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Résumé de l'article

Pendant la phase initiale de la déglaciation de la vallée du Saint-Laurent, dans la région à l'ouest de la ville de Québec, des eaux de fonte à haute énergie se sont déversées vers le nord dans une masse d'eau très probablement sous-glaciaire localisée dans l'axe de la vallée. Ce déversement est à l'origine d'un cône sableux de turbidité à pendage nord-ouest, associé à des dépôts de courants de fond hyperconcentrés et à des graviers et galets d'épandage proglaciaire. Vers 11 200 ^{14}C BP, des boues glaciomarines massives et des lits intercalés de rythmites sont déposés dans l'axe de la vallée enfoncée par glacioisostasie. Cet apport de boues marines engendre localement des glissements sous-aquatiques et des coulées de débris sur les pentes immergées. Entre 10 950 et 10 800 ^{14}C BP, l'Inlandsis laurentidien a progressé de nouveau jusque sur la rive sud de l'actuel Saint-Laurent et déposé le till sous-glaciaire de Saint-Nicolas. Les courants de marée ont ensuite remanié les littoraux progressivement émergés par relèvement glacioisostatique. Les réseaux fluviatiles ont commencé à inciser des vallées, en érodant et redéposant les dépôts antérieurs.

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LATE WISCONSINAN SEDIMENTATION IN THE QUÉBEC CITY REGION: EVIDENCE FOR ENERGETIC SUBAQUEOUS FAN DEPOSITION DURING INITIAL DEGLACIATION

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ABSTRACT In the St. Lawrence Valley just west of Québec City, initial deglaciation was accompanied by an energetic northward discharge of meltwater into a body of water, possibly subglacial, that was present in the axis of the valley. At Pointe Saint-Nicolas, a thick (> 35 m) ice-proximal sandy subaqueous fan was deposited during this event. The subaqueous fan is composed primarily of northwest-dipping turbidite sheets, with minor hyperconcentrated underflow channel fills and gravel-outwash deposits. By 11 200 ^{14}C BP, subaqueous fan sedimentation had stopped, and massive to rhythmically interbedded glaciomarine muds were being deposited. Introduction of muds into the basin promoted subaqueous slope failure and debris flowing locally. Between 10 950 and 10 800 ^{14}C BP, the Laurentide Ice Sheet readvanced southward onto the south shore, and deposited the subglacial St. Nicolas Till. With continued isostatic rebound and associated forced regression, tidal currents began to rework emergent coastal zones, and fluvial systems started to incise their valleys.

RÉSUMÉ *La sédimentation dans la région de Québec au Wisconsinien suspérieur : mise en place d'un cône sableux de turbidité au cours de la phase initiale de la déglaciation.* Pendant la phase initiale de la déglaciation de la vallée du Saint-Laurent, dans la région à l'ouest de la ville de Québec, des eaux de fonte à haute énergie se sont déversées vers le nord dans une masse d'eau très probablement sous-glaciaire localisée dans l'axe de la vallée. Ce déversement est à l'origine d'un cône sableux de turbidité à pendage nord-ouest, associé à des dépôts de courants de fond hyperconcentrés et à des graviers et galets d'épandage proglaciaire. Vers 11 200 ^{14}C BP, des boues glaciomarines massives et des lits intercalés de rythmites sont déposés dans l'axe de la vallée enfoncée par glacioisostasie. Cet apport de boues marines engendre localement des glissements sous-aquatiques et des coulées de débris sur les pentes immergées. Entre 10 950 et 10 800 ^{14}C BP, l'Inlandsis laurentidien a progressé de nouveau jusque sur la rive sud de l'actuel Saint-Laurent et déposé le till sous-glaciaire de Saint-Nicolas. Les courants de marée ont ensuite remanié les littoraux progressivement émergés par relèvement glacioisostatique. Les réseaux fluviatiles ont commencé à inciser des vallées, en érodant et redéposant les dépôts antérieurs.

RESUMEN *Sedimentación del wisconsiniano tardío en la región de la ciudad de Quebec, Canadá : evidencia de un depósito subacuático en cono de alta energia durante el deshielo inicial*. En el valle del San Lorenzo justo al oeste de la ciudad de Quebec un deshielo precoz fue acompañado de una descarga enérgica de agua de fusión en dirección norte hacia un cuerpo de agua probablemente subglacial ya presente en el eje del valle. En Punta San Nicolas ese derrame dio origen a un depósito arenoso próximo al hielo de un espesor de 35 m en forma de cono. Dicho cono subacuático esta compuesto en primer lugar por capas de turbit del noroeste asociados en lo alto con corrientes de fondo hiperconcentradas y aluvión de grava. Hace aproximadamente 11 200 ^{14}C BP, la sedimentación del cono subacuático se detuvo y simultáneamente cantidades masivas de lodos glaciomarinos fueron depositados de manera rítmica. La introducción de lodo en la cuenca provocó la fractura de la pendiente subacuática y conllevo la acumulación de desechos localmente. Entre 10 950 y 10 800 ^{14}C BP, La Capa glacial Lorenzana avanzó nuevamente en dirección sur hasta la rivera originando el depósito subglacial de las tillitas de San Nicolas. Posteriormente, las corrientes de mareas fueron definiendo el litoral emergente mientras que el sistema fluvial fue provocando la ablación de los valles.

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INTRODUCTION

The deglacial history of the Québec City region is poorly understood, and has proven difficult to integrate into larger basin-scale deglacial models of the St. Lawrence Valley (LaSalle *et al.*, 1977; Chauvin *et al.*, 1985; Parent and Occhietti, 1988, 1999; Occhietti *et al.*, 2001b). During deglaciation, the greater Québec City region acted as a gateway for major meltwater discharges into the Atlantic Ocean (Parent and Occhietti, 1988, 1999; Rodrigues and Vilks, 1994), experienced complex ice margin fluctuations (Blais and Shilts, 1989; LaSalle and Shilts, 1993; Fournier, 1998; Paradis and Bolduc, 1999; Bhiry *et al.*, 2001), was transgressed by the Champlain Sea (Occhietti *et al.*, 2001a), and underwent a subsequent episode of isostatic rebound and base level fall that forced shorelines to regress to their present day position. With limited bedrock striation and glacial landform data in regions below the Champlain Sea maximum (~200 m asl), these events are poorly constrained in time and space. In an attempt to provide insight into the deglacial history of the Québec City region, this paper investigates the sedimentology of a well-exposed outcrop in a sand pit at Pointe Saint-Nicolas that has served as the *de facto* type section for the Québec City region.

The Pointe Saint-Nicolas site is located in the axis of the St. Lawrence Valley ~10 km west of Québec City on the south shore of the St. Lawrence River (Fig. 1). Topography on the valley floor slopes gently northward (< 1º) towards a ~50 m high bedrock cliff that lines the south shore. The sand pit is perched in a knickmark cut into the bedrock cliff. Bedrock in the Québec City region can be divided into three major provinces, as follows: 1) granitoid rocks of the Precambrian Shield, which outcrop on the north shore of the St. Lawrence River, 2) carbonate mudstones and wackestones of the St. Lawrence Platform, which occur in the axis of the valley, and 3) volcanic, carbonate, and siliciclastic rocks of the Appalachian orogen, which outcrop on the south shore of the St. Lawrence River (Fig. 1).

STRATIGRAPHY AND PREVIOUS WORK

The initial Quaternary stratigraphic framework for the Québec City region (Fig. 2) was established by LaSalle (1984, 1989). He distinguished two subglacial tills deposited prior to the last deglaciation (Pointe Saint-Nicolas and Québec City Tills) with intervening silt, sand and gravel, which he grouped under the Anse-aux-Hirondelles Formation, and muddy varves which he called the Beaupré Formation. The uppermost till is overlain by undifferentiated Champlain Sea mud, sand and gravel. At a later date, he identified a Late Wisconsinan fossiliferous diamicton intercalated with the Champlain Sea deposits called the St. Nicolas Till (LaSalle and Shilts, 1993). Radiocarbon dates ranging between 28 375 ^{14}C BP (UGa-463) and > 42 000 ^{14}C BP (GSC-3420) obtained from plant macrofossils from Subunit 1 of the Anse-aux-Hirondelles Formation (Fig. 3) have been used to infer a Middle Wisconsinan age for the entire Anse-aux-Hirondelles Formation. A reworked *Balanus hameri* fossil collected from the St. Nicolas Till at the site has yielded a date of 11 200 BP (GSC-1476; LaSalle and Shilts, 1993). All of the units outlined in this stratigraphic framework have been previously identified at the Pointe Saint-Nicolas site, with the notable exception of the Québec City Till (Fig. 3).

LaSalle (1984, 1989) proposed a correlation between the Quaternary stratigraphy of the Québec City region and the more extensively studied Quaternary stratigraphy of the Central St. Lawrence Valley established by Gadd (1971). Specifically, he correlated the Pointe Saint-Nicolas and Bécancour tills, the Anse-aux-Hirondelles Formation and the St. Pierre Sediments, the Beaupré and Deschaillons Varves, and the Québec City and Gentilly tills (Fig. 2). Recent revisions to the stratigraphic framework in the Central St. Lawrence Valley (Lamothe, 1989; Occhietti *et al*.,1996; see Fig. 2) were not available to LaSalle when he proposed his basin-scale correlations (1984, 1989). These revisions have been extended in part to the Québec City region; for example, the Beaupré Formation is now correlated with the St. Maurice Rhythmites (Occhietti, 1990). The applicability of the revised framework of Occhietti *et al.* (1996) to the Québec City region will be commented on briefly in the discussion section.

DEGLACIATION OF THE ST. LAWRENCE VALLEY

Québec City is located between two regions of the St. Lawrence Valley with contrasting Late Wisconsinan deglacial histories. Deglaciation east of Québec City was marked by the development of a northeast flowing ice stream in the valley axis. Between ~13 500 and ~12 000 ^{14}C BP, an arm of marine water, possibly in the form of a calving bay (Thomas, 1977), migrated inland against the ice stream from the Atlantic Ocean to at least the Saguenay River and possibly to a position near Québec City, forming the Goldthwait Sea (Stea *et al.*, 1998; Occhietti *et al.*, 2001b). This effectively isolated a large ice mass over the Appalachians from the Laurentide Ice Sheet (LaSalle *et al.*, 1977; Chauvin *et al.*, 1985). Glacial landform and sedimentological data suggest that the Appalachian ice mass extended as far west as the Bois Francs region (Fig. 1).

