

# Deltaic Complexes of the Québec North Shore

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## Abstract

One of the most particular morphological features of the Québec North Shore (North Shore of the Estuary and Gulf of the St. Lawrence, eastern Canada) is the occurrence of deltaic complexes that form thick and extensive sediment bodies (gravel, sand and mud) along the modern coastline. The deltaic complexes were emplaced during the retreat of the Laurentide Ice Sheet from the region that commenced about 11 ka in the context of falling relative sea level. Deltaic complexes are made up of three distinct, superimposed depositional systems, consisting of: (1) ice-contact subaqueous fans and deltas, (2) ice-distal glacifluvial deltas, and (3) coastal suites and meandering channel belts. Ice-contact systems were emplaced immediately after deglaciation of the region at the front of the ice-margins. Subsequent ice retreat fed glacifluvial deltas in meltwater and glaciogenic sediments until the complete retreat of the ice-margin from the drainage basin a few thousand years ago. The resulting shutdown in sediment supply led to the

reworking of the now-inactive glacifluvial deltas by shore-related and fluvial processes that resulted in the deposition of coastal suites and meander channel belts. Submarine sediment accumulations and related morphologies revealed by high-resolution swath bathymetric and seismostratigraphic data collected off these deltaic complexes are the subaqueous counterparts of these deltas. The modern evolution of these deltaic complexes is controlled by the reworking, transport, and deposition of sediments by shore-related processes along the coast, on the shallow shelf, and through submarine channels and canyons.

## Keywords

Deltaic complexes • Laurentide Ice Sheet • Deglaciation • Ice-contact deposits • Glacifluvial deltas • Submarine fans

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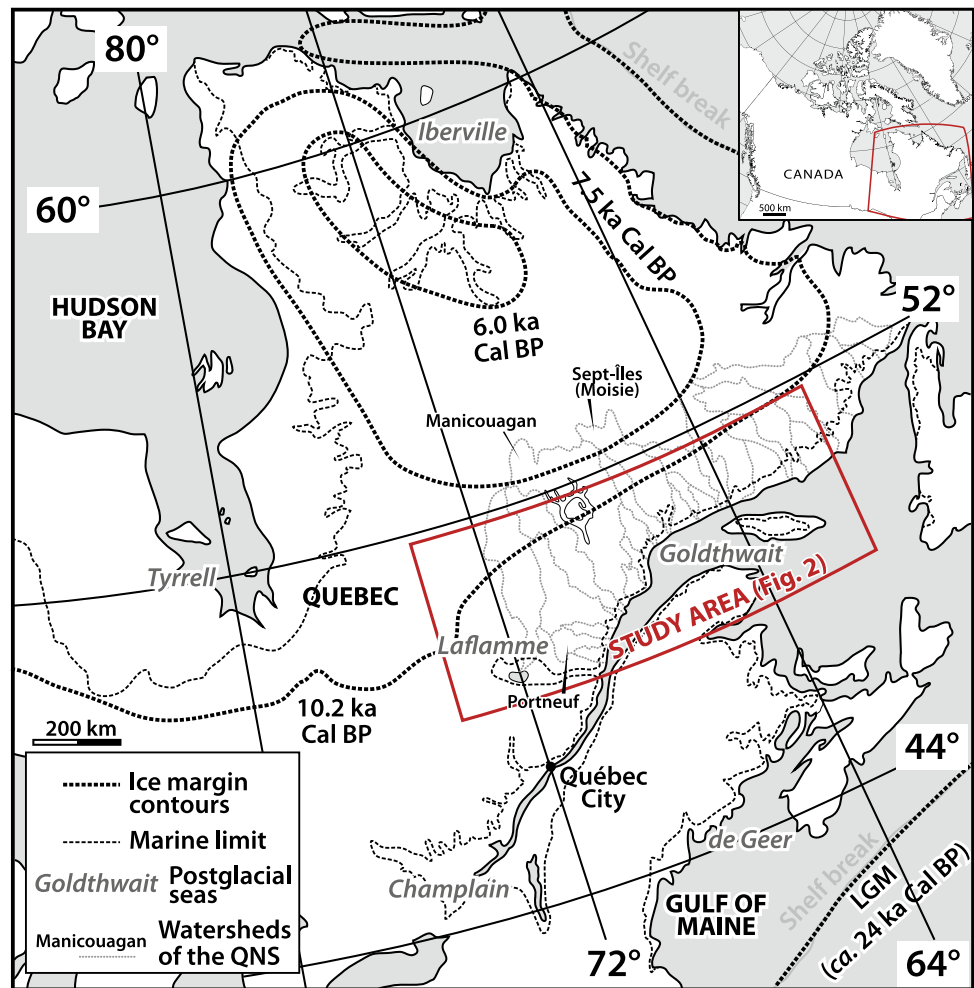
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## 10.1 Introduction

Thick and extensive (tens to hundreds of km<sup>2</sup>) sediment accumulations consisting of gravel, sand and mud form prominent deltaic complexes along the Québec North Shore (QNS, North Shore of the Estuary and Gulf of the St. Lawrence, Québec, eastern Canada (Figs. 10.1 and 10.2). These deltaic complexes lie at the outlet of deep and steep-sided valleys carved into the hinterland bedrock in which modern rivers flow. Although some of these deltaic complexes are conspicuously protruding in the Estuary and Gulf of St. Lawrence (e.g. Fig. 10.2), most are characterized by straight shorelines and are hence recognized by their smooth aspect on digital elevation models (DEM) and LiDAR compared to the rough aspect of the surrounding bedrock.

These deltaic complexes essentially consist of relict sedimentary bodies raised above the modern sea level (Normandeau et al. 2015; Dietrich et al. 2017a) as they were emplaced immediately after the retreat of the Laurentide Ice

**Fig. 10.1** Location map of the study area (Québec North Shore, Estuary and Gulf of St. Lawrence) within the frame of the deglaciated eastern Canada. Bold dashed lines represent successive contours of the retreating Laurentide Ice Sheet. Maximal extent of postglacial seas (the Goldthwait Sea in the study area) is symbolized by the marine limit. Watersheds of the Estuary and Gulf of St. Lawrence are also represented (gray dotted lines)



