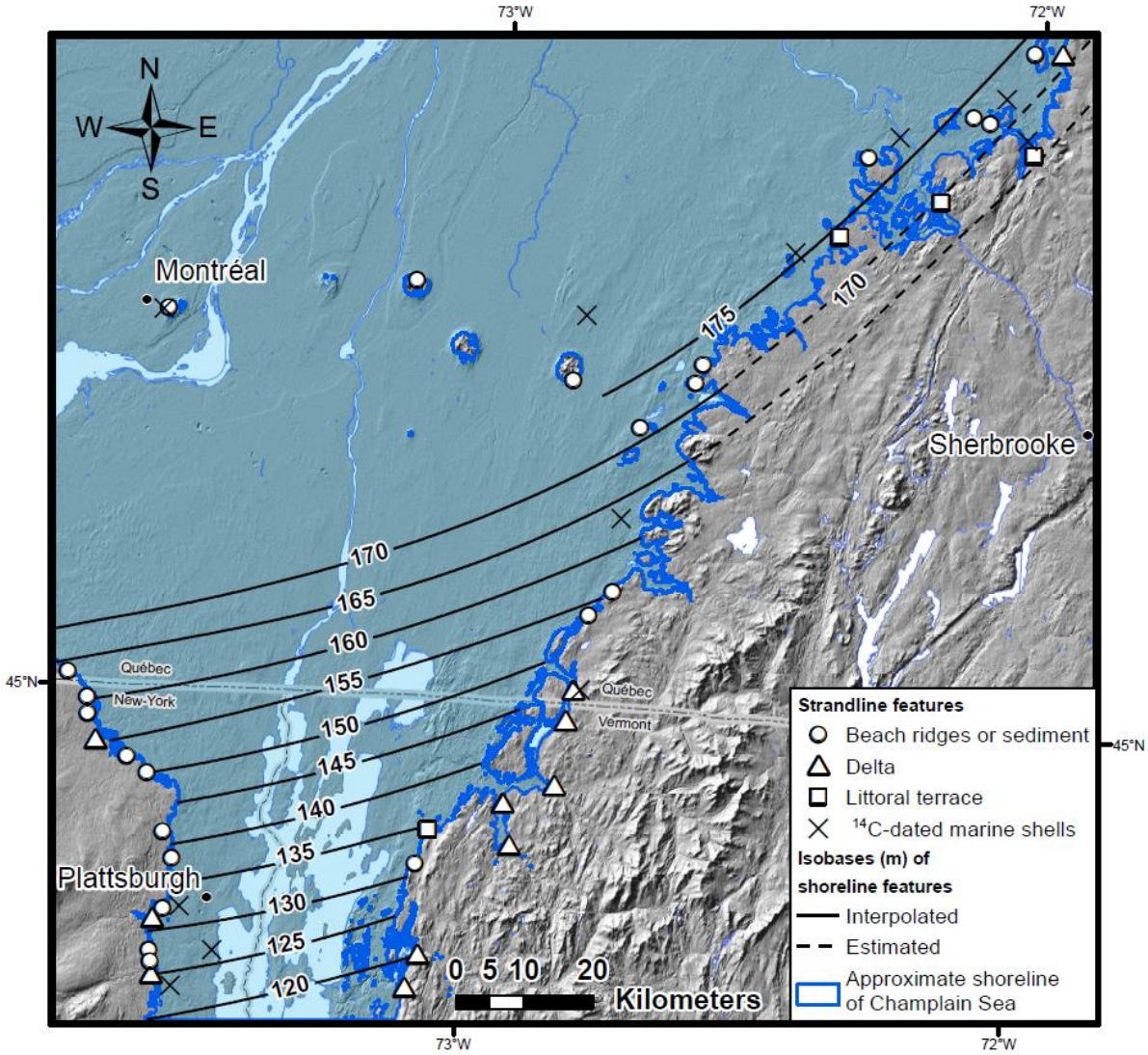

Figure 7: The Champlain Sea at its maximum upper limit in south-central Quebec and northern New-England (from Parent and Occhietti, 1988).

4. Fieldtrip stops

Site 1 – Mont St-Hilaire – rue Noiseux

Site	Map sheet	UTM_X	UTM_Y	Lat	Long	Z_SRTM
1	31 H/11 (Beloeil)	644765	5043902	45.5336	-73.1459	80 m

This stop is located in an abandoned gravel pit which exposes two of the most common Quaternary units in the region. The top unit consists of a variety of Champlain Sea littoral sediments. These sandy sediments overlie a compact till which can be observed in many of the small streams that run across the pit floor.

The littoral sediments range in elevation from 50 m at the pit entrance to about 110 m, which is marked by a well-developed cobblestone ridge. This fairly large elevation range allows us to observe several typical littoral lithofacies, mainly sand here, as well as marine faunal assemblages characteristic of shallow Champlain Sea environments. The fossil shells observed in the upper part (80 to 90 m ASL) of the pit consist essentially of *Hiatella arctica* and *Balanus crenatus*, two species that thrived on pebbly to stony substrates throughout the Champlain Sea history (Hillaire-Marcel, 1980; Fig. 8). This is why most of the fossil shells lie close to the contact of the littoral sands with the underlying till. At lower elevations, a few additional species, namely *Macoma balthica* and *Mya arenaria*, both of which thrived on sandy substrates, may be observed. The presence of *Mya arenaria* indicates that the cold waters of the early marine phase had become more temperate as relative sea level had fallen during the second half of the Champlain Sea episode (Elson, 1969).

The till exposed along the banks of the small streams is quite characteristic of that observed in boreholes and surface exposures in the study area. It is a matrix-dominated, compact and fissile diamicton that contains abundant faceted and striated stones. At this locality, the till is lithologically diverse, with stones of distant as well as local provenance. Abundant seeps observed at the sand-till contact indicate that, where present, this till unit acts as a partial barrier to infiltration on the lower flanks of the Monteregian Hills.