In contrast, in regions west of Québec City the Laurentide Ice Sheet receded northward as a single sheet, and deposited a series of end moraines and eskers on the Appalachian uplands (Fig. 1). Here, ice-ponded lakes formed between the ice front and the Appalachian Mountains. The last glacial lake, Lake Candona, extended > 350 km up the St. Lawrence Lowlands west of the Bois Francs region (Parent and Occhietti, 1988, 1999). At some time between 12 000 and 11 500 ^{14}C BP, Lake Candona drained into the Goldthwait Sea, dropping somewhere between 18 to 60 m in the process (Parent and Occhietti, 1988; Rodrigues and Vilks, 1994). Mixing of the marine waters with residual freshwater in the former Lake Candona basin formed the Champlain Sea. The next conclusive ice margin position north of moraines on the Appalachian uplands is the St. Narcisse Moraine (Fig. 1), which was deposited on the north shore of the St. Lawrence River by the Laurentide Ice Sheet at ~10 800 ^{14}C BP (LaSalle and Elson, 1975). The period of deglaciation between the draining of Lake Candona (12 000-11 500 ^{14}C BP) and the St. Narcisse Moraine

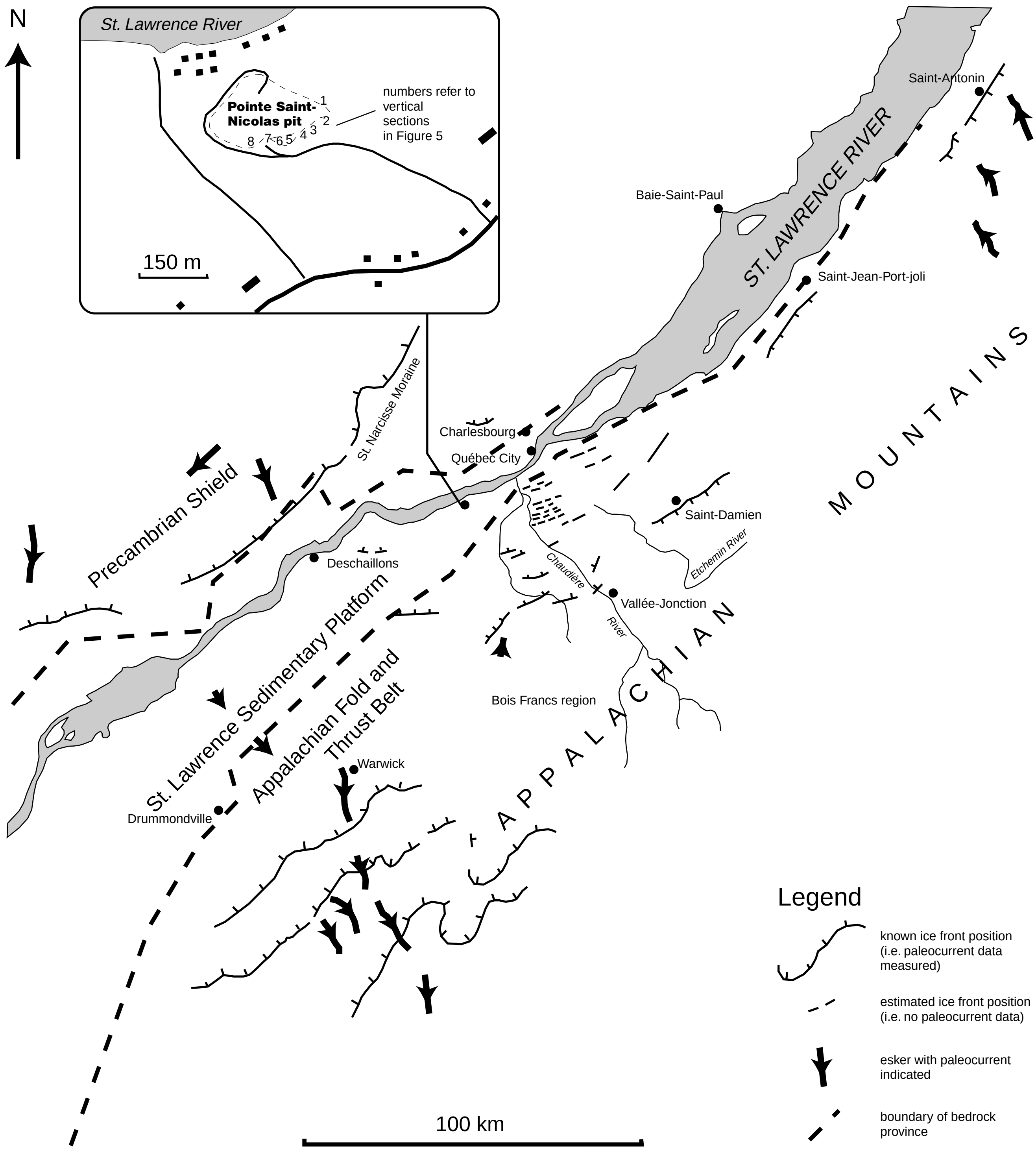


FIGURE 1. Location of the Pointe Saint-Nicolas pit, major deglacial landforms, and bedrock provinces in the greater Québec City region of the St. Lawrence Valley (from Chauvin *et al.,* 1985; Globensky, 1987; Parent and Occhietti, 1988).

Localisation de la sablière de la pointe Saint-Nicolas, emplacement des principales moraines et limites des provinces géologiques de la région de Québec (d'après Chauvin et al.*,1985 ; Globensky, 1987 ; Parent et Occhietti,1988).*

event (~10 800 ^{14}C BP), which is the interval being investigated in this paper, is very poorly understood. Radiocarbon ages from marine shells are presented in ^{14}C years before present (BP) and are reservoir corrected (^{13}C = 0 ‰), as used in previous papers dealing with the Champlain Sea.

METHODOLOGY

Field work was carried out in the summer and fall of 1998, when the Pointe Saint-Nicolas pit was relatively well exposed (Fig. 4). Vertical sections were cleared, and spraypaint was used to trace contacts laterally. Graphic logs of the vertical sections were drawn, noting sedimentary textures, types and orientations of sedimentary structures, and the nature and orientation of contacts. Following the field season, beds or groups of beds with similar characteristics were grouped together, and a list of sedimentary facies was compiled. Facies were then grouped together into facies associations (FAs). Facies within a facies association are related in that they represent various components of a common depositional system.

SEDIMENTARY FACIES AND INTERPRETATION

A total of eight sedimentary facies were identified from vertical sections cleared along the 50 m high by 150 m long south wall of the Pointe Saint-Nicolas pit (Fig. 5). Facies descriptions and interpretations are presented in detail below, and in abridged format in Table I.

FACIES 1: MUD WITH RARE PEBBLES

Facies 1 is composed of massive gray and olive coloured mud with rare pebble or cobble clasts (< 10 %) and occasional thin (< 1 mm) horizontal sandy partings (Fig. 6a). Lower

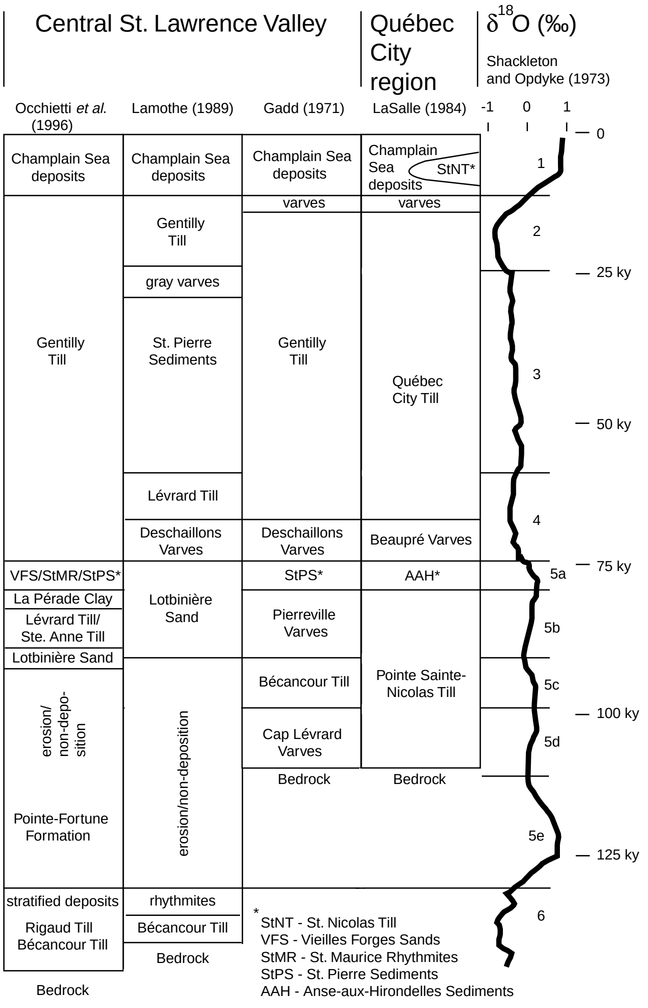


FIGURE 2. Proposed Quaternary stratigraphic frameworks for the Québec City area (modified from LaSalle, 1984, 1989; LaSalle and Shilts, 1993).

Cadre stratigraphique proposé pour la région de Québec (modifié de LaSalle, 1984, 1989 ; LaSalle et Shilts, 1993).