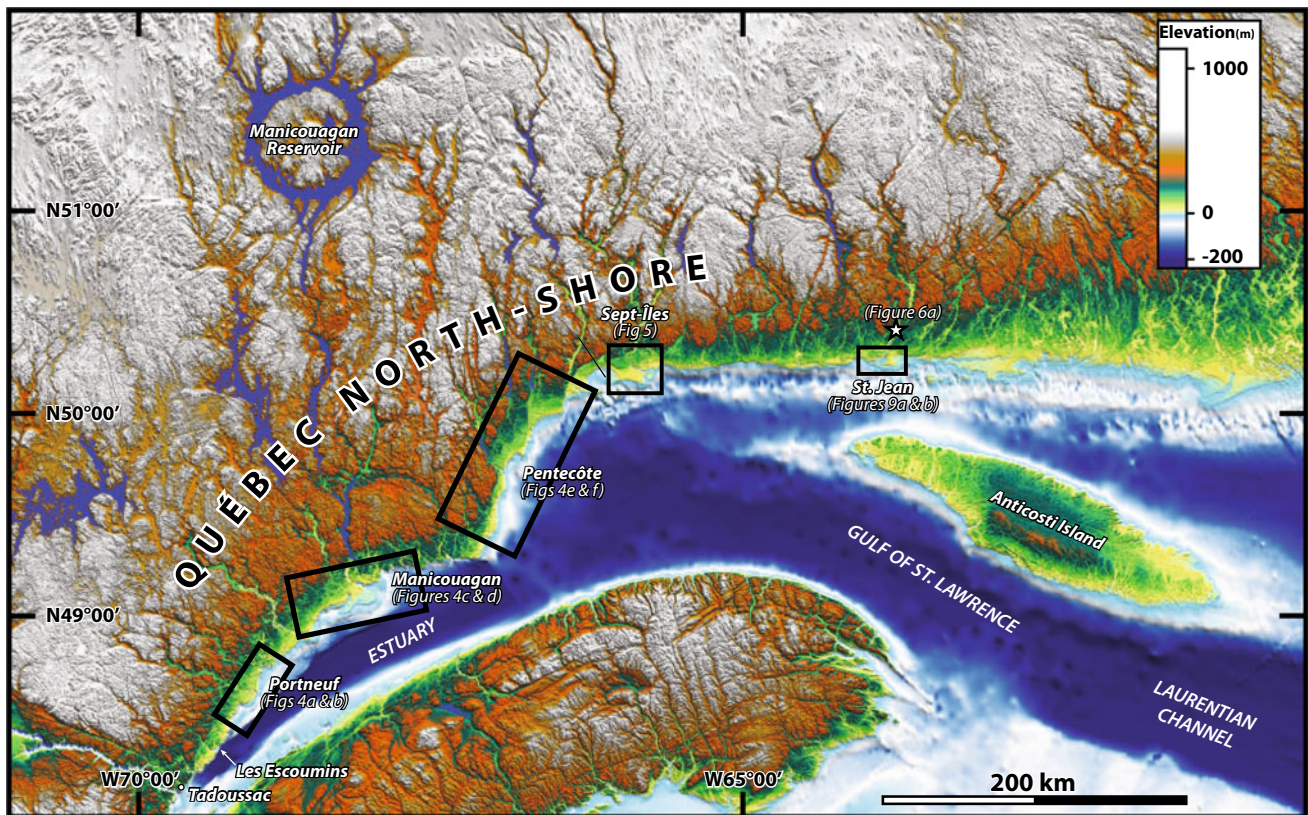
Sheet (LIS) around 11 ka in the glacial and postglacial Goldthwait Sea (Fig. 10.1), which subsequently experienced relative sea level (RSL) fall (Fig. 10.3). Prominent morphosedimentary structures such as relict-braided fluvial patterns, kettle lakes, raised beach ridges, and sandspits characterize the surface of these sedimentary systems (Dredge 1983; Drapeau 1992; Hein et al. 1993; Dionne et al. 2004).

High-resolution swath bathymetric and seismostratigraphic surveys conducted off the deltaic complexes revealed the presence of subaqueous sediment accumulations characterized by key morphological features such as bedforms and submarine channels (e.g. Normandeau et al. 2013, 2017). These subaqueous sediment accumulations and their correlative morphologies are the marine counterpart of the deltas observed on land. Both settings, subaqueous and subaerial, are part of the same system and as such have been studied as a continuum.

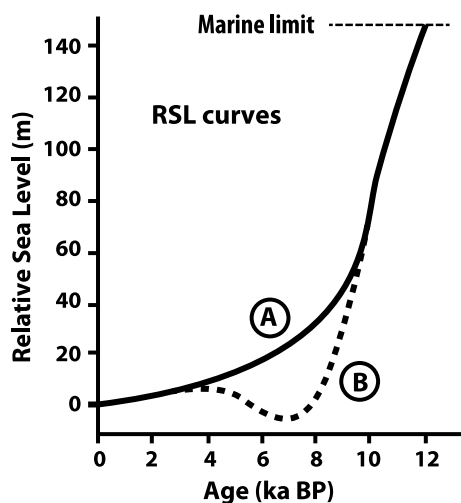
## 10.2 Setting

### 10.2.1 Geographic Setting

The St. Lawrence Estuary and Gulf form a deep (mean depth 150 m) semi-enclosed sea lying on the continental platform and supplied with fresh water from the St. Lawrence River to the southwest. The St. Lawrence Estuary and Gulf are bordered by the moderate to high relief forested Shield geomorphological region (Grenville geological province) and the Appalachian mountain geomorphological region (Appalachian geological province) on its western and south-eastern sides, respectively, and open to the Atlantic Ocean to the east (Fig. 10.1). Palaeozoic sedimentary rocks of the eastern part of the St. Lawrence Lowland (St. Lawrence platform) are also found from place to place along the QNS (Lajeunesse et al. 2013). The Estuary and Gulf of St. Lawrence are characterized by the prominent Laurentian



**Fig. 10.2** Map of the Québec North Shore (digital elevation model, SRTM3, available at <https://www2.jpl.nasa.gov/srtm/>) showing locations of deltaic complexes mentioned in the text. See Fig. 10.1 for location in eastern Canada



**Fig. 10.3** Relative sea level curves for the Québec North Shore, where A is from Dietrich et al. (2017a) and B from Dionne (2001). The latter inferred the presence of a lowstand between 7 and 6 ka followed by a 10 m RSL rise (the so-called *Laurentian transgression*) for which there is evidence on the Québec South Shore (Dionne 2001) but none observed on the Québec North Shore by the present authors