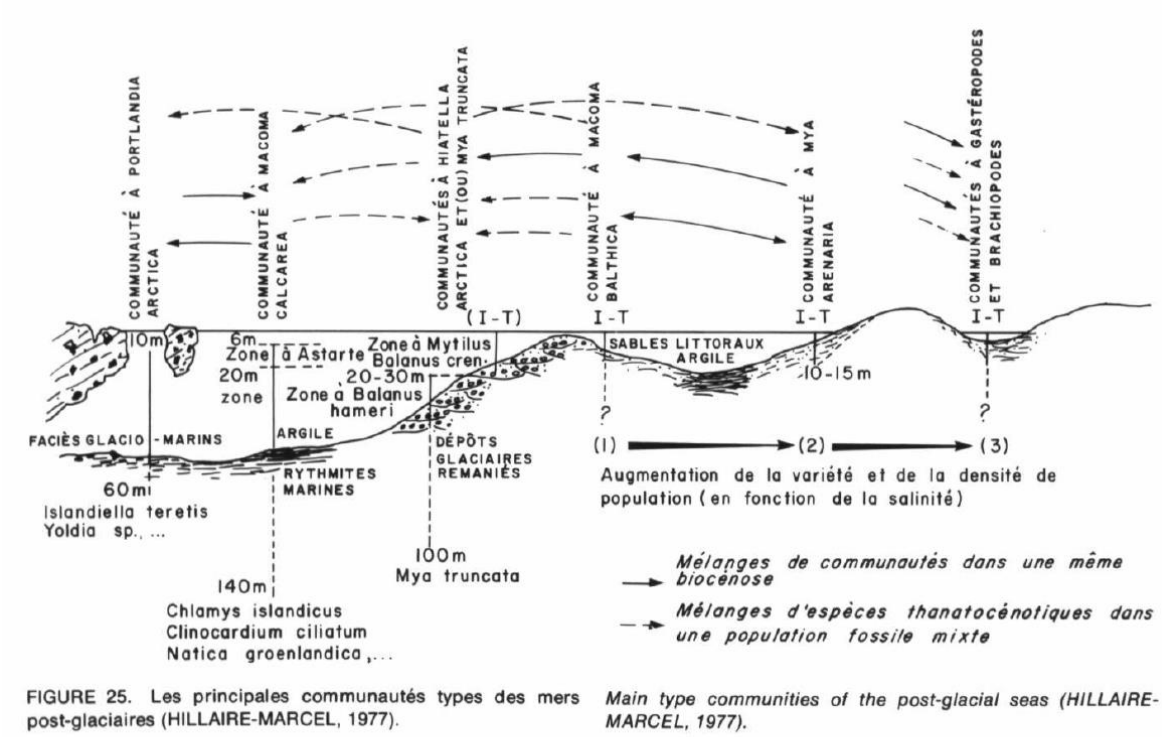

FIGURE 25. Les principales communautés types des mers post-glaciaires (HILLAIRE-MARCEL, 1977).

Main type communities of the post-glacial seas (HILLAIRE-MARCEL, 1977).

Figure 8: Main fossil shell communities of eastern Canadian postglacial marine basins (Champlain Sea, Goldthwait Sea, Laflamme Sea, Tyrrell Sea, Iberville Sea; from Hillaire-Marcel, 1980).

Site 2 – La Présentation – Sablière Luc Beauregard

Site	Map sheet	UTM_X	UTM_Y	Lat	Long	Z_SRTM
2	31 H/11 (Beloeil)	650487	5063387	45.7077	-73.0667	39 m

Alluvial sands deposited along paleochannels of the Proto-St. Lawrence River are exposed in this shallow sand pit. The alluvial sand blanket observed here thins out laterally to less than 1 m. In the region, because of the scarcity of this resource, cover sand veneers such as this one are exploited commercially.

Two radiocarbon dates, one (9250 ± 50 years BP) from a small wood fragment collected in this pit, another (9300 ± 60 years BP) from a 50 cm-long *Betula sp* stem recovered in an adjacent pit by the owner (Mr. Luc Beauregard), are consistent with our current understanding of post Champlain Sea drainage evolution and choronology.

Site 3 – St-Jude – Lanslide of May 10, 2010 – Lampsilis rythmites

Site	Map Sheet	UTM_X	UTM_Y	Lat	Long	Z_SRTM
3	31 H/15 (St-Guillaume-d'Upton)	658231	5074326	45.8043	-72.9637	26 m

Although the landslide (lateral spread) of May 10th, 2010 was a relatively small one (Fig. 8), it swept away not only the road but also the lives and home of a family of four. Landslides such as this one are a relatively common event in thick marine clays of the northern St. Lawrence platform and in other similar contexts in southern Quebec. This lansdslide was thoroughly investigated by a geothechnical team of the Quebec Department of Transport (Locat et al., 2011, 2017). Fortunately, this landslide did not generate widespread liquefaction of the clays.

Figure 9: View of the upper part of the landslide of May 10th, 2010. The road pavement can be seen in the foreground, the landslide scarp is in the background.

The landslide provided an apportunity for our team to observe silty clay rhythmites (Fig. 10) forming the upper part of the clay succession; although no analysis of the microfauna was conducted to establish a biostratigraphic record, these rhythmites are thought to have been deposited in Lake Lampsilis.

Figure 10: Silty clay rhythmites observed near the top of the debris pile in the Saint-Jude landslide. These rhythmites were presumably deposited in Lake Lampsilis.

Site 4 –Bridge over Yamaska River near St-Hugues – RS-4 et RS-2

Site	NTS Map sheet #	Map sheet name	UTM X	UTM Y	Lat	Long	Z
4	31 H/15	Saint-Guillaume-d'Upton	665200	5072350	45.7849	-72.8747	13 m

We stop at this location to present a few results of the subsurface investigations that were carried out during our project as this allows us to discuss key aspects of the regional Quaternay stratigraphic architecture (Fig. 11) and record (Fig. 12) as well as an important regional hydrogeological feature, namely the occurrence of saline groundwater trapped in sediments and rocks under Champlain Sea clays (Beaudry et al., 2011). The cross-section shown in Figure 11, which passes about 10 km south of where we stand, was chosen among many sections depicting

the architecture and morphology of sediments underlying Champlain Sea clays. The section is based on water well records compiled from a variety of sources, including a few boreholes carried out by private consultants as well as by government agencies, and on a 3C high-resolution seismic reflection profile carried out by our colleagues from the Geological Survey of Canada in Ottawa. The seismic profile allowed us to site a sonic borehole (RS-02) on a large buried ridge at km 5 (Fig.11). Although we had hoped to encounter a gravel aquifer in the bedrock channel underlyingthe ridge, the channel is filled by compact till. Hence below Champlain Sea clays, we drilled through a thin sandy till unit, then into a 25 m-thick unit of medium to fine sand interpreted as subaquatic outwash sediments, and then into a 16 m-thick compact till unit resting directly on the bedrock channel (Fig. 12).