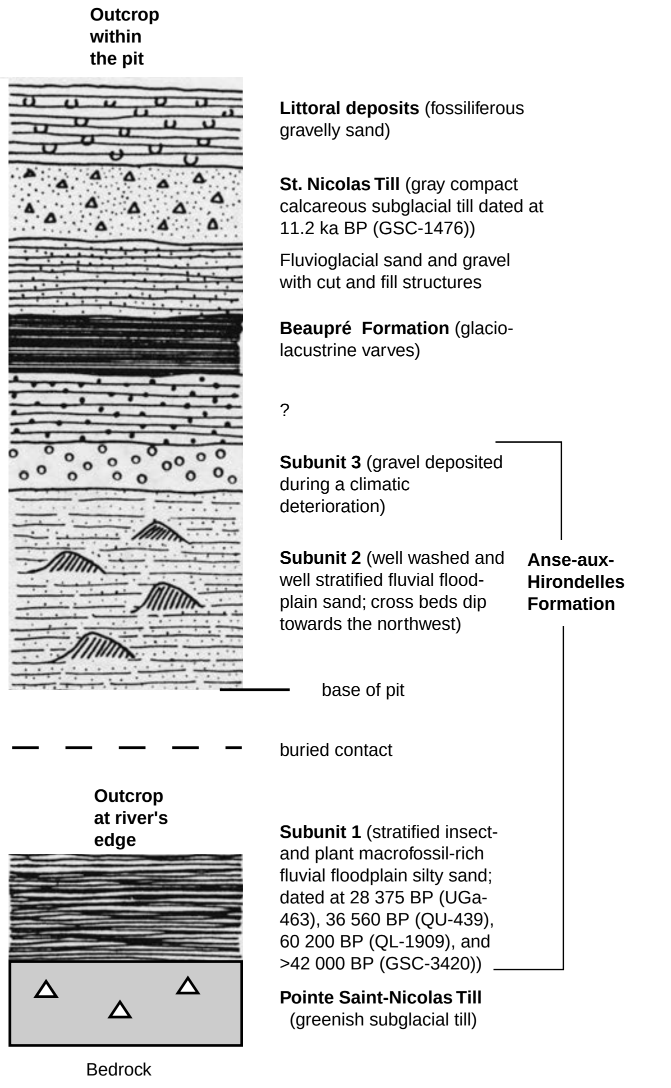


FIGURE 3. Previous descriptions of the Pointe Saint-Nicolas section (from LaSalle *et al.*, 1977 and LaSalle 1989).

Descriptions antérieures de l'affleurement de la pointe Saint-Nicolas (d'après LaSalle et al.,1977; LaSalle, 1984).

contacts are gradational, draped or intercalated. Clasts are commonly striated, and are of mostly carbonate wackestone and mudstone lithology, with minor percentages of red shale, granitoid, and sandstone (Fig. 7a). A very low-density, low-diversity faunal assemblage consisting of *Balanus hameri* and *Portlandia arctica* is present. Shells are typically articulated and are occasionally in growth position.

Interpretation: Glacial marine suspension deposits. These muds are interpreted to have settled out of subaqueous suspension from turbulent meltwater overflows or interflows. The thin (< 1 mm) sandy partings may record the transition from traction to suspension sedimentation, or possibly slightly more vigorous overflowing. Striated clasts are interpreted to be melt-out debris deposited from either seasonal sea ice or icebergs. The low-density, low-diversity fossil assemblage with *Portlandia arctica* suggests deposition in a cold, deep-water, low-salinity glaciomarine environment (Hillaire-Marcel, 1980). Interstratification, which is commonly pervasive in modern tidewater glaciomarine settings, is absent in these muds (thin sandy partings notwithstanding), suggesting that tidal, seasonal, and/or other factors that can cause stratification in glaciomarine deposits did not significantly affect deposition of this facies.

FACIES 2: STRATIFIED FINE SAND AND MUD

Facies 2 is composed of thinly interbedded fine sand and pebbly mud (Fig. 6b). Mud/sand couplets are between 4-20 cm thick, with an average of ~10 cm. The mud beds are massive, have a grayish to olive brown colour, and contain rare (< 10 %) pebble and cobble clasts. Clasts, particularly those of gray carbonate mudstone and wackestone lithology, are often striated. Rare *Portlandia arctica* are present in the mud beds. The fine sand beds are massive to vaguely laminated, and contain no shells or pebbles. Both fine sand and mud beds are ungraded. Contacts between sand and mud interbeds are typically sharp and non-erosional.

Interpretation: Glacial marine suspension deposits with superimposed seasonal and/or other cyclical influence. The interstratified sands and muds are interpreted as being deposited by suspension settling from turbid meltwater plume overflows in quiet glaciomarine water with seasonal and/or other factors that can cause rhythmicity and stratification (Phillips *et al.*, 1991; Cowan *et al.*, 1999). Although previously interpreted by LaSalle (1984) as glaciolacustrine varves of the Beaupré Formation (see Figs. 2 and 3), the presence of rare *Portlandia arctica* shells indicates that this facies was deposited in a glaciomarine environment (Hillaire-Marcel, 1980). In modern temperate glaciomarine environments, similar interbedded facies have been interpreted as glaciomarine varves formed by seasonal changes in meltwater discharge and iceberg activity (Cowan *et al.*, 1999). If this facies is varved, sedimentation rates would have been high during deposition, ranging between 40-200 m per 1000 years. This estimate, although seemingly high, falls well within the range of sedimentation rates in modern temperate glaciomarine environments, which can reach several decametres of sediment deposited from suspension per year (Cowan and Powell, 1991).

FACIES 3: NORMALLY GRADED SAND

Beds of well sorted normally graded sand account for 90 % of the sediment exposed in the lower 35 m of the Pointe Saint-Nicolas pit (Fig. 4). Beds are 5 to 100 cm thick. Lower bedding contacts are roughly flat, and can be erosional or non-erosional. Beds typically consist of a conformable succession of subfacies, the most common being (bottom to top) horizontally laminated medium sand to climbing unidirectional ripple cross-stratified fine sand to a wavy laminated mud drape (Fig. 6c). Beds are sheet-like, dip gently to the northwest (5-12^{o}), pinch out laterally over several decametres, and thin slightly towards the northwest (Fig. 4). Ripple and small scale (< 15 cm) dune cross-stratification consistently dips towards the northwest. Pebble and small cobble are very rare, but when present lie along basal contacts. No shells or organics were observed in normally graded sand sheets in the lower 35 m of the pit.

Normally graded sand sheets also occur in the upper 15 m of the pit. Here, beds are 10 to 20 cm thick, and typically fine up from granule-rich coarse sand with shell hash (*Balanus hameri* >> all other species) to medium coarse sand. Lower bedding contacts are roughly flat, and can be erosional or non-erosional. Beds have a crude horizontal stratification. Northwestward dipping small-scale dune cross-strata were observed in one location.

Interpretation: Turbidites. The normal grading, climbing ripples, and Bouma T_{bcd} subfacies successions are suggestive of deposition from waning subaqueous turbulent gravity flows (Middleton, 1993; Hiscott *et al.*, 1997; Shanmugan 1996, 1997). In the lower 35 m of the pit, the 5-12^{o} northwest dip of bedding surfaces, northwest paleoflows, northwest thinning and fining trends, and sheet-like bed geometries suggest that the turbidity currents were unconfined, and flowed and decelerated down a gently inclined depositional surface towards the northwest. Rare gravel clasts located at the base of beds are interpreted to have been transported as rolling bedload at the base of the turbid underflows (Hiscott *et al.*, 1997). Lack of obvious flow-rafted clasts or massive beds suggests that the flows had little strength coming from grain support mechanisms other than fluid turbulence (Middleton and Southard, 1984; Middleton, 1993; Shanmugan, 1996, 1997). These features imply that grain-to-grain contacts were negligible, which in turn implies that sediment concentrations in the turbidity currents were low (probably < 9 % sediment per unit volume — *cf*. Bagnold, 1954).

FACIES 4: DIFFUSELY LAMINATED SAND

Diffusely laminated sand (Fig. 6d,e) accounts for ~10 % of the sediment in the lower 35 m of the Pointe Saint-Nicolas pit. This facies is composed of very well sorted fine grained sand with rare to occasional pebbles (maximum diameter = 2 cm). Individual laminae are typically 0.25-3 cm thick, very gently curved to flat based, and are roughly horizontal. Gradational contacts between laminae give the facies a “diffusely” stratified appearance (Fig. 6d). The diffusely laminated sands infill broad, shallow, erosively based channels (maximum 20 m wide by 5 m deep; Fig. 6e). Channel fills do not appear to fine

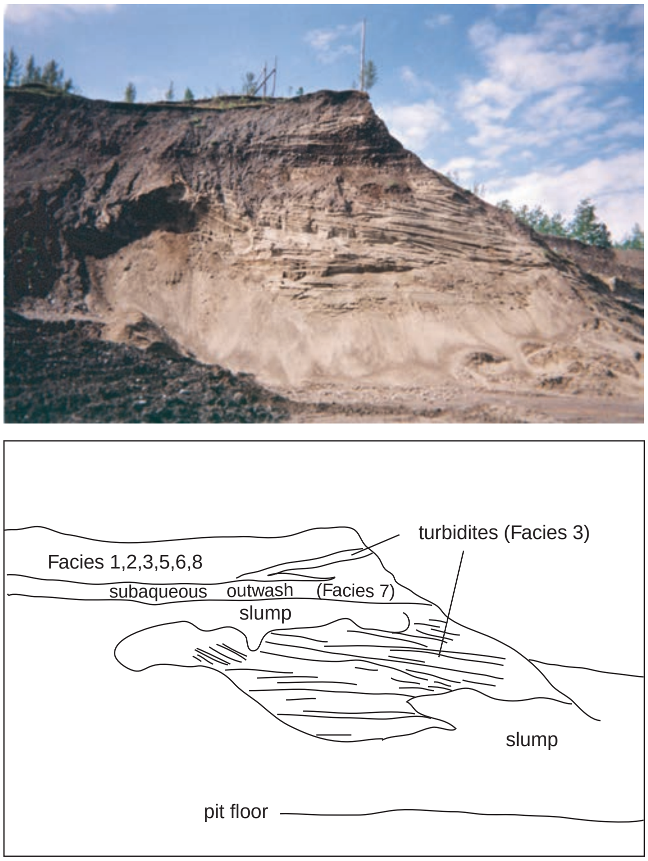
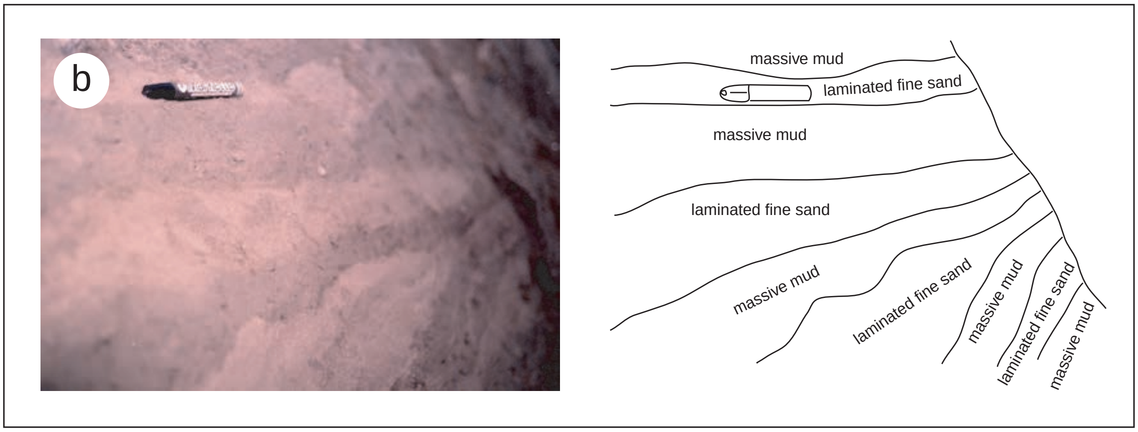


FIGURE 4. Pointe Saint-Nicolas pit, portion of the south wall. Paleoflows throughout the section are towards the right (northwest).