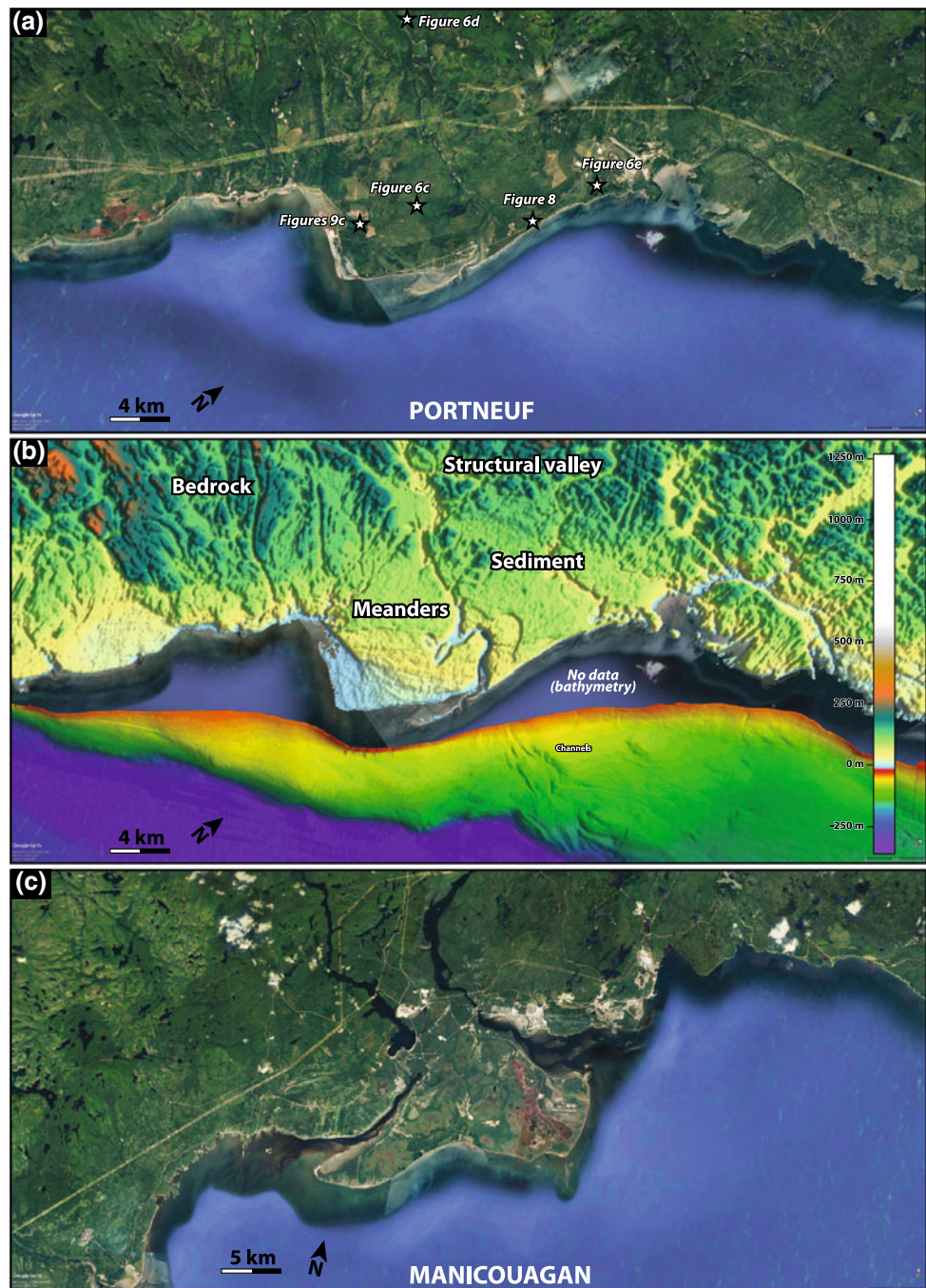
Channel, a 1000 km-long and 80–90 km-wide U-shaped cross-shelf trough that extends from Tadoussac to the edge of the continental platform (Fig. 10.2; Todd 2016; Pinet et al. 2016). The Laurentian Channel is separated from the QNS by a shallow 0–20 km-wide structural shelf that extends from Tadoussac to Sept-Iles (Fig. 10.2; Pinet et al. 2011). The slopes linking the Laurentian Channel to the shallow shelf vary in angle from 2 to 20°. The terrestrial landscape of the QNS is characterized by a series of gently sloping hills reaching hundreds of meters in elevation (Figs. 10.2 and 10.4). These hills, consisting of glacially carved crystalline bedrock of the Grenville Province, are deeply incised (100–400 m) by steep-flanked structural valleys, 0.5–3 km in width, oriented at 90° to the axis of the Estuary and with their bases lying between 50 m above and 300 m below the sea level (Figs. 10.4; Lajeunesse 2014).

## 10.2.2 Deglaciation and RSL History

After the last glacial maximum (LGM) that occurred approximately 23 ka, the Laurentide Ice Sheet (LIS) began



**Fig. 10.4** Google Earth and correlative digital elevation model (DEM) images of some of the deltaic complexes mentioned in the text (**a, b** Portneuf, **c, d** Manicouagan, and **e, f** Pentecôte). Onland topography is from SRTM3 (see Fig. 10.1) and bathymetric data derive from Normandeau et al. (2015)