The bedrock that can be observed in the Yamaska River bed belongs to the parautochtonous domain bound by regional faults separating the Appalachians from the St. Lawrence platform. The Quaternary sediment architecture depicted by Fig. 11 actually extends from here upstream to St-Hyacinthe, a distance of about 25 km, with the notable exception that rocks of the parautochtonous domain crop out near river level at numerous sites. This situation allows deep groundwater flow discharging from the Appalachians to be intercepted and to seep into the Yamaska River, thus preventing the flushing of old Champlain Sea waters from the large regional aquifer underlying Champlain Sea clays (Beaudry et al., 2011).

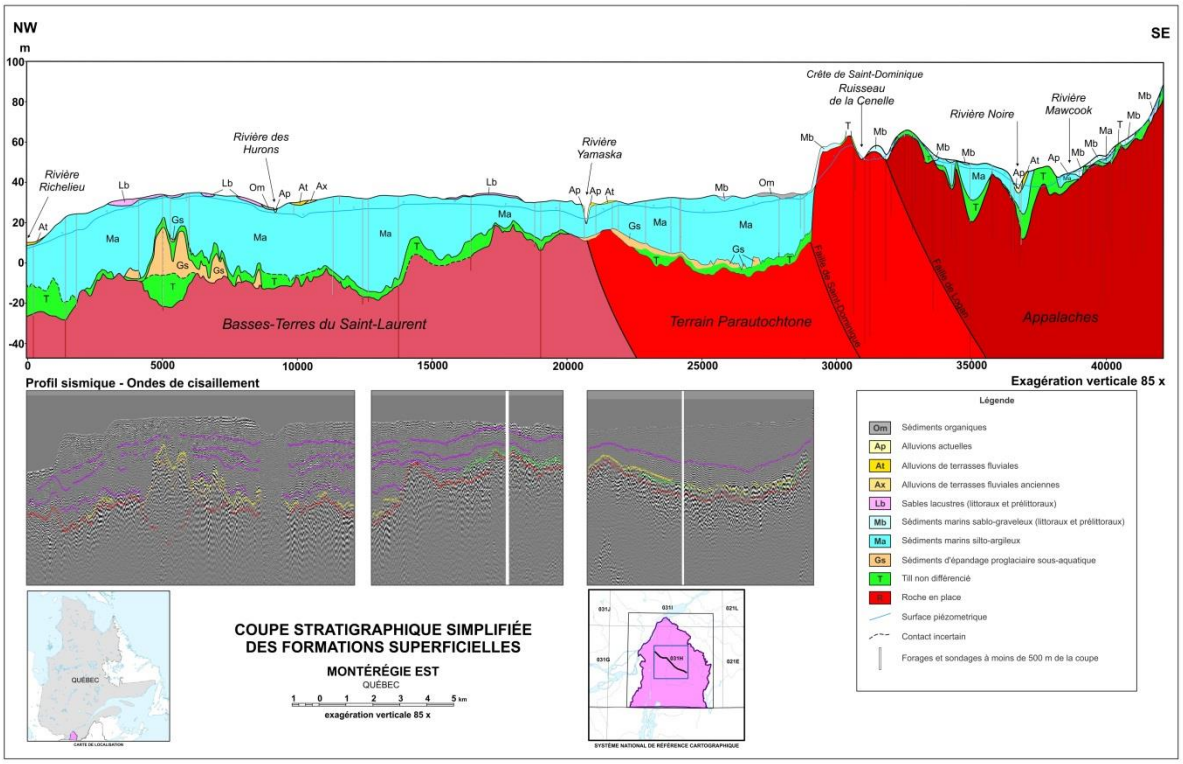

Figure 11. Representative cross-section of Quaternary units between the Richelieu River and the Appalachian Piedmont. Notice the vertical exaggeration of 85 X of this 40 km-long section. The buried subaquatic outwash/esker ridge complex at km 5 was first identified by the 3C seismic survey and then confirmed by a rotosonic cored borehole (RS-02).