Vue partielle de la paroi sud de la sablière de la pointe Saint-Nicolas. Les structures de paléocourants sont orientées vers la droite (nord-ouest).

FIGURE 6. Facies – (a) Mud with rare pebbles (Facies 1); (b) Stratified mud and sand (Facies 2); (c) Normally graded sand (Facies 3); (d) Diffusely laminated sand (Facies 4); (e) Diffusely laminated sand channel fill (Facies 4); (f) Homogeneous diamicton (Facies 5); (g) Heterogeneous diamicton (Facies 6); (h) Matrix-poor gravel (Facies 7).

Faciès – (a) Silt argileux avec quelques cailloux (faciès 1) ; (b) faciès stratifié de silt argileux et sable (faciès 2) ; (c) sable à granoclassement normal (faciès 3) ; (d) sable à stratification fine et diffuse (faciès 4) ; (e) chenal rempli de sable à stratification fine et diffuse (faciès 4) ; (f) diamicton homogène (faciès 5) ; (g) diamicton hétérogène (faciès 6) ; (h) gravier à matrice faible (faciès 7).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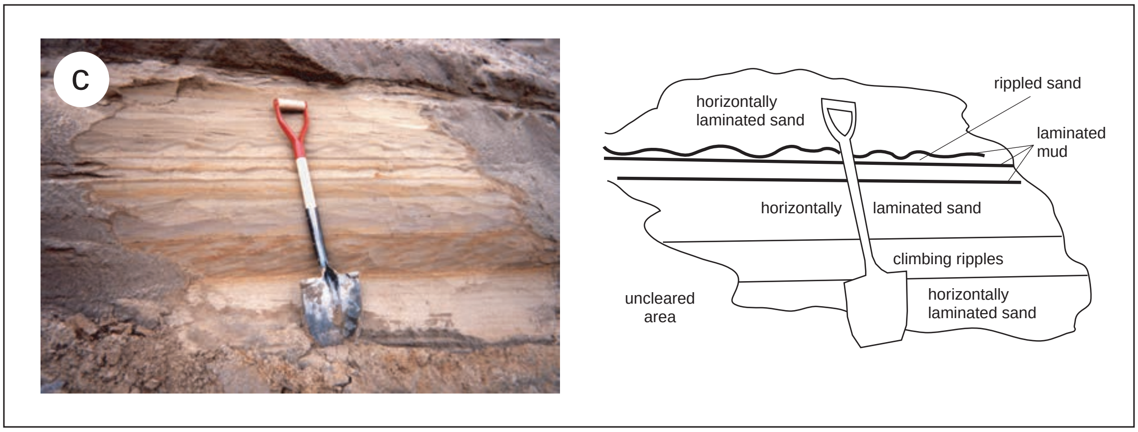
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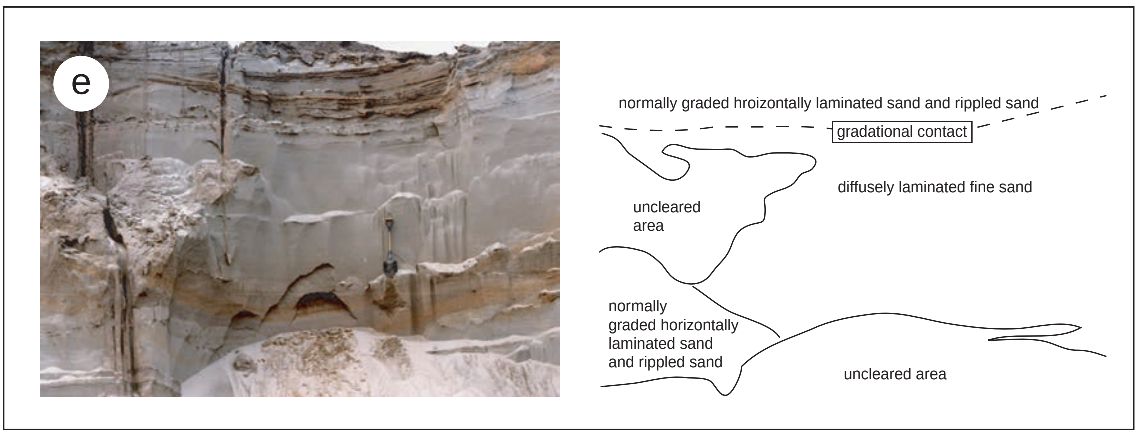
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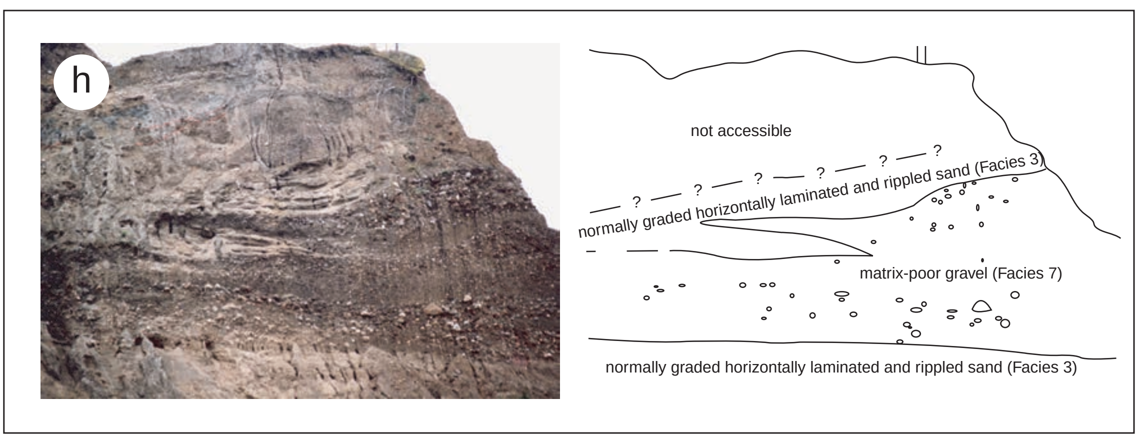
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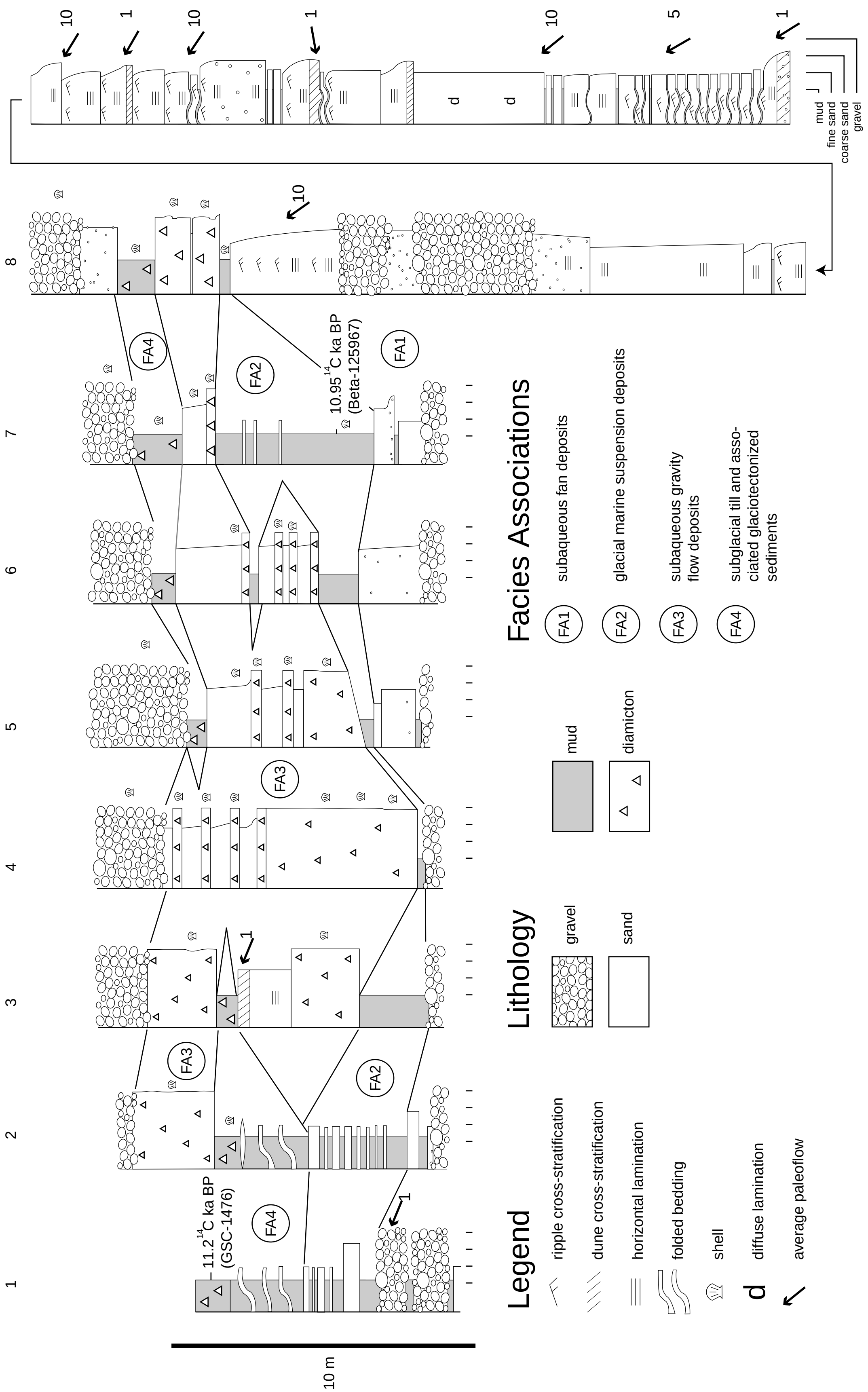

FIGURE 5. Sedimentology and facies associations (FAs), Pointe Saint-Nicolas pit.

