17 Quaternary Heritage and Landscape in the Témiscouata–Madawaska Valley, Eastern Québec

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Abstract

The Quaternary heritage and landscape of the Témiscouata–Madawaska Valley consists of an assemblage of landforms and deposits associated with former stabilizations of glacial margins during the Late Pleistocene development of an ice-free corridor in the Notre-Dame Ice Cap (NDIC), through which Glacial Lake Madawaska developed. This lake occupied an area of more than 500 km^2 in the Témiscouata–Madawaska valley from late-glacial times to the middle of the Holocene, depositing a thick series of varves. The contact between Madawaska Lake and the ice margin of the NDIC contributed to the acceleration of deglaciation and the fragmentation of NDIC into two local ice caps: the Lejeune Ice Cap (LIC) and the Pohénégamook Ice Cap (PIC). In the Bas-Saint-Laurent and particularly in the Témiscouata–Madawaska valley, the Quaternary landscape is the product of the coexistence of an Appalachian ice margin and the glacial lake Madawaska.

Keywords

Quaternary heritage • Laurentide ice sheet complex • Bas-Saint-Laurent • Témiscouata–Madawaska valley • Glacial Lake Madawaska • Notre-Dame Ice Cap

17.1 Introduction

The Bas-Saint-Laurent (BSL) region is located between the towns of La Pocatière and Matane, along the south shore of St. Lawrence estuary (Québec; Fig. 17.1). The landscape consists of stepped plateaux with different altitudes from the sea-level coastal plain to the highlands around 500 m, influenced by past glaciations. A smooth transition occurs from the St. Lawrence Lowlands in the west to the Gaspé high plateau toward the east (Fig. 17.1), with a lower plateau between Lake Témiscouata and the Matane River. There is a clear contrast between the coastal plain (0–250 m) to the north and the Appalachian Highlands (400–900 m) to the south, separated by a steep piedmont (250–400 m) (Fig. 17.1).

This landscape generally follows the regional southwest–northeast Appalachian bedrock structure except for the Témiscouata and Matapédia valleys, which notched the Appalachian Mountains following the transform fault in the Gaspé rift zone (Allen et al. 2009). The BSL was occupied by the Laurentide Ice Sheet Complex (LISC) during the MIS 2 (Late Wisconsinan) glaciation (Gadd 1964; Chauvin et al. 1985; Dyke et al. 2002; Occhietti et al. 2004, 2011), while the eastern Gaspé peninsula was occupied by the regional Gaspé Ice Cap (GIC) (David and Lebuis 1985; Charbonneau and David 1993; Olejczyk and Gray 2007).

During deglaciation, the LISC margin retreated toward the north (Occhietti et al. 2004, 2011) while the St. Lawrence estuary opened (Thomas 1977). Consequently, the Notre-Dame Ice Cap (NDIC) became isolated from the LISC in the BSL, thereby favoring the deposition of moraines in the piedmont of the Appalachians (Martineau and Corbeil 1983; Chauvin et al. 1985). These moraines are the only ones associated with the northern margin of an Appalachian ice in the BSL, with the Saint-Antonin (Martineau and Corbeil 1983; Chauvin et al. 1985; Occhietti et al. 2004, 2011) and St-Jean-Port-Joli (Martineau and Corbeil 1983; Chauvin et al. 1985; Occhietti et al. 2004, 2011) moraines to