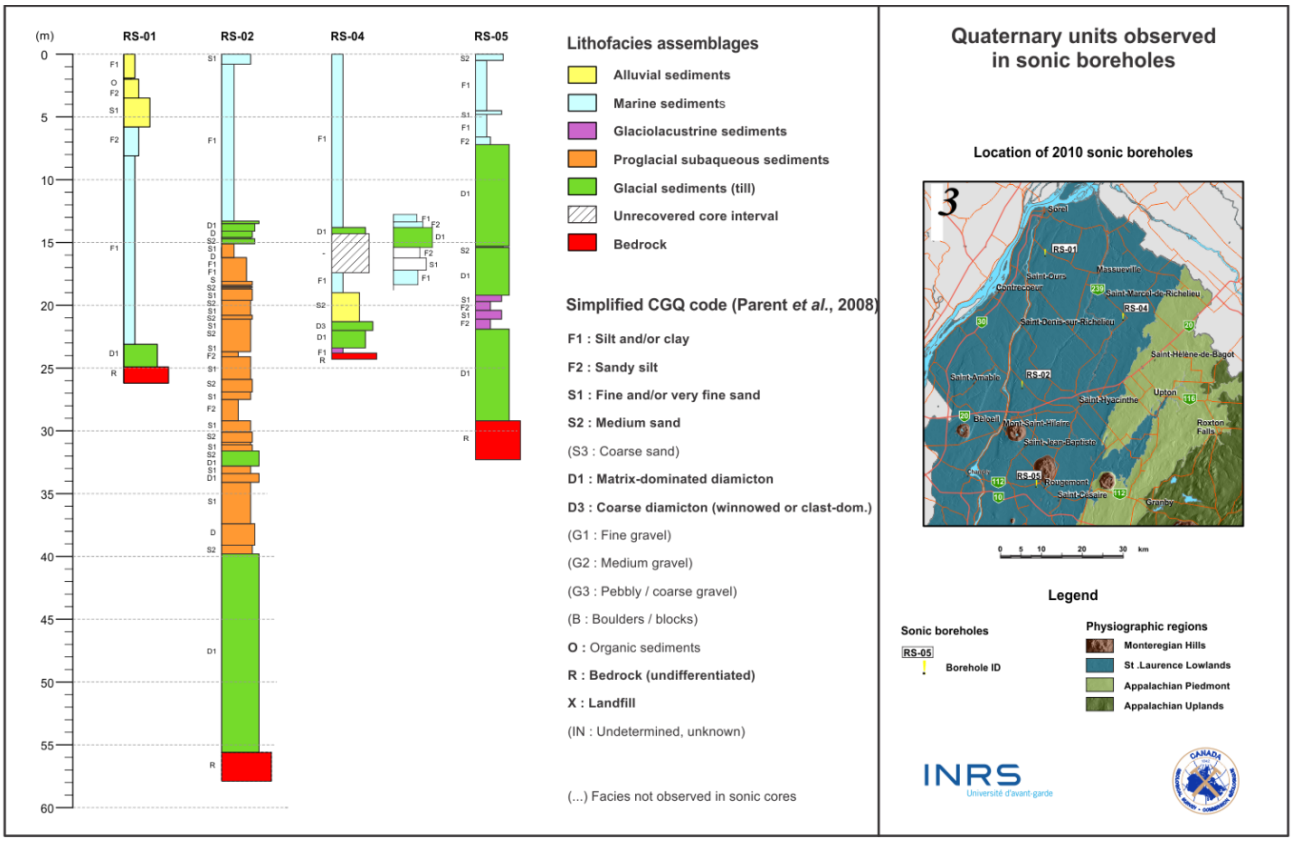

Figure 12: Summary stratigraphic logs of sonic cores recovered in Montérégie Est (modified from Parent et al., 2014)

These cores show the complex stratigraphic record of units concealed below Champlain Sea sediments. Core RS-04 was pulled from a site about 5 km north of here (stop #4). Due to inadequate recovery at the time of the original drilling, we returned later (May 2013) to the drilling site in order to recover new cores from the missing interval.

Biostratigraphic investigations and ^{14}C dating of the missing core intervals have now been completed. Core RS-04 shows that the till underlying Champlain Sea muds overlies an older marine unit which in turn overlies an organic-rich alluvial unit dated at 31 270 ± 200 years BP (Beta-343397). Underlying the alluvial sand is another till unit which overlies thin rhythmites resting on bedrock. This subtill stratigraphic record is entirely new in southern Québec and we expect it will lead us to revisit the nature and timing of events that preceded the advance of the Laurentide Ice Sheet in the St. Lawrence Valley prior to the LGM.

The microfaunal record of RS-04 was established by Jean-Pierre Guilbault of the Museum of Paleontology and Evolution in Montreal. As shown in Figure 13, the observed biostratigraphic succession is relativey standard in Champlain Sea sediments (0 to 15 m); Dr. Guilbault is here with

us to present his results and interpretation, particularly for the marine unit underlying the Gentilly Till and overlying the alluvial micaceous, organic-rich sand dated at 31 270 ± 200 years BP.

Core RS-01 (Fig. 12) was also investigated for its biostratigraphic (foraminifers and ostracods) and paleosalinity record; this work indicates that RS-01 provides a particularly useful record of the second half of Champlain Sea history.