Sédimentologie et associations de faciès (FAs) de la sablière de la pointe Saint-Nicolas.

TABLE I

Facies

Facies	Textures	Sedimentary structures	Macro-fauna	Bed contacts & bed thickness	Geometry	Interpretation
FACIES 1 Mud with rare pebbles (< 10 %)	mud with occasional horizontal sand partings (~1 mm) and gravel clasts (< 10 %); gravel clasts are often striated	massive looking (but actually stratified due to sandy partings)	contains low-diversity low density articulated and mildly reworked or *in situ* shells of *B. hameri* and *P. arctica*	lower contact can be either intercalated gradational or draped; bed thicknesses hard to discern due to massive appearance	thick sheet-like geometry	glacial marine suspension deposits
FACIES 2 Inter-stratified mud and fine sand	mud and fine sand are ungraded; mud often contains gravel clasts (often striated); fine sand beds are well sorted with no gravel clasts	muds are massive and ungraded; silts are are also ungraded	rare *Portlandia arctica* in mud beds	intra-facies contacts are sharp and non-erosional; lower contacts are gradational	thick sheet-like geometry	glacial marine suspension deposits with superimposed seasonal and/or other cyclical influence
FACIES 3 Normally graded sand	coarse pebbly sand to laminated mud	Beds often fine upwards. Beds have subfacies successions that are similar (but not identical) to the Bouma sequence. All cross bedding dips northwest.	none observed	conformable to erosional; planar contacts; beds are inclined from 5-12° towards the northwest	thin sheet-like geometry; beds pinch out laterally over 5-25 meters; beds dip from 5-12° in the downcurrent direction	turbidites
FACIES 4 Diffusely laminated fine sand	fine sand; very well sorted; save for occasional floating small pebble	ungraded, diffusely bedded	no macro-fauna observed	erosive, channel-form lower contacs	shallow channel geometries	hyperconcentrated underflow deposits
FACIES 5 Homo-geneous matrix-supported diamicton	fine sandy mud matrix with granule to small boulder clasts; clasts are often striated	massive; ungraded; clasts A/B planes inclined towards the north	rare broken fragments of *B. hameri* or *P. arctica*	lower contact is often sharp and planar, with material folded up across contact locally; bed is 20-200 cm thick	thin sheet-like geometry	subglacial till
FACIES 6 Heterogeneous clast to matrix-supported muddy diamicton	pebble to boulder (max 50 cm) clasts in a sandy mud matrix; clasts often striated and covered with *Balanus hameri* basal plates	massive, ungraded; occasional chaotic or vertical clasts fabrics; can grade to normally graded granule gravel with horizontal lamination	no *in situ* macro-fauna observed; can contain abundant fragments of *B. hameri*. Clasts often covered in *B. hameri* basal plates.	intra-facies contacts are amalgamated, and only discernible when lined with sand; contacts can be dewatered to sharp, and are often channelized; bed thickness hard to determine due to amalgamation	can have either channel geometry or be thin and sheet-like	subaqueous debris flow deposits
FACIES 7 Matrix poor gravel	pebbles to cobbles; little to no matrix; well sorted; clasts are round to subrounded and are unstriated	typically inversely graded; normal. graded and ungraded beds observed; crudely stratified	no macro-fauna observed	intra-facies contacts are planar and non-erosive (?); amalgamated contacts present; lower contact of unit is sharp, erosive and planar; beds are 20-75 cm thick	thick sheet-like geometry; can pinch out in lenticular fashion; dip of unit hard to ascertain... seems close to horizontal	subaqueous outwash
FACIES 8 Massive to crudely stratified gravel	pebble to small cobble gravel; no outsized clasts; sandy mud matrix; clasts are subrounded and unstriated	crude horizontal fabric; ungraded	no *in situ* macro-fauna observed; contains fragments of *B. hameri*	erosive, planar and roughly horizontal contacts; beds are on ave. ~50 cm; occasional ice-wedge structures along contact	sheet-like	fluvial deposits

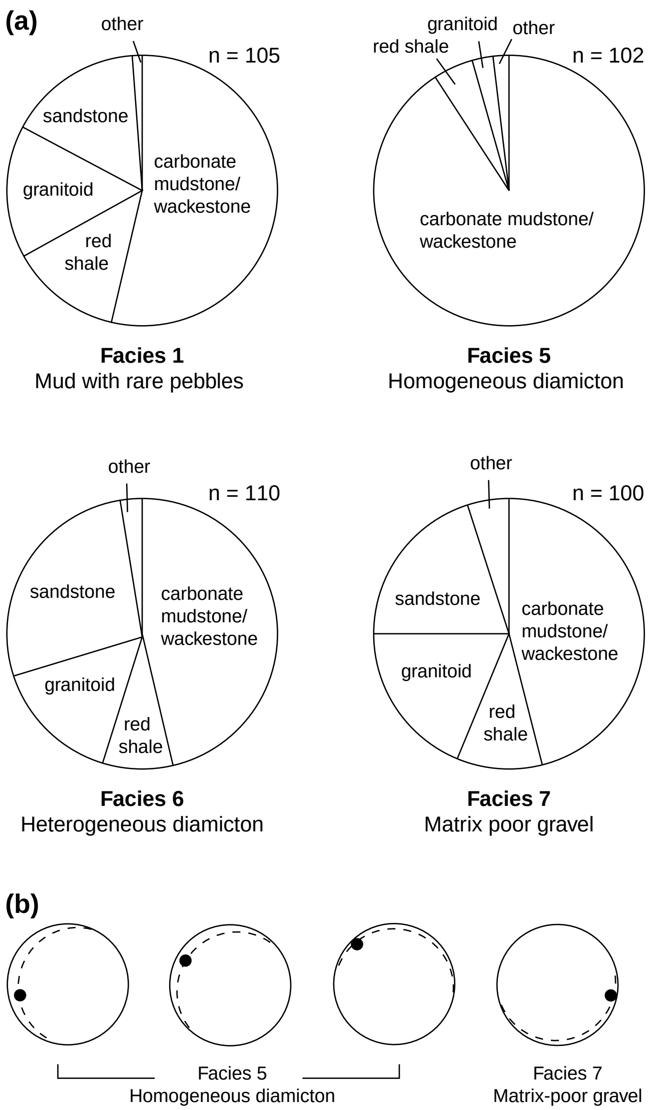

FIGURE 7. Clast (a) lithologies and (b) fabrics from various facies. For clast fabrics, the average A/B plane is indicated by the dashed line, with the dot representing the A axis orientation. Each clast fabric stereoplot is an average of the orientation of 50 clasts.

Lithologie (a) et fabriques (b) de différents faciès. Pour les fabriques établies avec 50 fragments, l'orientation moyenne du plan A/B est indiquée par une ligne brisée ; l'orientation moyenne de l'axe A est représentée par un point noir.

or coarsen upwards. Channels exposed at the north end of the pit tend to contain fewer pebbles than channels at the south end of the pit. The top contacts of channels are typically flat, and can be either sharp, gradational over < 10 cm into normally graded sands, or loaded. No shells or organics were observed in this facies.

Interpretation: Hyperconcentrated underflow deposits. The typically well sorted nature of the diffusely laminated sands suggests that the sediments underwent substantial hydraulic sorting prior to deposition. Subtle centimetre-scale "diffuse" stratification suggests that the channel fills were not deposited in a single *en-masse* event. Gradational contacts between successive laminae, as well as the absence of pebble lags along lamination planes, suggests that laminae-depositing 'events' were largely non-erosive. Gradational contacts between laminae also suggest that sedimentation was continuous throughout channel filling.

The diffusely laminated channel fills at Pointe Saint-Nicolas are interpreted to have been deposited quickly by steady hyperconcentrated underflows. Hyperconcentrated flows have sediment concentrations (20-40 % sediment per unit volume; Beverage and Culberston, 1964), flow dynamics, and sediment support mechanisms that are intermediate between clear water flows and debris flows. The diffuse stratification of Facies 4 is similar to lamination formed experimentally when upper plane bed is subjected to an intense rain of sediment from suspension (Arnott and Hand, 1989). Diffusely laminated channel fills are often observed in glacial and deep-sea fans (Rust, 1977; Lowe, 1982; Postma *et al.*, 1983; Gorrell and Shaw, 1991; Kneller and Branney, 1995; Barnett *et al.*, 1997), and are commonly deposited by lahar-related hyperconcentrated streamflows in volcaniclastic environments (Pierson and Scott, 1985; Smith, 1986; Best, 1992; Vallance, 2000).

It is hypothesized that the slight grain size changes that define each diffuse lamina are related to vertical (Middleton, 1970; Druit, 1995) and/or lateral segregation (Hand, 1997; Vallance, 2000) of grain populations that existed within the parental flows. Absence of cross-stratification in the channel fills may indicate that turbulent flow separation, which is believed to initiate and maintain ripple and dune bedforms (Raudkivi, 1963), was suppressed due to high suspended sediment concentrations (Middleton and Southard, 1984; Smith, 1986; Best, 1992). The occasionally observed loading along the upper contact suggests that the grain framework was metastable following deposition. Loading features are often observed along the tops of subaerial hyperconcentrated flow deposits (Vallance, 2000). Lack of coarsening or fining upward trends in the channel fills suggest that flow was relatively steady during channel filling events (Kneller and Branney, 1995).