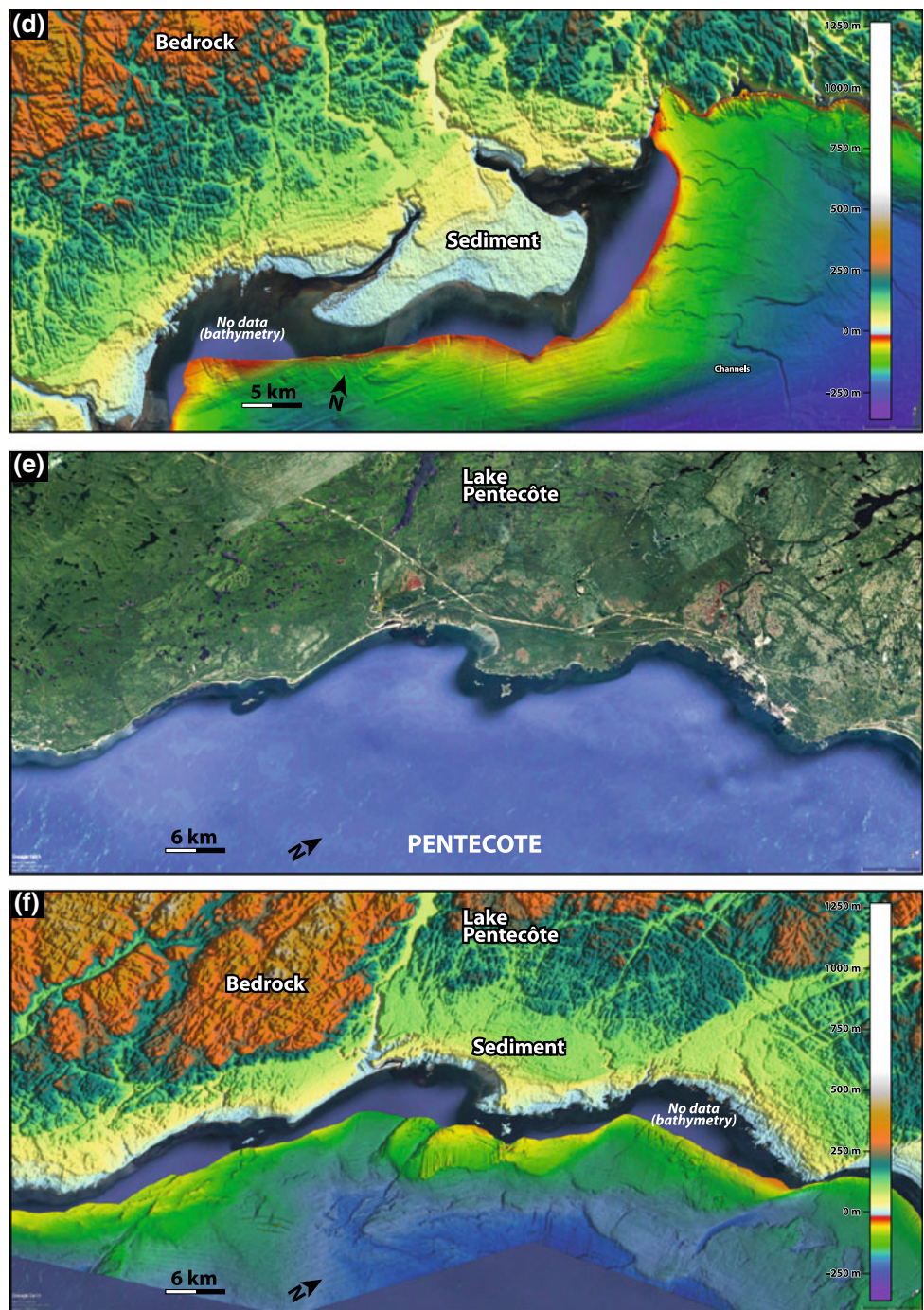


retreating by rapid collapse, generating massive iceberg calving in the Gulf of St. Lawrence (Shaw et al. 2002, 2006). The QNS was essentially deglaciated by c. 11 ka. Retreat of the LIS was subsequently achieved by ablation, deglaciating the northern extent of the Québec North Shore drainage basins by c. 7 ka (Fig. 10.1; Occhietti et al. 2011; Nutz et al. 2015). Along the QNS, immediately after the ice retreat, the invasion of the Goldthwait Sea on glaci-isostatically flexured

lowlands allowed the relative sea level (RSL) to reach an elevation of 130–150 m above the modern sea level, forming the marine limit (Figs. 10.1 and 10.3). This ‘postglacial’ sea also occupied the bottom of some of the structural valleys that formed fjords or fjord-lakes at that time. Glaci-isostatic adjustment (GIA) led to a continuous RSL fall with rates reaching several centimeters per year, in spite of the concomitant global eustatic sea level rise (Fig. 10.3;



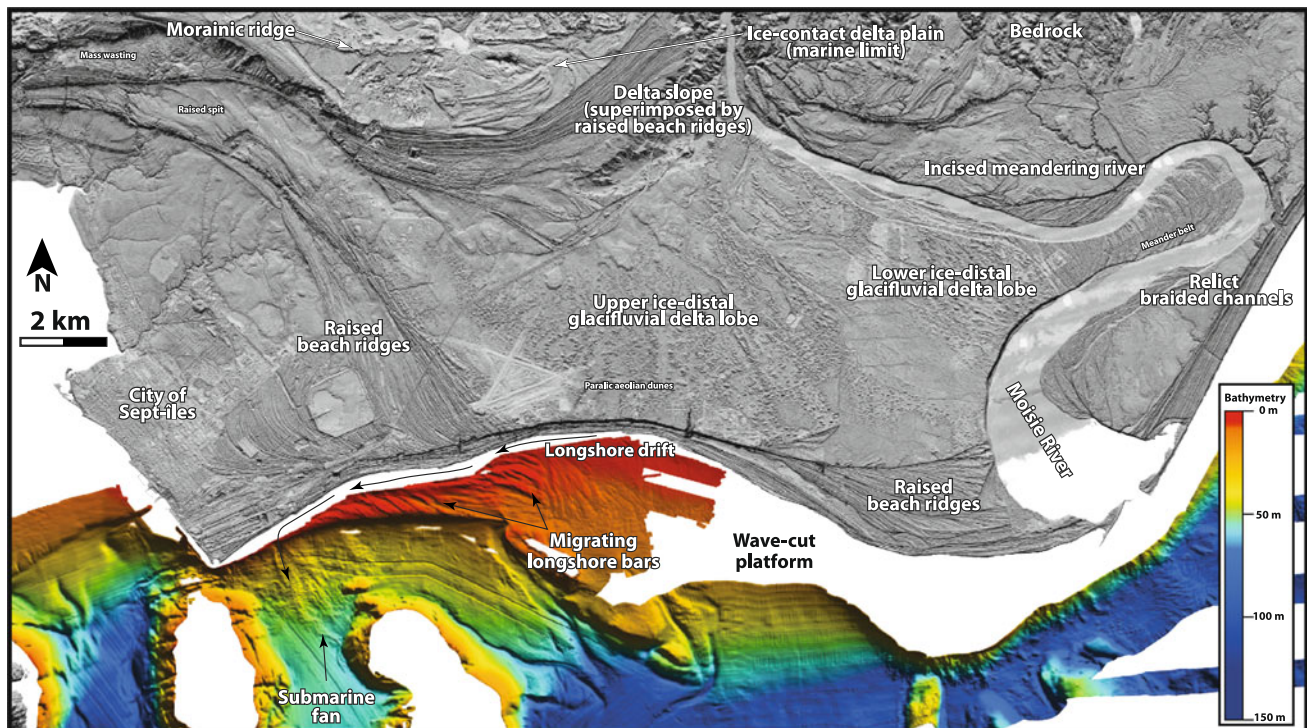
Fig. 10.4 (continued)



Boulton 1990; Peltier et al. 2015). The deltaic complexes were thus emplaced in a context of falling RSL forced by the GIA and fed by meltwater and glacial sediments from the retreating LIS margin. Nowadays, RSL is stable in this region, as the still ongoing GIA is essentially compensated by modern global eustatic rise (Sella et al. 2007; Woodworth et al. 2011). The modern evolution of deltaic complexes is characterized by a generalized retreat of the shoreline (Bernatchez and Dubois 2008).

### 10.3 Deltaic Complexes

The deltaic complexes lying on the QNS are made up of three distinct depositional systems, each one deposited in accordance with the pattern of ice-margin retreat and associated glaci-isostatically-forced RSL fall (Dietrich et al. 2017a). The three depositional systems, either vertically superimposed or laterally juxtaposed, consist of (1) ice-contact



**Fig. 10.5** LiDAR cover and multibeam bathymetry of the Sept-Iles deltaic complex. Note well-expressed morphologies (morainic ridges, braided channels, paralic aeolian dunes, etc.) on the LiDAR. The bathymetric cover illustrates the modern sediment dynamics on delta fronts. The delta front is now being eroded and sediment is transported

by longshore drift. Where the shelf narrows, sediment overflows on the slope and generates turbidity currents, that in turn accumulate as submarine fans. See Fig. 10.2 for location. LiDAR available at <https://geoegl.msp.gouv.qc.ca/igo/mffpecofor/>; bathymetry derives from Normandeau et al. (2013)

subaqueous fans and ice-contact deltas, together referred to as ice-contact depositional systems; (2) ice-distal glaci-fluvial deltas and submarine counterparts; and (3) coastal suites and meandering channel belts. As these depositional systems have specific and unique morphological and surficial expressions, they can confidently be identified on satellite and aerial imagery (Figs. 10.2, 10.4, 10.5, and 10.6) which renders their identification straightforward. Submarine channels and canyons revealed by high-resolution swath bathymetry and seismostratigraphic surveys intrinsically belong to one or more of these three architectural elements (Figs. 10.4 and 10.5; Normandeau et al. 2017).