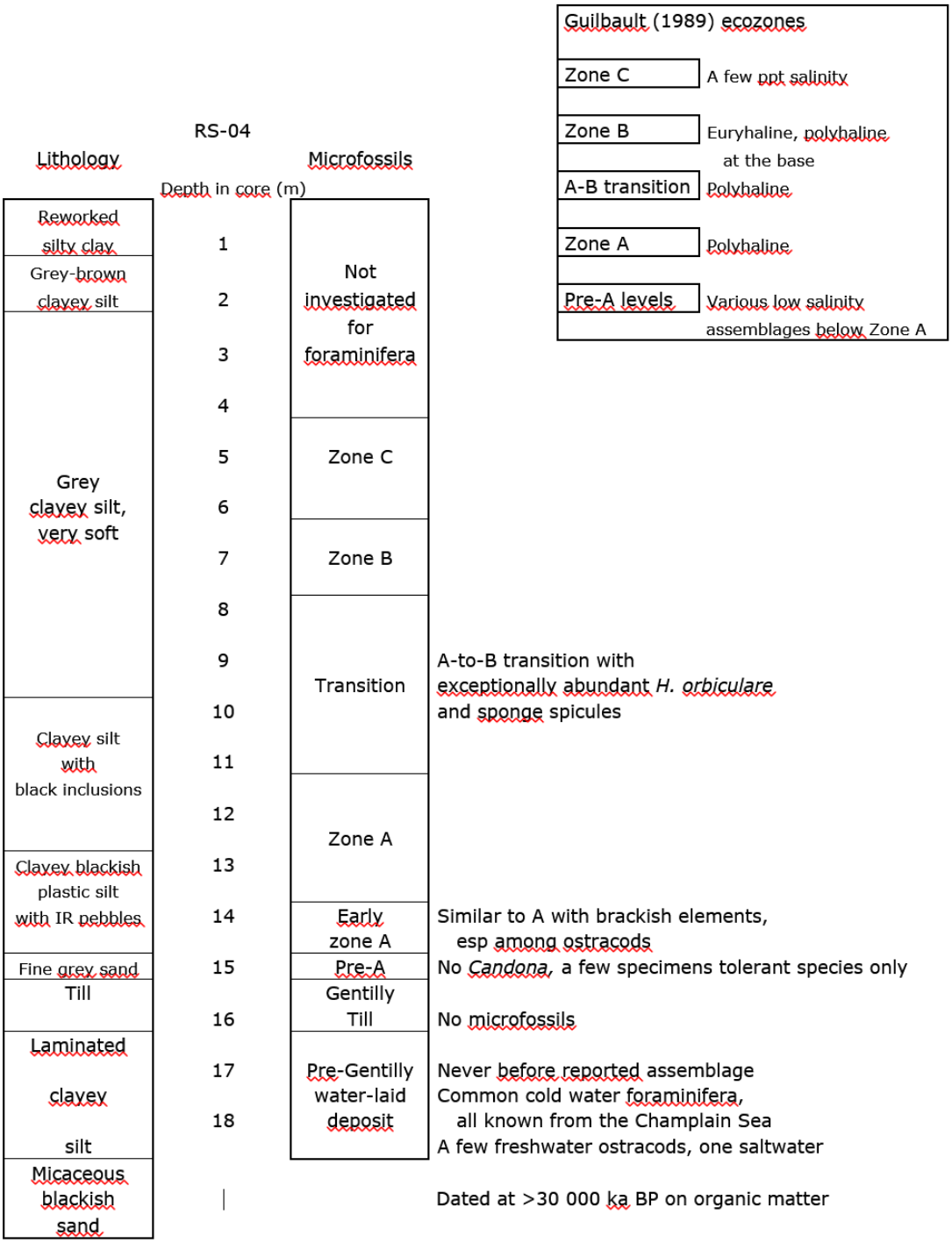

Figure 13: Lithologic and microfossil record of borehole RS-04 collected near St-Hugues.

Site 5 – St-Nazaire d'Acton – SE-trending striae on SW-trending roches moutonnées

Site	NTS Map sheet #	Map sheet name	UTM X	UTM Y	Lat	Long	Z
5	31 H/10	Saint-Hyacinthe	687723	5067623	45.7367	-72.5871	73 m

Figure 14 : SW-trending roches moutonnées on pinkish quartzo-feldsphatic sandstone of the Granby nappe.

The North-trending asymmetrical strike ridge shown in Figure 14 displays distinct stoss-and-lee relationships comparable to those commonly observed in Shield terrains of northern Québec. This outcrop has distinctly plucked steep surfaces facing SW and smooth stoss surfaces facing NE. The ridge also shows a series of metric-sized SW-trending ondulations that are characteristic of glaciated surfaces. We interpret these asymmetrical landforms as "roches moutonnées", which are rather uncommon features in the Appalachian Piedmont of southern Québec. Their southwestward trend is almost parallel to that of striae observed at a few nearby sites (Lortie and Martineau, 1987) where they are crosscut by a younger set of SSE-trending striations. Likewise, the top surfaces of the roches moutonnées at this site (Figure 15) bear SE-trending striae (150°).

These occurrence of roches moutonnées lead us to reassess the regional implications of such a massive 'Appalachian' ice movement in the region.

Figure 15 : Striae trending 150° superimposed on the surface of SW-trending "roches moutonnées" near St-Nazaire-d'Acton.

Site 6 – St-Dominique – Till overlying subaqueous outwash sediments

Site	NTS Map sheet #	Map sheet name	UTM X	UTM Y	Lat	Long	Z
6	31 H/10	Saint-Hyacinthe	670238	5044463	45.5329	-72.8197	53 m

This site, located on the St-Dominique ridge, shows the remaining margins of an esker that has been exploited as a gravel pit for many years. These margins currently show subaqueous sandy silt sediments overlain by a diamictic glacial unit. Figure 16 is a general view of the till sheet overlying the subaqueous silty sands. The inset photo provides an excellent example of the brecchiated glaciolacustrine silt and sand that constitutes the basal part of the till sheet.

Figure 16: General view of the St-Dominique pit exposure, with an inset photograph showing the the brecchiated unit forming the base of the till sheet.

Site 7 – St-Césaire – Till overlying subaqueous outwash sediments

Site	NTS Map sheet #	Map sheet name	UTM X	UTM Y	Lat	Long	Z
7	31 H/06	St-Jean-sur-Richelieu	653330	5029560	45.4028	-73.0408	42 m

Altough this site is somewhat similar to the St-Dominique locality visited at the previous stop, it adds one aspect which we did not have much opportunity to discuss during the fieldtrip, that is the occurrence of pre-Champlain Sea varves. This pit is actually the one in which varves containing a *Candona subtriangulata* fauna, much as at the Rivière Landry site (Parent and Occhietti, 1988, 1999), were reported by de Vernal et al. (1989). However the varve exposure was destroyed several years ago and no longer can be observed.

At the St-Césaire site (Fig. 17), the surface till overlies thick compact sandy sediments that are interpreted as a discontinuous esker system bordered by a particularly continuous series of subaqueous sandy fans. In fact, gravelly facies are seldom observed in the St-Césaire esker system, a feature that was confirmed by the current pit owner. Here, as in most of the nearby exposures, the surface till has been partly winnowed and reworked by Champlain Sea waves and currents and its upper contact with the overlying littoral sediments is locally marked by fossil shells or, even more locally, by shell-rich horizons.

Figure 17: General view of the subaqueous outwash sands underlying a surface till sheet. Though not really visible in this photograph, abundant glaciotectonic fractures affect the subtill sediments.

The esker system can be observed in several pits aligned southeastward of Mont Rougemont (Fig. 18), but its subsurface extent and continuity are not fully constrained because of the limited availability of subsurface data.