FACIES 5: HOMOGENEOUS MATRIX SUPPORTED MUDDY DIAMICTON

Facies 5 is composed of massive gray coloured diamicton with a homogeneous fine sandy mud matrix (Fig. 6f). The bed (there is only one) is 2-4 m thick and extends discontinuously across the south wall of the pit (Fig. 5). The lower contact is typically sharp and either flat or very gently undulating on a decametre scale. Wisps of material from underlying beds are locally folded up into the diamicton along the basal contact. Underlying material is typically undisturbed, but occasionally is ductilely folded (see sections 1 and 2 in Fig. 5). (At a nearby pit, the lower contact of the diamicton is thrust faulted [Cummings, 2000].) The diamicton contains rare to occasional broken shells of *Balanus hameri* and very rare *Portlandia arctica*. Clasts range from granule to small boulder, and are often striated. Clasts are almost entirely of carbonate mudstone and wackestone lithology (Fig. 7a). Clast A/B planes dip shallowly toward the north to northwest (Fig. 7b).

Interpretation: Subglacial till. Facies 5 is interpreted to be a subglacial till deposited by grounded ice that flowed roughly southward across Pointe Saint-Nicolas. Injection of underlying sands up across the basal contact, as observed in this facies, is a common feature of subglacial tills (Dreimanis, 1988; Iverson *et al.*, 1997). The folded nature of the injections suggests that subglacial deformation was largely ductile, although thrust faulting in adjacent pits suggests that brittle deformation occurred locally. The muddy matrix and presence of a glaciomarine fossil assemblage (Hillaire-Marcel, 1980) indicates that the diamicton is derived mainly from underlying glaciomarine mud (Facies 1 and 2). However, the relatively high abundance of carbonate mudstone and wackestone clasts in Facies 5 (Fig. 7a) suggests at least partial derivation from the carbonate mudstone and wackestone rich St. Lawrence Platform (Fig. 1).

FACIES 6: HETEROGENEOUS CLAST- TO MATRIX-SUPPORTED MUDDY DIAMICTON

Heterogeneous diamicton occurs in the top ~15 m of the outcrop as thin sheets and as channel fills (Fig. 6g). Channel bases are erosive, and have rare local matrix-free pipes with vertical clast fabrics. Sheets of heterogeneous diamicton pinch out on a decametre scale, and have lower contacts that are flat and sharp. The diamicton is heterogeneous in that matrix texture, as well as clast content, clast support, and clast fabric can vary over small vertical and horizontal distances. The matrix ranges from fine sandy mud to muddy coarse sand. Clasts range from pebble to small boulder (average diameter ~4 cm; maximum diameter ~60 cm), and are often striated and covered with *Balanus hameri* fragments.

Interpretation: Subaqueous debris flow deposits. The marked spatial changes in matrix texture, clast fabric and matrix support, lack of grading, presence of larger clasts, and occasional dewatered lower contact suggests that the heterogeneous diamicton was deposited rapidly from subaqueous muddy debris flows (Middleton and Southard, 1984; Postma, 1986). Mud in the matrix may have added considerable buoyant strength to the flows, which, along with bed-normal dispersive pressure and possibly elevated pore pressures, would have helped raft larger outsized clasts (Rodine and Johnson, 1976; Hampton, 1979; Iverson, 1997). Pipe-like zones in the diamicton with little matrix and vertical clast fabrics are associated with dewatering of the underlying sediments, and are interpreted to be elutriation pipes (Lowe, 1975; Druitt, 1995). The abundance of clasts covered with *Balanus hameri* basal plates suggests that the debris flows were derived from the colonized subaqueous flanks of the basin.

FACIES 7: MATRIX-POOR GRAVEL

This facies is composed of clast-supported pebbles and cobbles (Fig. 6h). The gravel is generally matrix-poor and moderately sorted. Any matrix material present is typically poorly sorted muddy coarse sand. Beds are sheet-like, 20-150 cm thick (where bed thickness is discernable), and pinch out laterally over several decametres. Beds are typically inversely graded (Fig. 6h), although ungraded and normally graded beds occur. Clasts are unstriated and are sub- to well rounded. Clast A/B planes are inclined towards the southeast (Fig. 7b). No shells or organics were observed.

Interpretation: Subaqueous outwash deposits. The sheet-like nature of the beds suggests that the parental flows were unconfined on at least a decametre scale. Lack of cross-stratification indicates that flow separation and bedform development did not occur. Absence of striated clasts and the matrix-poor nature of the facies suggest that the gravels were hydraulically sorted prior to deposition. The southeast inclination of the clast A/B planes (Fig. 7b) suggests that the gravel was deposited by flows moving towards the northwest.

Although inversely graded beds are typically ascribed to kinetic sieving or (erroneously — J. Vallance, personal communication, 2001) dispersive pressure sorting mechanisms in highly concentrated flows (Bagnold, 1954; Middleton, 1970), the inversely graded gravel beds at Pointe Saint-Nicolas are interpreted to have been deposited as tractional bedload by flows where coarser bedload grains lagged behind finer bedload grains. Progressive deposition from such flows would theoretically produce an inversely graded bed (Hand, 1997; Vallance, 2000). Although grainflowing can produce inversely graded beds (Bagnold, 1954), pure gravitationally-driven grainflowing would have been unlikely at Pointe Saint-Nicolas, as the maximum dip of underlying beds (5-12º) is much less that the subaqueous angle of repose for gravels (Fig. 4; see Sohn, 2000). However, traction-carpet type flow (Sumer *et al.*, 1996; Sohn, 1997; Pugh and Wilson, 1999), where the bed is sheared by an overlying fluid, cannot be ruled out completely, and is considered here as a viable alternative mechanism for generating the inversely graded beds. (This scenario becomes more appealing when one considers that the deposition environment could have been subglacial and pressurized.)

FACIES 8: MASSIVE- TO CRUDELY-STRATIFIED GRAVEL

This facies is present only at the very top (and often inaccessible part) of the Pointe Saint-Nicolas section, where is occurs as a thick sheet-like unit. The gravel sheet has an erosive lower contact and is composed of crudely to massive pebble and cobble gravels. Rare deep and narrow gravel-infilled vertical triangular structures (*e.g*. 1 m wide by 2 m deep) are present along the basal contact. The gravel is generally matrix poor and clast supported, although zones that are slightly matrix supported exist. The matrix texture is muddy sand. Gravel clasts are well rounded and unstriated, and the gravel contains common to rare broken *Balanus hameri* shells.

Interpretation: Fluvial deposits. The crudely stratified gravel facies is interpreted to be a fluvial deposit. The triangular wedge-like structures are interpreted to be ice wedge casts, which suggest a subaerial setting (Eyles and Eyles, 1992). Lack of obvious cross bedding suggests that lateral or downstream accretion of angle of repose bars and bedforms was not significant during deposition. Shell fragments are interpreted to be reworked from underlying deposits.

FACIES ASSOCIATIONS

Four facies associations, each representing a distinct depositional environment, have been identified in the Pointe Saint-Nicolas pit (Table II). The relationship of the facies associations is shown diagrammatically in Figure 8. The facies associations form the building blocks of the depositional model (Fig. 9), which is outlined in the next section.

FACIES ASSOCIATION 1: SUBAQUEOUS FAN

Facies Association 1 makes up the lower half of the outcrop (Fig. 8), and is equivalent to subunits 2 and 3 of LaSalle's Anse-aux-Hirondelles Formation (see Fig. 3). This facies association, which has a northwest-thinning wedge-like geometry, is interpreted to be an ice-proximal subaqueous fan. The subaqueous fan is composed primarily (~90 %) of normally graded sandy turbidites (Facies 3). The turbidites dip 5-12º towards the northwest, and form the subaqueous fan foresets (Fig. 4). The foresets are cut locally by channels that are filled with sandy hyperconcentrated underflow deposits (Facies 4).

A prominent, flat-based pebble to cobble gravel sheet (Facies 7) caps the subaqueous fan. The upper contact of the gravel sheet is locally convex-up and lobate (Fig. 6h), and is intercalated locally with turbidites with northwest paleoflows (section 8, Fig. 5) and locally with glaciomarine muds (section 1, Fig. 5). The turbidites that are intercalated with the top contact of the gravel sheet are locally dewatered and deformed, and are associated with elutriation pipes in overlying debris flow deposits (Facies 6, Facies Association 3). These data suggest that the gravel sheet is conformable with the overlying ^{14}C-dated deglacial facies associations.

The lower contact of the gravel sheet is flat and erosive. However, several features of the gravel sheet suggest that it is genetically related with the underlying sandy subaqueous fan, and that it was deposited during a sheetflooding event near the end of fan deposition. First, local intercalation of the gravel sheet with overlying turbidites and glaciomarine muds suggests a subaqueous depositional environment akin to that of the underlying sandy fan. Secondly, the gravel sheet was deposited

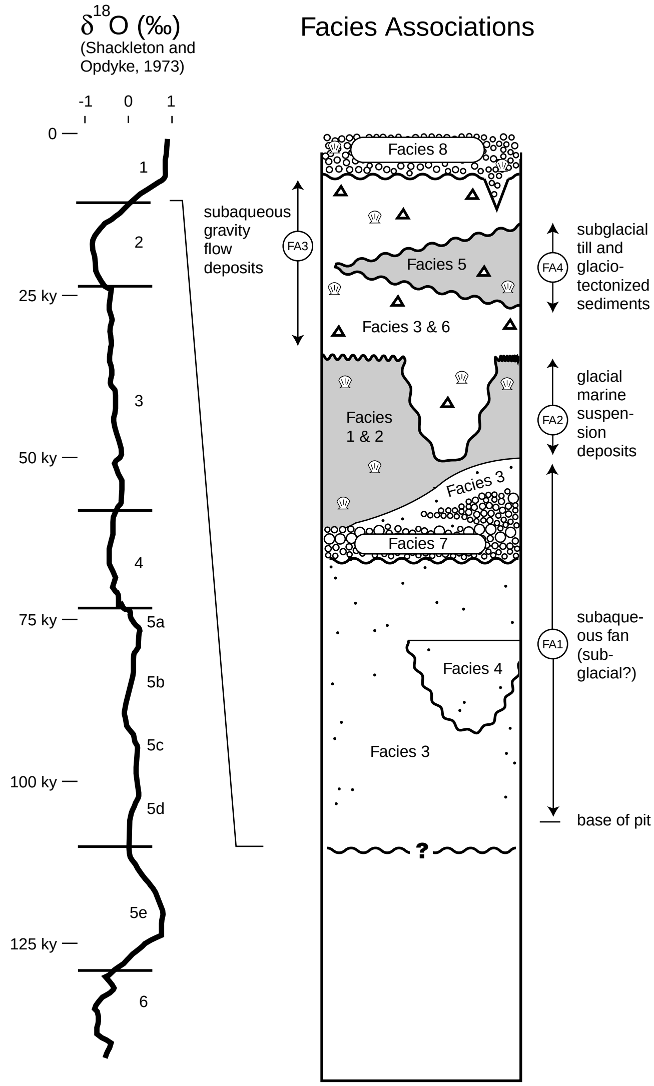

FIGURE 8. Facies associations, Pointe Saint-Nicolas, and proposed correlation with the marine delta ^{18}O isotope curve.