### 10.3.1 Subaqueous Ice-Contact Fans and Ice-Contact Deltas

Ice-contact depositional systems form sediment wedges that were deposited at the direct vicinity of a stillstanding ice-margin, immediately following deglaciation of the area. They, therefore, most often lie directly on the bedrock (Fig. 10.7). Although grounding zone wedges and morainal banks have recently been mapped on the shallow structural shelf (Lajeunesse 2016; Lajeunesse et al. 2018), subaqueous ice-contact fans and ice-contact deltas are present on land, at

the outlet of structural valleys (Dietrich et al. 2017a, b; Gagnon-Poiré et al. 2018). Ice-contact systems generally constitute the core of the deltaic complexes. Ice-contact deltas are characterized by flat-lying topsets (delta plain) and basinward-dipping clinothems (delta slope), regularly superimposed by raised beach ridges (Fig. 10.5). As deposition of these specific ice-contact systems occurred during early stages of deglaciation, in the context of high RSL, their topsets lie directly at, or slightly below, marine limit (Figs. 10.5 and 10.7). As revealed by aerial and satellite imagery (Fig. 10.5), their topsets are characterized by relict kettle holes occupied today by circular lakes, inactive braided channels, and more rarely by morainic ridges, indicative of the direct vicinity of the ice-margin during deposition (Dubois and Dionne 1985; Dietrich et al. 2016).

The ice-margin stillstands that punctuated the general retreat of the LIS over the study area and permitted the deposition of ice-contact subaqueous fans and deltas generally occurred at the outlet of the structural valleys. After the retreat of the ice-margin from its stillstanding position, the ice-contacts systems may have dammed fjord-lakes, some of which still exist, in the axes of the structural valleys (Normandeau et al. 2016; Dietrich et al. 2017b; Gagnon-Poiré et al. 2018).





**Fig. 10.6** **a** Steep-flanked structural valley carved into the bedrock of the Québec North Shore in which the modern St. Jean River flows. Note that the bottom of the valley lies below marine limit (highest elevation reached by the sea immediately after the deglaciation of the area). The valley was invaded at times by the sea and thus formed a fjord (see Fig. 10.7). Ice-distal glacialfluvial sediments are preserved in the valley in which the modern meandering river is incised. **b** Relict-braided fluvial pattern characterizing the top surface of an ice-contact depositional system. **c** Abandoned meandering channel of

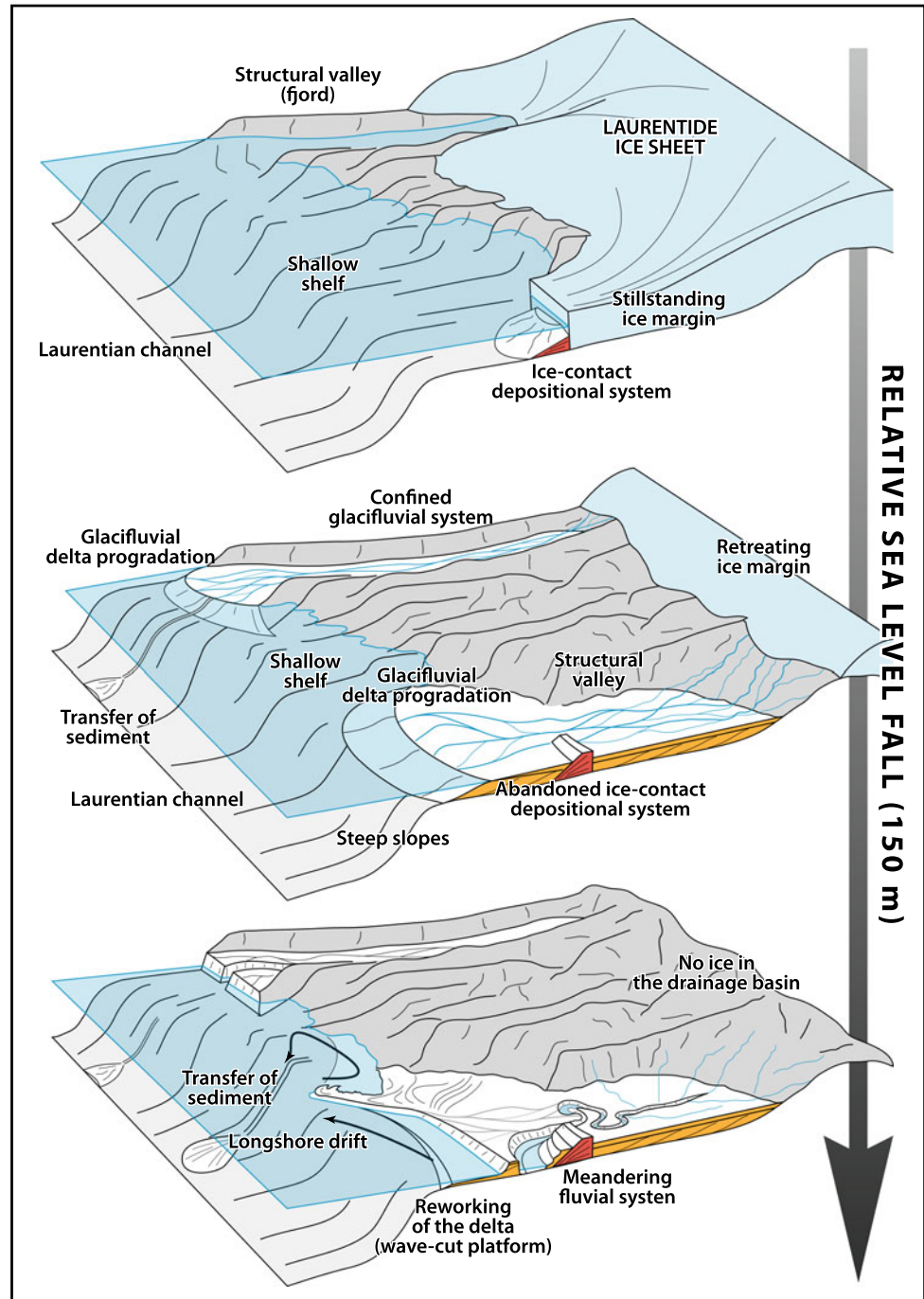
the proto-Portneuf River incised of 20–30 m within the glacialfluvial delta. Abandoned channels are occupied by lakes and peat bogs. **d** The modern meandering Portneuf River deeply incised (40 m) within the ice-distal glacialfluvial delta sediments. **e** The meandering Sault-au-Cochon River. Although standing very close to the modern shoreline, the river lies at 15 m above the modern sea level because a bedrock sill on the river path prevents any further adjustment of the river long profile to the sea level. See Figs. 10.2 and 10.4 for location