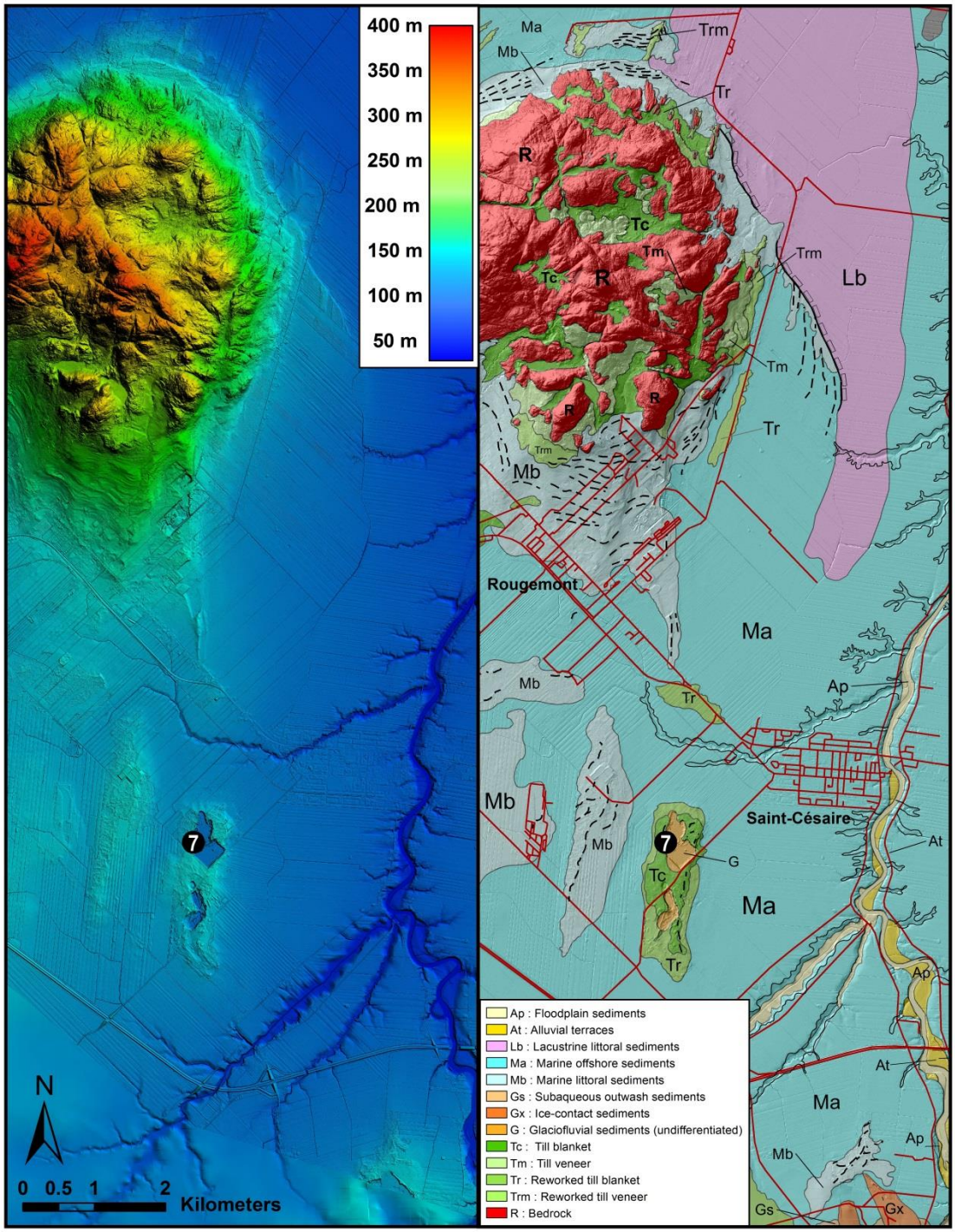

Figure 18: Surficial geology map and LIDAR image of the area surrounding site #7 south of Mont Rougement.

Site 8- West Brome - Lake Candona delta

Site	NTS Map sheet #	Map sheet name	UTM X	UTM Y	Lat	Long	Z
8	31H/02	Cowansville	691740	5004832	45.1709	-72.5600	215 m

Although the West-Brome delta (215 mASL) was one of the features used to delineate the shoreline of Glacial Lake Candona in the Sutton region (Parent and Occhietti, 1988, Appendix I, site #33), it had remained poorly exposed until recently (Fig. 19). This deltaic sand plain was emplaced at the mouth of the ancestral Jackson Brook. The sand pit has now been almost completely exhausted and thus will not likely be visited during our fieldtrip. The origin of the subhorizontal fault exposed at a depth of about 1 m remains speculative. It may have been produced by the slight displacement of a frozen sediment slab attached to the bottom of an icefoot formed on the shore of Lake Candona and pushed by drift icepack. The senior author has observed ice-wedge pseudomorphs in glaciolacustrine littoral sediments at several localities in the SE Québec Appalachians and this site may constitute another example of late-glacial periglacial conditions in the region.

Figure 19 : Gilbert-type foreset and topset beds emplaced in Glacial Lake Candona at an elevation of about 215 mASL by the ancestral Jackson Brook. Note the subhorizontal fault at a depth of about 1 m (Photograph by Hugo Dubé-Loubert, 2011).

Site 9 – Mansonville – Lake Vermont rhythmites

Site	NTS Map sheet #	Map sheet name	UTM X	UTM Y	Lat	Long	Z
9	031H01	Lac Memphremagog	704751	4991220	45.0448	-72.4001	160 m

The Mansonville site is one of the most accessible and best exposures of Lake Vermont rhythmites in the upper Missisquoi River Valley. Mapping by Dubé (1983) and Dubé-Loubert et al. (2014) shows that fine-grained rhythmites as well as deltaic sands associated with a late phase of Glacial Lake Vermont, presumably the Coveville phase, are very common on the floor and flanks of the Misssisquoi Valley. While varves have yet to be studied in detail in this valley, Dubé (1983) did reconstruct a series of glacial lake levels between 305 and 200 m ASL, the latter coinciding with the level of Lake Candona (Figure 6).

Figure 20 : Sequence of rhythmites, probably varves deposited during one of the late phases (Coveville) of Glacial Lake Vermont.

Acknowledgements

The authors would like to acknowledge the many contributions of our colleagues, Dr. Christine Rivard (Geological Survey of Canada), M. André Brazeau (Québec Ministry of Energy and Natural Resources) and Dr. René Lefebvre (INRS-Eau, Terre et Environnement) during fieldwork in 2010 and 2011 as well as in the following years. We would also like to thank Dr. Woodrow B. Thompson, the secretary of the Northeastern Friends of the Pleistocene, for his help and advice in preparing this fieldtrip. Many thanks to Drs. Pierre J.H. Richard and Jean-Pierre Guilbault for their outstanding contribution to this Annual Reunion of the NEFOP, and to my current Ph.D. student, Guillaume Légaré-Couture, for his help in preparing the guidebook. Many thanks also to fieldtrip participants for their keen interest and for their much appreciated questions and comments during the fieldtrip. We also thank our respective organisations, the Geological Survey of Canada and the Québec Ministry of Energy and Natural Resources, who encouraged and supported us in organizing this fieldtrip.