Association de faciès à la pointe Saint-Nicolas et corrélation avec la courbe isotopique marine.

TABLE II

Facies associations

Facies Association (FA)	Constituent facies	3D architecture	Stratigraphic position
FA1: Subaqueous fan	Facies 3, 4, 7	NW thinning wedge	lower contact is buried below pit surface; presumed erosional (see text)
FA2: Glacial marine suspension deposits	Facies 1, 2	draped bank or blanket-like unit (< or = 5 m thick); locally channeled into by FA3	lower contact draped or intercalated with FA1 mud deposition had started by 11.2 ^{14}C ka BP (GSC-1476)
FA3: Subaqueous gravity flow deposits	Facies 6, 3	thin (20-100 cm) and sheet like, or as channel fills	erodes into FA2 muds
FA4: Subglacial till and associate glaciotectonized deposits	Facies 5 and deformed versions of Facies 1 and 2	thin (< 3m) and sheet-like	sharply overlies and deforms FA2 mud; deposited between 10.95 ^{14}C ka BP (Beta-125967) and ~10.8 ^{14}C ka BP (St. Narcisse Moraine deposition)

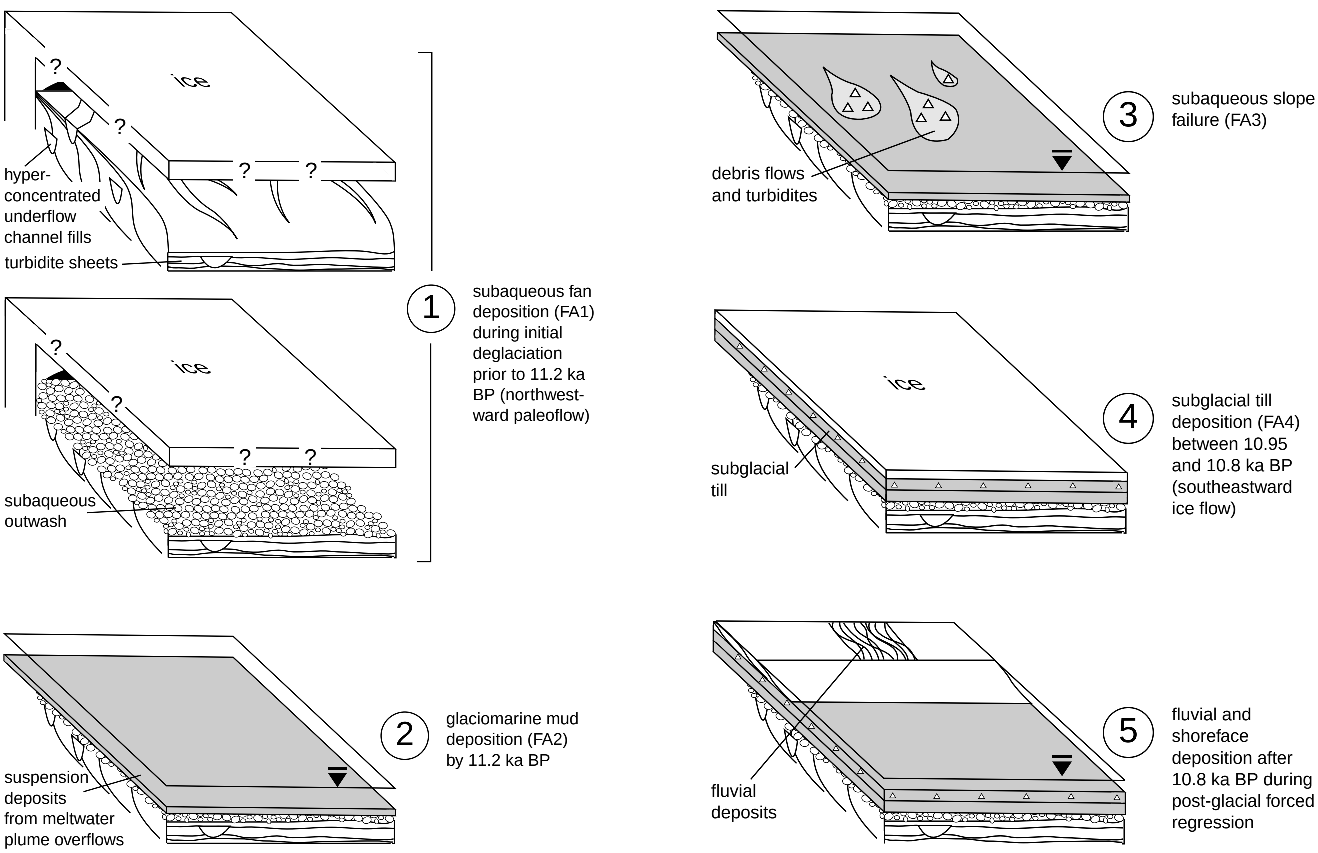

FIGURE 9. Deglacial depositional model for the Pointe Saint-Nicolas sand pit.

Modèle de sédimentation pendant la déglaciation au Wisconsinien supérieur appliqué aux unités de la sablière de la pointe Saint-Nicolas.

towards the northwest, as were the turbidites located both immediately above and below the gravel sheet (section 8, Fig. 5). Thirdly, the sandy subaqueous fan coarsens-up in the 2 m underlying the gravel sheet (section 8, Fig. 5), suggesting that meltwater discharge increased just prior to gravel deposition. Finally, the flat base of the sheet, sheet-like geometry of the gravel beds and locally convex up nature of the top contact are not compatible with deposition in front of a small efflux, where channelization would be expected (Powell, 1990). In concert, these data are suggestive of sheetflooding from a nearby ice front during final stages of subaqueous fan deposition.

FACIES ASSOCIATION 2: GLACIAL MARINE SUSPENSION DEPOSITS

A thick mud bank overlies the subaqueous fan (Fig. 8). The mud bank is composed of stratified (Facies 2) and unstratified (Facies 1) glaciomarine mud with rare pebbles (< 10 %). The lower contact of the mud bank is usually draped overtop of the subaqueous fan (Facies Association 1); locally this contact is intercalated (section 1, Fig. 5). *In situ Portlandia arctica* shells collected from this facies association ~1 m above the lower contact yielded a ^{14}C age of 10 950 BP (Beta-125967). Muds with similar characteristics, often termed Champlain Sea clays, are found in deglacial successions throughout the St. Lawrence Valley.

FACIES ASSOCIATION 3: SUBAQUEOUS GRAVITY FLOW DEPOSITS

Facies Association 3 is composed of fossiliferous subaqueous debris flow deposits (Facies 6) and normally graded fossiliferous sandy turbidites (Facies 3). The lower contact of Facies Association 3 is erosive, locally dewatered, and can be highly channelized into the underlying mud bank (section 4, Fig. 5). Locally, the underlying mud bank is completely eroded, and Facies Association 3 debris flow deposits lie directly overtop of the subaqueous fan (Facies Association 1). Channels are filled predominantly with debris flow deposits (Facies 6) with occasional thin (< 10 cm) normally graded sandy turbidite interbeds (Facies 1). Debris flow and turbidite beds can also occur as sheet-like 'couplets' that pinch out laterally on the decametre scale. These are interpreted to be slope-failure derived debris flows that developed sandy turbulent tails during downslope translation (Mohrig *et al.*, 1998).

FACIES ASSOCIATION 4: SUBGLACIAL TILL AND ASSOCIATED GLACIOTECTONIZED MUDS

Facies Association 4 consists primarily of a thin sheet of homogeneous diamicton interpreted to be subglacial till (Facies 5) that runs discontinuously across the entire outcrop (Fig. 8). Also included in this facies association are ductilely deformed glaciomarine muds (Facies Association 2) underlying the subglacial till (see sections 1 and 2, Fig. 5). The lower contact of the till sheet is sharp. *Balanus hameri* fragments collected by Lasalle and Shilts (1993) from a gray, compact, calcareous diamicton (that is presumably equivalent to Facies Association 4) yielded a ^{14}C age of 11 200 ^{14}C BP (GSC-1476).

DEPOSITIONAL MODEL

A depositional model for the Pointe Saint-Nicolas sand pit is presented in Figure 9. Although some of the events outlined in the model can be extended ~10 km west of the pit (Cummings, 2000), the depositional model should be considered as having only local significance. In order to give context, the sequence of regional events is shown in Figure 10.

Initial deglaciation at the Pointe Saint-Nicolas was accompanied by an energetic northwestward discharge of meltwater that was issued from a grounding line located nearby to the south (Fig. 9). This discharge deposited a subaqueous fan composed of normally graded sandy turbidites, diffusely laminated sandy channel fills, and gravel outwash. The predominance of turbidites in the subaqueous fan suggests that underflowing was facilitated by relatively low density fresh basinal waters and/or very high suspended sediment concentrations. The presence of diffusely laminated sands suggests that meltwater underlows were often hyperconcentrated (20-40 % vol) and highly energetic. Maximum cross-bed thickness observed in the subaqueous fan (~2.5 m) suggests that flow depth may have been ~15 m or more during subaqueous fan deposition (as dunes, unlike ripples, typically scale to the boundary layer at a ratio between 1:6 and 1:10 [Allen, 1985; Leclair and Bridge, 2001]).