### 10.3.2 Ice-Distal Glacifluvial Delta

Ice-distal glacifluvial deltas relate to spatially extensive (several tens of km<sup>2</sup>; Fig. 10.5) and thick (up to 70 m, Fig. 10.8) sediment bodies that were deposited over or next to ice-contact systems. Glacifluvial deltas were deposited when the ice-margin retreated throughout the drainage basins, and fed meltwater and glacigenic sediment into the coastal delta systems (Fig. 10.7). Glacifluvial deltas are

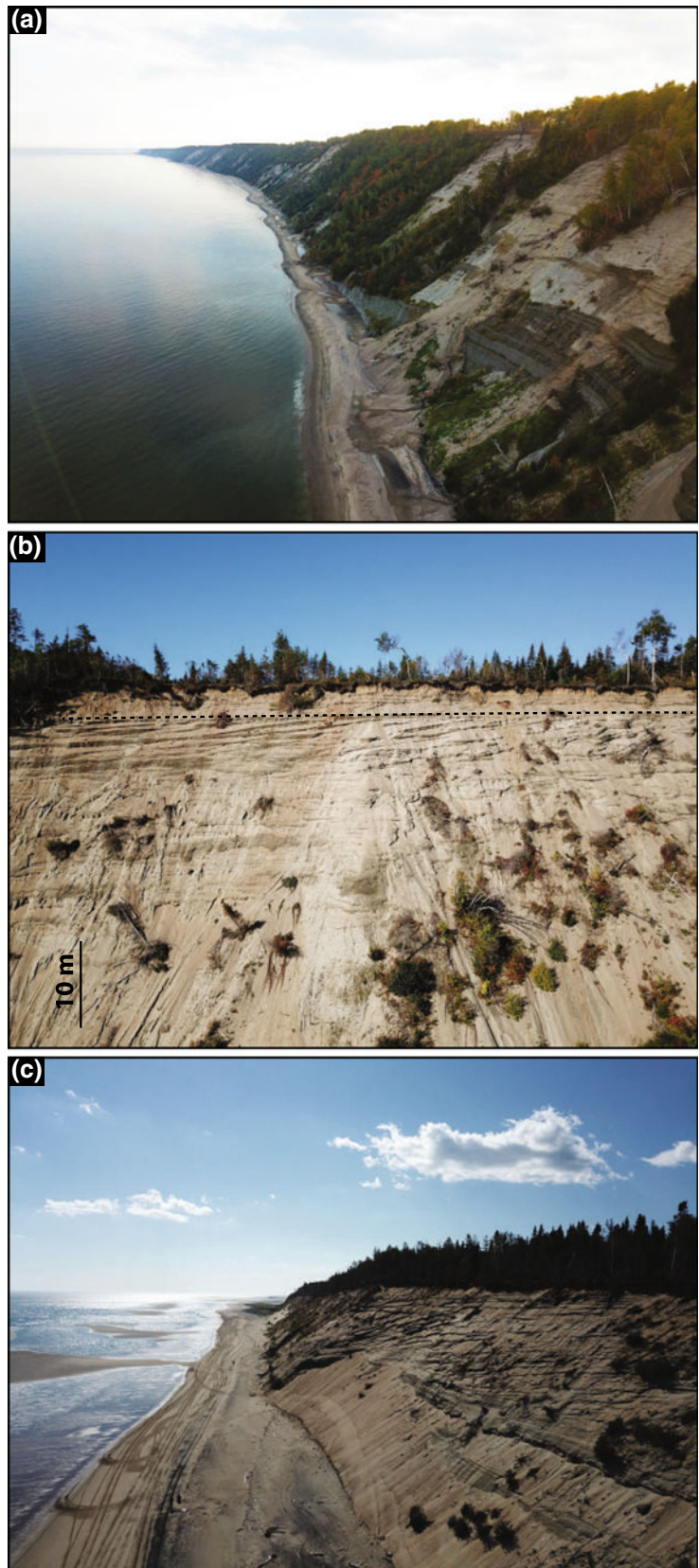
identified by their well-defined stratigraphic architecture formed by topset, foreset (Fig. 10.8b), and bottomset beds, respectively, corresponding to delta-plain, delta-slope, and prodelta deposits. As the deposition of glacifluvial deltas occurred following the ice-contact systems during a period of RSL fall, the elevation of the sea level was at that time lower than marine limit by tens of meters, although much higher than today (Figs. 10.3 and 10.7). The top surface (sandy delta plain) of glacifluvial deltas hence lies at

**Fig. 10.7** Three-staged conceptual model of the deposition of the deltaic complexes of the Québec North Shore





**Fig. 10.8** Aerial (drone) pictures of the Portneuf deltaic complex. **a** Panoramic view of the whole Portneuf deltaic complex. Ice-contact and ice-distal glaci-fluvial sediments are well-exposed in the cliff that experience active retreat due to wave erosion processes. Note that the extensive top surface of the deltaic complex gently dips basinward due to its emplacement throughout RSL fall. **b** Panoramic view of the exposed foreset beds of the ice-distal glaci-fluvial delta truncated by erosive-based coastal suites (dashed black lines). Note the dipping of the foreset beds toward the left of the picture. **c** Panoramic view of the spit platform (belonging to coastal suites) lying at an extremity of the deltaic complex. Note the steeply dipping foresets, the modern beach, and the currently active longshore bars fed by the erosion of the deltaic complex. The cliff is 20 m high. See Fig. 10.2 for location



elevations between 120 and 40 m asl and dips gently toward the sea (Dredge 1983; Dionne et al. 2004). In addition, the top surfaces of the glacifluvial deltas are characterized by rare and poorly expressed relict-braided fluvial patterns and isolated raised beach ridges lying on otherwise featureless flat surfaces (Fig. 10.5; Dietrich et al. 2017a).

After the retreat of the stillstanding ice-margin that deposited ice-contact systems, ice-distal glacifluvial deltas supplied by meltwater and glacial sediments from the ablation-dominated ice-margin were initially confined in structural valleys, either occupied by fjord-lakes, or by the sea (fjords; Fig. 10.7). Restricted in-valley accumulation space combined with high rates of sediment supply permitted high rates of delta progradation. Subsequently, as the entire in-valley space was filled, glacifluvial deltas emerged on the St. Lawrence shallow, structural shelf, where the increase of accommodation space caused sudden drops in progradation rates (Dietrich et al. 2017b). In some cases, depending on the width of the shallow shelf and the duration of the glacifluvial dynamic, coarse-grained materials were supplied to the deep realm of the St. Lawrence (Laurentian Channel, see below; Normandeau et al. 2017).