References

Beaudry, C. 2013. Hydrogéochimie de l'aquifère rocheux régionale en Montérégie Est, Québec. Mémoire de maîtrise, INRS - Centre Eau Terre Environnement, Québec, 195 pp.

Beaudry, C., Malet, X., Lefebvre, R. et Rivard, C. 2011. Délimitation des eaux souterraines saumâtres en Montérégie Est, Québec, Canada. Commission géologique du Canada, Dossier public 6960, 26 p. 10.4095/289123.

Benoit, N., Lavoie, D., Walsh, G., Rivard, C., Huot-Vézina, G. 2013. Géologie du socle rocheux, Bassins Richelieu - Lac Champlain et Yamaska, Québec, New York et Vermont / Bedrock geology, Richelieu - Lake Champlain and Yamaska watersheds, Quebec, New York and Vermont, Geological Survey of Canada, Open File 7283, 1 : 1 000 000 scale map, doi:10.4095/292441.

Carrier, M.-A., Lefebvre, R., Rivard, C., Parent, M., Ballard, J.-M., Benoit, N., Vigneault, H., Beaudry, C., Malet, X., Laurencelle, M., Gosselin, J.-S., Ladevèze, P., Thériault, R., Beaudin, I., Michaud, A., Pugin, A., Morin, R., Crow, H., Gloaguen, E., Bleser, J., Martin, A., Lavoie, D. 2013a. Portrait des ressources en eau souterraine en Montérégie Est, Québec, Canada. Rapport final INRS R-1433, (in French only), report: http://espace.inrs.ca/1639/1/R001433.pdf and appendices: http://www1.ete.inrs.ca/pub/rapports/R001433.zip.

Carrier, M.-A., Lefebvre, R., Rivard, C., Parent, M., Ballard, J.-M., Benoit, N., Vigneault, H., Beaudry, C., Malet, X., Laurencelle, M., Gosselin, J.-S., Ladevèze, P., Thériault, R., Beaudin, I., Michaud, A., Pugin, A., Morin, R., Crow, H., Gloaguen, E., Bleser, J., Martin, A., Lavoie, D. 2013b. Atlas hydrogéologique de la Montérégie Est, Québec, Canada. Rapport de recherche INRS R-1432, (in French only), http://espace.inrs.ca/1640/1/R001432.pdf.

Clark, P.U. and Karrow, P.F. 1983. Till stratigraphy in the St. Lawrence Valley near Malone, New York: revised glacial history and stratigraphic nomenclature. Geological Society of America Bulletin, v. 94 : 1308-1318

Clark, T.H. 1964a. Région d'Upton. Ministère des Richesses naturelles (Québec). Rapport géologique 100, 39 p. (carte 1411)

Clark, T.H. 1964b. Région de Saint-Hyacinthe (moitié ouest). Ministère des Richesses naturelles (Québec). Rapport géologique 101, 148 p. (carte 1412)

De Vernal, A., Goyette, C and Rodrigues, C. 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, v. 26 : 2450-2464

Dubé, C. 1983. Géomorphologie quaternaire et déglaciation à l'ouest du lac Memphrémagog. Mémoire de M.Sc. (Géographie), Université de Sherbrooke, 138 p. (1 map in pocket)

Dubé-Loubert, H., Parent, M. and Brazeau, A. 2014. Cartographie des dépôts de surface des bassins versants contigus des rivières Richelieu, Yamaska, et de la baie Missisquoi. Ministère des Ressources Naturelles (Québec), RG-2014-01. 26 p., 14 cartes 1 :50 000

Elson, J.A. 1969. Radiocarbon dates, *Mya arenaria* phase of the Champlain Sea. Canadian Journal of Earth Sciences, v. 6: 367-372

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

Gadd, N.R. 1988. The Basin, the Ice, the Champlain Sea. *In* The Late Quaternary Development of the Champlain Sea Basin (Gadd, N.R, ed.), Geological Association of Canada, Special Paper 35, p. 15-24

Gadd, N.R., McDonald, B.C. and Shilts, W.W. 1972. Deglaciation of Southern Québec. Geological Survey of Canada, Paper 71-47, 19 p. (Map 10-1971)

Globensky, Y. 1987. Géologie des Basses-Terres du Saint-Laurent. Ministère de l'Énergie et des Ressources (Québec), MM 85-02, 39 p, Map 1999

Hillaire-Marcel, C. 1980. Les faunes des mers post-glaciaires du Québec : quelques considérations paléoécologiques. Géographie physique et Quaternaire, vol. 34 : 3-59.

Ladevèze, P., Laurencelle, M., Lefebvre, R., Rouleau, A., Rivard, C. and Crow, H., 2013. Fracture systems controls on fluid flow in the regional sedimentary rock aquifer system of Montérégie Est, Southern Quebec, Canada. *GéoMontréal2013, 66th Canadian Geotechnical Conference* and the *11th Joint CGS/IAH-CNC Groundwater Conference*, Montreal, Quebec, Canada, Sept. 29 to Oct. 3, 2013.

Laforêt Nova Aqua inc. 2005. Ville de Saint-Césaire - Puits municipaux (Puits No 1/71 et Puits No 2/77), Expertise hydrogéologique, Détermination de la vulnérabilité de la formation aquifère et des périmètres de protection associés aux puits, rapport technique, N/D A.Q.U.A.-04-5617, 41 p.

La compagnie Internationale des Eaux ltée. 1977. Étude hydrogéologique St-Césaire, Rapport No. 1-1-01-1803-20, rapport technique, 77 p.

LaSalle, P., David, P. and Bouchard, M.A. 1982. Guidebook – 45th Annual Meeting of the Friends of the Pleistocene (Drummondville – St-Hyacinthe – Québec). University of Montreal, 60 p.

Lamothe, M. 1989. A new framework for the Pleistocene of the central St. Lawrence Lowland, southern Québec. Géographie physique et Quaternaire, v. 43: 119-129.