Given the current lack of evidence of early marine incursion up the axis of the St. Lawrence Valley west of Québec City (see Parent and Occhietti, 1988), it seems most likely that the subaqueous fan at Pointe Saint-Nicolas was deposited in a subglacial (brackish?) body of water. Establishing a unequivocal relationship between the episode of subaqueous fan deposition at Pointe Saint-Nicolas and an apparent period of early marine incursion east of Québec City (*e.g*. 12 400 ^{14}C BP date at Charlesbourg — GSC-1533) requires additional supporting ^{14}C data. The timing of initial deglaciation at Pointe Saint-Nicolas therefore remains unconstrained, as plant macrofossils from underlying organic-rich silty sand Subunit 1 of the Anse-aux-Hirondelles Formation have previously yielded a date of > 42 000 ^{14}C ka BP (GSC-3420).

By 11 200 ^{14}C BP (GSC-1476) subaqueous fan deposition at Pointe Saint-Nicolas had ended. An ice-free and glaciomarine Champlain Sea occupied the axis of the valley, and muds were being deposited from suspension (Fig. 9). Iceberg calving during mud deposition is equivocal, as no iceberg homogenization/turbation, iceberg mound-dump, or keel structures (Thomas and Connell, 1984; Powell and Molnia, 1989; Dowdeswell *et al.*, 1994) were observed at Pointe Saint-Nicolas. Striated pebbles and cobbles in glaciomarine mud facies may simply have been rafted by seasonal sea ice (Powell and Molnia, 1989; Cowan *et al.*, 1999). Mud deposition continued until at least 10 950 ^{14}C BP (Beta-125967).

Subaqueous failure along the flanks of the basin ensued following the introduction of glaciomarine muds into the basin (Fig. 9). Large channels cut into the top of the glaciomarine mud bank at Pointe Saint-Nicolas are interpreted here as slump scars. Failure of the muddy subaqueous flanks of the Champlain Sea basin at Pointe Saint-Nicolas produced fossiliferous debris flows and turbidites.

Following the advent of slope modification, a grounded Laurentide Ice Sheet readvanced through the Champlain Sea towards the south and deposited the mildly fossiliferous St. Nicolas Till (Fig. 9; LaSalle and Silts, 1993; Cummings, 2000). The muddy texture and fossiliferous nature of the St. Nicolas Till suggests that it was sourced primarily from the underlying

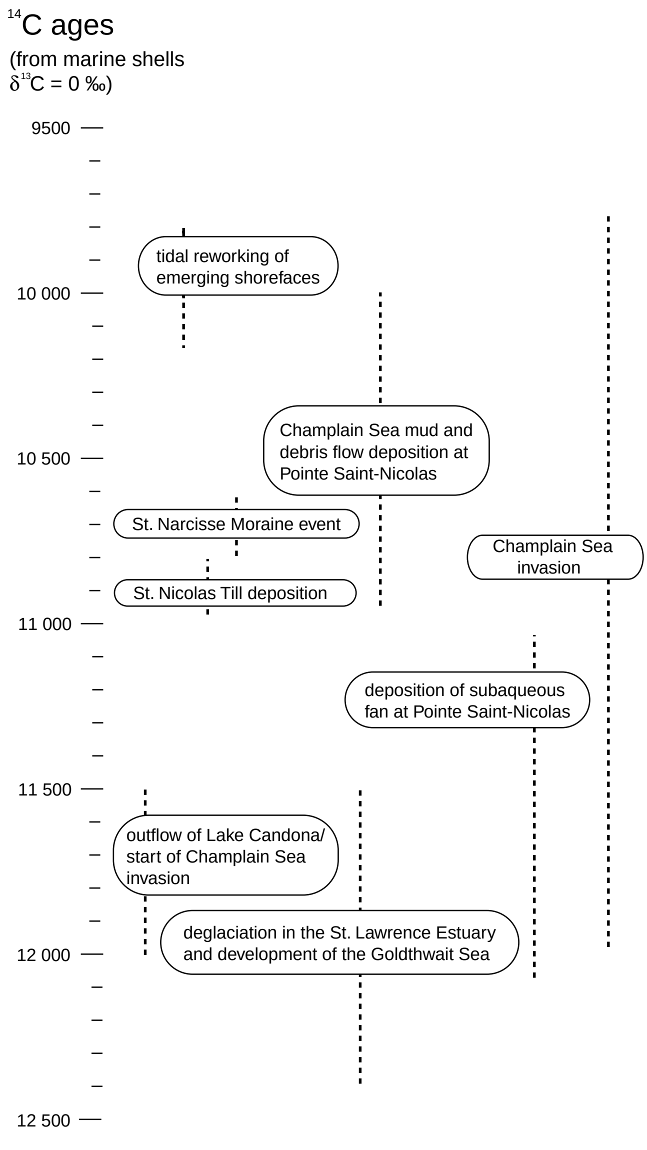

FIGURE 10. Sequence of deglacial events in the Québec City region.
Séquence des évènements dans la région de Québec, au Wisconsinien supérieur.

Champlain Sea glaciomarine mud. The St. Nicolas readvance (surge?) occurred after 10 950 ^{14}C BP (Beta-125967) but prior to ~10 800 ^{14}C BP, when the St. Narcisse Moraine was deposited on the north shore (Fig. 10). Deposition of the St. Nicolas Till after 10 800 ^{14}C BP is unlikely, as no obvious breaks that could have been caused by a readvance are observed in the St. Narcisse Moraine.

During postglacial isostatic rebound and associated forced regression, the emergent flanks of the basin around Pointe Saint-Nicolas were reworked by tidal currents (Cummings, 2000; Occhietti *et al*., 2001a), and fluvial systems began to incise their valleys. At Pointe Saint-Nicolas, a fluvial system reworked underlying fossiliferous sediments and deposited a crudely stratified gravel sheet (Fig. 9). A large ice wedge cast present along the base of the gravel sheet suggests that the climate was still relatively cold at this time.

DISCUSSION

Previously, the subaqueous fan (FA1), which is equivalent to subunits 2 and 3 of LaSalle's Anse-aux-Hirondelles Formation (Fig. 3), has been interpreted as a Middle Wisonsinan fluvial floodplain unit (LaSalle, 1984, 1989). This interpretation is largely based on the assumption that the lower subaqueous fan contact, which remains buried below the base of the pit, is conformable with the underlying ^{14}C-dated Subunit 1, which is exposed below pit level at the edge of the St. Lawrence River. Although a subaerial fluvial floodplain depositional environment seems compatible with the insects and plant macrofossils present in Subunit 1 (LaSalle 1989), it is definitely incompatible with the organic-free sandy turbidites (Facies 3) and hyperconcentrated underflow deposits (Facies 4) that make up the foresets of the subaqueous fan (*i.e*. Subunit 2). As the subaqueous fan is not genetically related to Subunit 1, the subaqueous fan is most likely either separated from Subunit 1 by another unit, or overlies Subunit 1 unconformably. Given the high-energy nature of the facies in the subaqueous fan (*e.g*. hyperconcentrated underflow deposits), the lower fan contact is hypothesized to be an erosion surface formed during an energetic meltwater discharge that accompanied initial deglaciation.

The presence of a Late Wisconsinan subaqueous fan below Champlain Sea deposits at Pointe Saint-Nicolas suggests that a body of water, possibly subglacial, formed during deglaciation in the axis St. Lawrence Valley while ice remained on the south shore. Although there are no obvious ice front landforms near Pointe Saint-Nicolas (are they buried?), northwest paleoflows in the high-energy subaqueous fan facies suggest that both the grounding line and the meltwater source were located updip to the south. Candidate meltwater sources include Lake Candona, or Lake Chaudière-Etchemin, which was located in the Chaudière-Etchemin Valley (see Occhietti *et al.*, 2001b), or possibly even the Champlain Sea after it invaded the Lake Candona basin. Development of a body of water in the valley axis west of Québec City would have effectively severed the pressure gradient that maintained southward flow in subglacial streams that fed these ice-ponded glacial lakes (see esker data in Warwick area on Fig. 1). This would effectively have allowed the ponded lake water to drain downdip into the valley axis. Although this hypothesis should be considered preliminary until tested by further regional study, it is interesting to note that several major paleohydraulic events occurred during deglaciation in the greater Québec City region (*e.g.* Lake Candona drainage), and no associated deposits have been discovered.

The re-interpretations presented in this paper, in combination with work both upstream and downstream of Pointe Saint-Nicolas (Clet *et al.*, 1991; Clet and Occhietti, 1996; Clet-Pellerin and Occhietti, 2000), suggest that stratigraphic terminology used in the Québec City region (Fig. 2) should be abandoned in favor of terminology used in the central St. Lawrence Valley. The Anse-aux-Hirondelles Formation is composed of two genetically distinct units: 1) an organic-rich lower unit dated between 28 375 and > 42 000 ^{14}C BP (Subunit 1), and 2) the overlying Late Wisconsinan subaqueous fan (subunits 2 and 3). The organic-rich unit can probably be correlated with one of the Late Sangamonian-Wisconsinan units in the central St. Lawrence Valley (St. Pierre Sediments or the base of the St. Maurice Rhythmites). The subaqueous fan, which is located stratigraphically below Champlain Sea muds, is a new deglacial unit related to a local (?) early phase of deglaciation in the St. Lawrence axis. Further regional study is needed to determine the extent of this early deglacial episode.

CONCLUSIONS

An ice-proximal subaqueous fan was deposited at Pointe Saint-Nicolas during an energetic Late Wisconsinan meltwater discharge. The presence of a northward built subaqueous fan at Pointe Saint-Nicolas suggests that a relatively fresh and possibly subglacial body of water formed during early deglaciation in the axis of the valley while ice remained on the south shore. By 11 200 ^{14}C BP, the basin at Pointe Saint-Nicolas was occupied by the Champlain Sea, and massive to stratified mud was being deposited. Introduction of mud into the basin promoted slope failure and debris flowing on the subaqueous flanks of the basin. Between 10 950 and ~10 800 ^{14}C BP, the Laurentide Ice Sheet readvanced (surged?) through the Champlain Sea towards the south and deposited the St. Nicolas Till at Pointe Saint-Nicolas. During the subsequent glacio-isostatically induced forced regression, emergent shorefaces were reworked by shore parallel tidal currents, and the St. Lawrence and its tributaries incised their valleys.

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