### 10.3.3 Submarine Channels

The ice-distal glacifluvial deltas described above prograded into the Goldthwait Sea as long as glacial meltwaters were present in their glaci-hydrological drainage basins. The inherited morphology of these deltas in some cases can still be observed in the St. Lawrence Estuary (Fig. 10.4). Multibeam bathymetric data shows numerous channels at river mouths, on the shallow shelf and on the slopes of the Laurentian Channel (Fig. 10.4). The channels may reach lengths of tens of kilometers offshore and may be as wide as 1 km (Fig. 10.4). Channel fills consist of an alternation of hemipelagic mud, deposited from normal settling of sediment in the water column, and turbidites, resulting from hyperpycnal flows at the mouths of the rivers. The generation of hyperpycnal flows, formed by the direct plunging of a mixture of sediment and water at the mouth of the river, was made possible due to the high content of suspended and bedload sediments carried by glacifluvial rivers entering the Goldthwait Sea (Mulder and Syvitski 1995). Hyperpycnal flows were responsible for the formation of the channels observed offshore. High sedimentation rates at river mouths also favored the formation of slope failures on delta fronts (Duchesne et al. 2003). Seismic reflection data show that the channels have bedforms both on their levees and in their axes, interpreted as sediment waves formed during the passage of turbidity currents. The morphology of these bedforms and channels is today much more attenuated than it was during their formation. Today, they are either

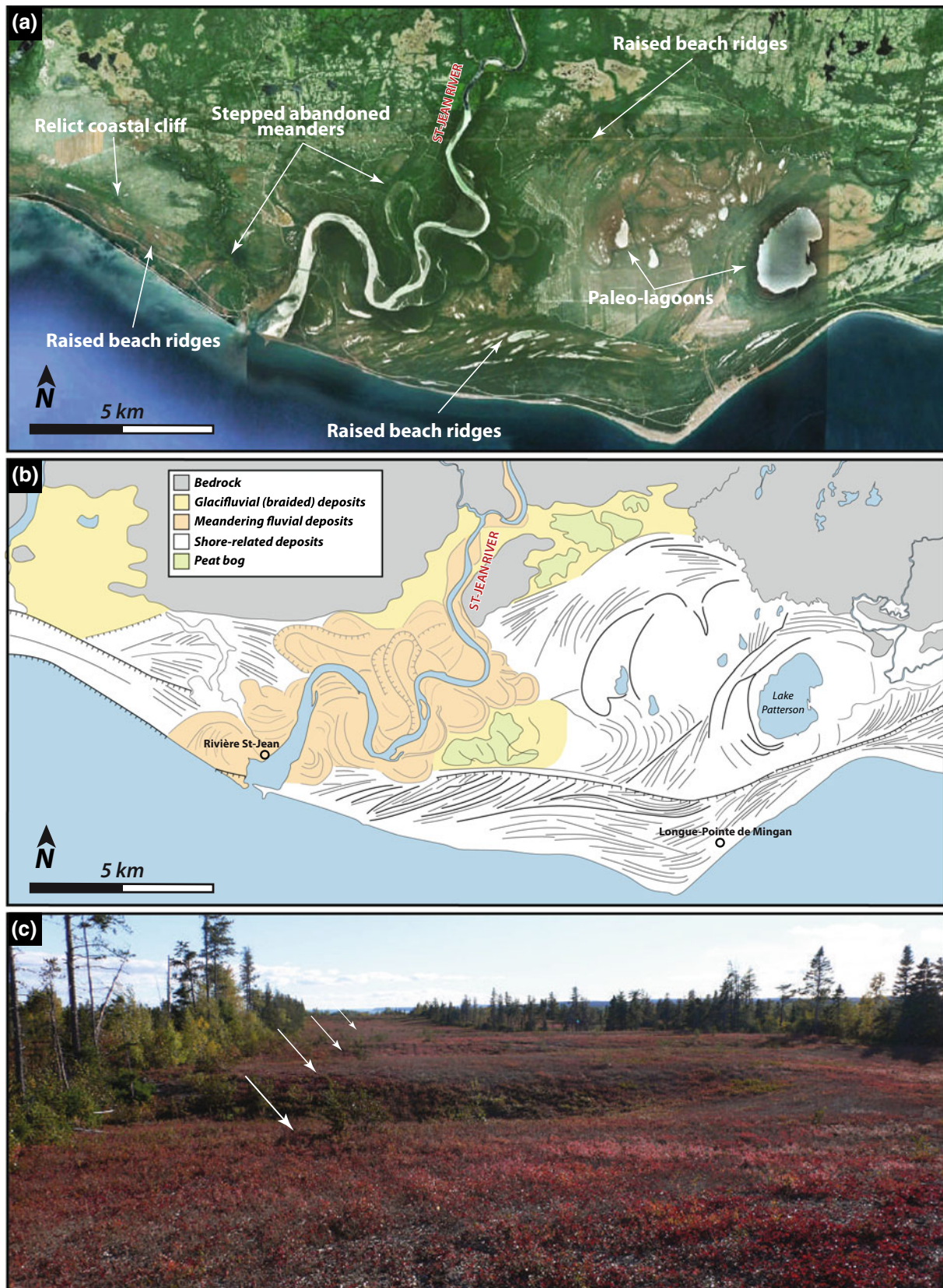
completely or partly buried by tens of meters of mud, because sediment concentration in the rivers is no longer high enough to overcome the density of the seawater, thus not generating hyperpycnal flows. Related channels are hence relict forms.

Some of the submarine components of the deltas do not reveal any type of channels or bedforms that would provide evidence for the activity of hyperpycnal flows during their formation. One example is the Pentecôte River, where the offshore environment is devoid of delta-related morphologies (Fig. 10.4f). For those deltas, it is assumed that sediments were trapped inland in lakes, such as Lake Pentecôte (Fig. 10.4f). Sediment supply at the mouth of the river was greatly reduced, precluding the formation of large ice-distal glacifluvial deltas. This lake trapping can be observed for the Aux-Rochers and Magpie rivers as well (Gagnon-Poiré et al. 2018).