Laurencelle, M., Morin, R.H., Lefebvre, R., Rivard, Paradis., D., Lavoie, D., Benoit, N., Carrier, M.-A., Beaudry, C. 2011. Initial characterization of fractures and hydraulic properties of the Montérégie Est rock aquifer system. GeoHydro2011, CANQUA and AIH-CNC joint conference, Québec, Qc, August 28-31 2011.

Laurencelle, M., Lefebvre, R., Ladevèze, P., Carrier, M-A., Rivard, C. Parent, M., Benoit, N. 2013. Modeling the evolution of the regional fractured-rock aquifer system in the Northern Lake Champlain watershed following the last deglaciation. *GéoMontréal2013, 66th Canadian Geotechnical Conference* and the *11th Joint CGS/IAH-CNC Groundwater Conference*, Sept.29 to Oct. 3, 2013.

Locat, A., Locat, P., Demers, D., Leroueil, S., Robitaille, D. and Lefebvre, G. 2017. The Saint-Jude landslide of 10 May 2010, Quebec, Canada: Investigation and characterization of the landslide and its failure mechanism. Canadian Geotechnical Journal, v. 54 : 1357–1374

Locat, P., Locat, A., Fournier, T., Robitaille, D., and Locat, A. 2011. Glissement de terrain du 10 mai 2010, Saint-Jude, Montérégie, Rapport sur les caractéristiques et les causes. Ministère des transports du Québec. Rapport MT11-01.

Lortie, G. et Martineau, G. 1987. Les systèmes de stries glaciaires dans les Appalaches du Québec. Ministère de l'Énergie et des Ressources (Québec), DV 85-10, 45 p.

McDonald, B.C. 1968. Deglaciation and differential postglacial rebound in the Appalachian region of southeastern Quebec. Journal of Geology, v. 76, 664-667

Muller, S.D., Richard, P.J.H., Guiot, J., de Beaulieu, J.L., Fortin, D. 2003. Postglacial climate in the St. Lawrence lowlands, southern Québec: pollen and lake-level evidence. Palaeogeography, Palaeoclimatology, Palaeoecology, 193 : 51-71..

Occhietti, S. 1990. Lithostratigraphie du Quaternaire de la vallée du Saint-Laurent: méthode, cadre conceptuel et séquences sédimentaires: Géographie physique et Quaternaire, v. 44: 137-145.

Occhietti, S., Parent, M., Shilts, W.W., Dionne, J.C., Govare, É. and Harmand, D. 2001. Late Wisconsinan glacial dynamics, deglaciation and marine invasion in southern Quebec. Geological Society of America, Special Paper 351 *(Deglacial History and Relative Sea-Level Changes, Northern New England and Adjacent Canada* (T.K. Weddle and M.J. Retelle, editors), p. 243-270

Parent, M. 1987. Late Pleistocene stratigraphy and events in the Asbestos-Valcourt region, Québec. Ph.D. thesis (Geology), University of Western Ontario, 320 p.

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

Parent, M. and Occhietti, S. 1999. Late Wisconsinan deglaciation and glacial lake development in the Appalachians of southeastern Québec. Géographie physique et Quaternaire, v. 53 : 117-135.

Parent, M., Cloutier, M., Doiron, A., Bolduc, A.M. et Michaud, Y. 1997. The Champlain Sea-Lampsilis Lake - Proto-St. Lawrence transition in the central St. Lawrence valley. CANQUA, 8th Biennal Meeting, (Montréal, May 22-25, 1997), Programme and abstracts, p. 52

Parent, M., Rivard, C; Lefebvre, R; Carrier, M -A; Séjourné, S. 2014. Hydrogeological systems of the Montérégie Est region, southern Quebec: fieldtrip guidebook. GeoMontréal 2013 conference. Geological Survey of Canada, Open File 7605, 42 pages, doi:10.4095/294604

Richard, P.J.H. and Occhietti, S. 2005. ^{14}C chronology for ice retreat and inception of Champlain Sea in the St. Lawrence Lowlands, Canada. Quaternary Research, v. 63: 353-358.

Ridge, J. C.,. Bensonen, M.R., Brochu, M., Brown, S.L., Callahan, J.W., Cook, G.J., Nicholson, R.S. and Toll, N.J. 1999. Varve, paleomagnetic, and 14 C Chronologies for late Pleistocene events in New Hampshire and Vermont (U.S.A.). Géographie physique et Quaternaire, v. 53: 79–107

Ridge, J.C., G. Balco, R.L. Bayless, C.C. Beck, L.B. Carter, J.L. Dean, et al. 2012. The new North American Varve Chronology: A precise record of southeastern Laurentide Ice Sheet deglaciation and climate, 18.2-12.5 kyr BP, and correlations with Greenland ice core records. American Journal of Science, v. 312: 685-722.

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

Ross, M., Parent, M., Benjumea, B. and Hunter, J. 2006 The Late Quaternary stratigraphic record northwest of Montreal: Regional ice sheet dynamics, ice stream activity and early deglacial events. Canadian Journal of Earth Sciences, v. 43, p. 461-485

Séjourné S. and Malo M. 2007. Pre-, syn- and post-imbrication deformation of carbonate slices along the southern Québec Appalachian front - Implications for hydrocarbon exploration. Canadian Journal of Earth Sciences, v. 44, p. 543-564.

Slivitsky, A. and St-Julien, P. 1987. Compilation géologique de la région de l'estrie-Beauce. Ministère de l'Énergie et des Ressources (Québec), MM 85-04, 40 p, Map 2030

FRIENDS participating in the 2017 Field Conference

*Leaders, guidebook editors

*Michel Parent

*Hugo Dubé-Loubert

David Franzi

Duane Braun

Ruth Braun

Dan Karig

Laurie D. Grigg

Robert Dineen

Martey Costello

James Dawson

Richard Dunn

Woody Thompson

Louise Thompson

Nathan Scholl

Thom Davis

Cliff Vanover

George Springston

Jean-Pierre Guilbault

Fred Bickford

Paul Heisig

Stephen Wright

Steve Bill

Daniel Tinkham

Najat Bhiry

Priscilla Duskin

Pierre J.H. Richard