### 10.3.4 Coastal Suites and Meandering Channel Belts

After the retreat of the LIS margin from individual drainage basins and the resulting shutdown in meltwater and glacial sediment supply, deltaic progradation was no longer possible. Therefore, reworking processes started to dominate in a setting characterized by a still ongoing RSL fall (Fig. 10.7). Shallow-marine processes (wave ravinement) allowed the development of well-expressed shorelines, beach ridges, spits and spit platforms (Fig. 10.9c), coastal cliffs, and backshore systems, referred to as coastal suites (Fig. 10.9; Dionne et al. 2004). These coastal suites were successively formed, abandoned, and then raised as the RSL was falling (Fig. 10.3). The pattern of deposition and successive abandonment of shorelines was also likely controlled by the availability of local finite sediment sources (erosion of inactive ice-contact and/or glacifluvial depocenters; Hein et al. 2014), progressive emersion of bedrock exposures (Fraser et al. 2005), inherited delta morphology, and patterns of local longshore drift and coast morphology, among other autogenic or local processes. The resulting modern surface expression of the most basinward side of the deltaic complexes is characterized by stepped, relict and raised shorelines and associated morphologies, from 100 m asl down to the modern sea level (Figs. 10.5 and 10.9). On the other hand, the abrupt decrease in supply of glacial sediments also forced the transition from braided to meandering fluvial systems (Fig. 10.6). In a similar manner as for the coastal suites, the successive incisions, avulsions, and abandonments of meandering channels throughout the ongoing RSL fall left behind stepped and relict meander belts within the ancient and inactive glacifluvial deltas (Fig. 10.6). These abandoned and stepped meander belts are prominently





**Fig. 10.9** **a** and **b** Satellite and correlative line-drawing of the St. Jean deltaic complex evidencing the large array of coastal structures (beach ridges, coastal cliffs, raised spits) characterizing the top surface of the deltaic complex imputed to coastal processes. Also note the presence of

the abandoned meandering channels. **c** Stepped beach ridges raised well above the modern sea level (altitude: ~50 m). See Figs. 10.2 and 10.4 for location

exposed on aerial and satellite imagery as well as on LiDAR and DEM (Figs. 10.4 and 10.5). Although modern rivers are still meandering and encased within the glacifluvial deltas they are eroding (Figs. 10.6d, e), RSL fall has now mainly stopped. Presently, meandering, meander amplification, and avulsion processes are thought to be partly controlled by bedrock threshold exhumed along the path of the rivers (Fig. 10.6e; Tooth et al. 2004), or in places by retreat of the shoreline that forces constant readjustment of the fluvial longitudinal profiles.

Drainage basins of the QNS have different spatial extents and shapes, ranging from a few hundreds to more than 45,000 km<sup>2</sup> (Manicouagan; Fig. 10.1) in area. Therefore, the retreat of the ice-margin from the respective drainage basins, the resulting shutdown of glacifluvial delta progradation, and the onset of reworking processes did not occur at the same time in each drainage basin of the QNS. The smallest drainage basins experienced an early transition (10.5 ka; Portneuf; Fig. 10.1; Dietrich et al. 2017a) from a glacifluvial dynamic to reworking processes. More extensive basins, and/or those located in regions deglaciated later, experienced a later shift (7 ka; Manicouagan; Fig. 10.1; Normandeau et al. 2017). Hence, deltaic complexes with drainage basins that have been deglaciated earlier were submitted to a greater RSL fall (up to 100 m) after this transition, which permitted enhanced deposition of prominent stepped shore-related landforms on deltaic complexes. Conversely, drainage basins that were deglaciated later only endured a short RSL fall after glacial retreat, and hence have poorly developed, or at least weakly stepped, coastal suites and meander belts.

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#### 10.4 Recent Sedimentary Processes on the Shelf and Through Submarine Channels and Canyons

Following the complete retreat of the ice-margin from the watersheds of the respective rivers, glacifluvial discharge was greatly reduced. Deltas ceased being dominated by river discharge (fluvial-dominated) and became dominated by wave action. Nearshore, as erosion processes were now dominant, delta fronts began to be cannibalized by shore-related processes, which made the deltas more linear (Figs. 10.7 and 10.8; Bernatchez and Dubois 2008). The erosion of the deltas, which began in some cases when RSL was still falling, led to the transfer of sediment along the coast instead of directly offshore (Normandeau et al. 2017). Eroded sediments were transferred in adjacent bays by longshore drift, or reached the edge of the narrow, shallow shelf (Fig. 10.7). At these locations, sediments were transferred toward the Laurentian Channel. Accumulation of sediment on steep slope eventually led to slope failures, either due to wave action during storms or oversteepening of

the slope. In some cases, as along the Les Escoumins region (Fig. 10.2), the alongshore sediment transfer occurred over long distances, until the shelf narrows enough to amplify offshore transfer (Gagné et al. 2009). Here, three small submarine canyons formed in response to the activity of longshore drift and resulting slope failures and turbidity currents on the Laurentian Channel slope. These three canyons incise the shelf from less than 300 m from the coast and extend down to 300 m water depth. At the base of the canyons, submarine fans form, one of which is characterized by crescent-shaped sediment waves, termed cyclic steps. In other cases, as in Sept-Îles (Fig. 10.5), longshore-transport processes occur on the delta itself. Sediments supplied at the river mouth are transferred almost immediately westward along the coast through longshore-drift instead of being exported offshore. Combined with RSL fall, the longshore-drift transport created beach ridges west of the river mouth. In addition to the sediments coming from the river, coastal erosion began playing an important role in supplying sediment to the west. The erosion of the delta resulted in the formation of a coastal, wave-cut platform which was previously part of the delta front (Fig. 10.7). Oblique nearshore bars and longshore bars formed on this shelf (Fig. 10.5) and actively migrate westward, where the shelf narrows (Normandeau et al. 2013). Repeated swath bathymetry mapping in the area showed that sediment also accumulates at the western extremity of the narrowing shelf and at the head of a channel. Occasionally, most likely during storms, turbidity currents are triggered at the shallow head of this channel and transfer sediment downslope. This offshore transport of sediment created a bird's foot-like submarine fan (Fig. 10.5).

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#### 10.5 Conclusions

Deltaic complexes of the Québec North Shore form the thickest and most extensive accumulation of coarse and fine-grained sediments in eastern Canada. The various morphologies of the drainage basins led to different morphostratigraphies and geomorphological characteristics of the deltaic complexes. Some deltas protruded into the St. Lawrence Estuary and Gulf and are conspicuously characterized by extensive submarine channels on the seafloor. In other cases, the presence of lakes in the watershed trapped most glacial sediments, and resulted in an attenuated geomorphology of the deltas in the St. Lawrence. Nonetheless, the deltaic complexes of the QNS are composed of a lower ice-contact depositional system, superimposed by ice-distal glacifluvial deltas that are currently being reworked by coastal and fluvial processes. These three components of the deltas are attributed to the progressive north-westward retreat of the ice-margin on the QNS.



Ice-contact deposits were emplaced at the front of the LIS margin. Glacifluvial deltas were formed as the ice-margin retreated on land, while supplying large volumes of meltwaters and glacial sediments to the rivers. The retreat of the LIS from the watersheds forced a transition from previously fluvial- to wave-dominated deltaic conditions. Deltas subsequently began to be eroded, forming coastal suites. The erosion of the deltas also led to the transport of sediment alongshore and direct transfer offshore ceased. Instead, offshore sediment transport was focused where the shallow shelf narrows. Sediment accumulation leads to slope failures and turbidity currents that can reach deeper marine basins.

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