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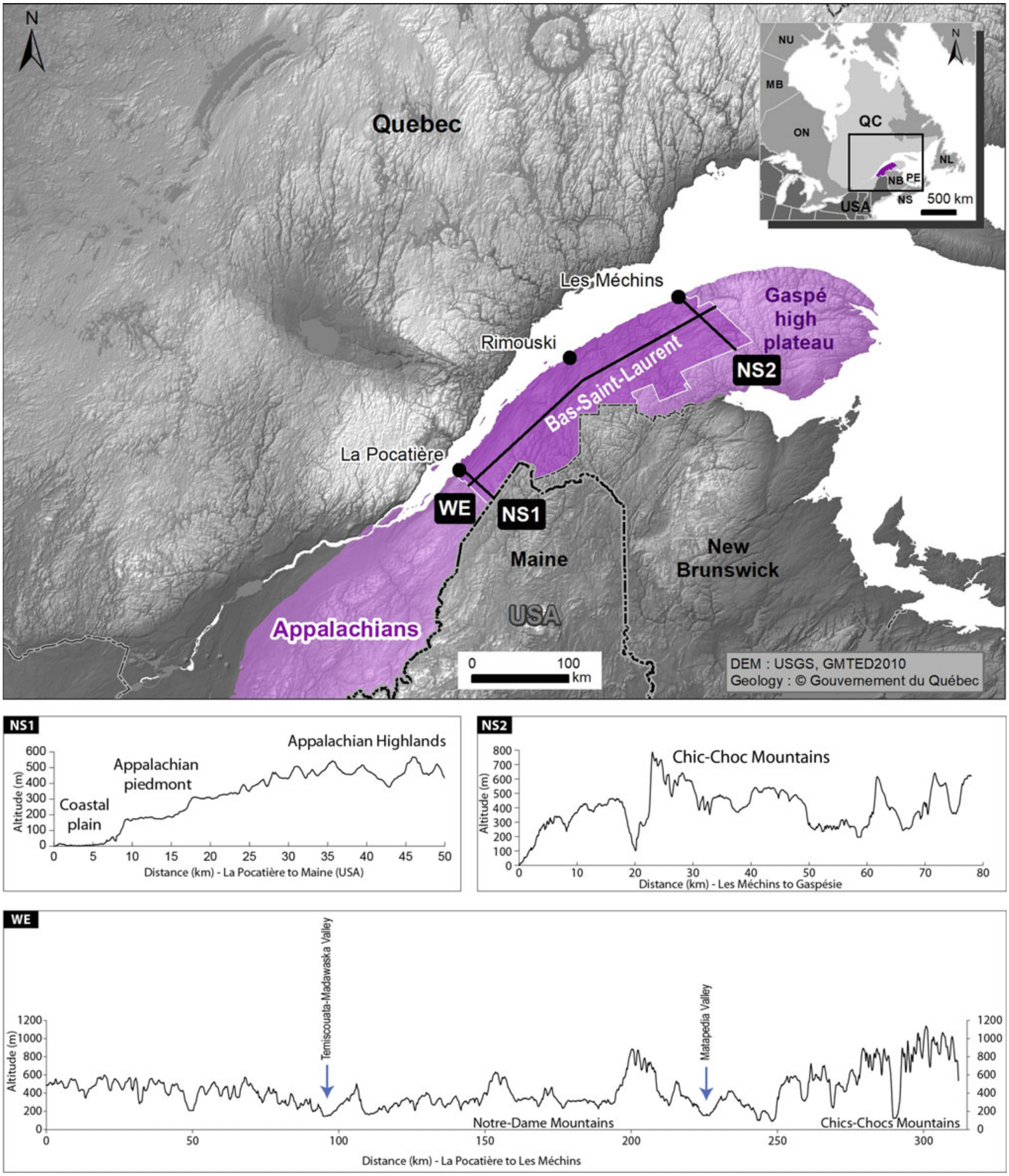

Fig. 17.1 Top: Location and geological and physiographic regions of the Bas-Saint-Laurent, Eastern Québec. NS1: Topographic profile of the Bas-Saint-Laurent along a north-south transect near La Pocatière showing relief contrast between the coastal plain, the Appalachian piedmont and the Appalachian Highlands. NS2: Topographic profile of the Bas-Saint-Laurent along a north-south transect near Les Méchins, where the Chic-Choc Mountains rise. The coastal plain is not represented in this part of the BSL; the structural front of the Chic-Choc replaces the Appalachian piedmont and the Chic-Choc thrust sheet forms the high plateau of the Chics-Chocs Mountains. WE: Topographic profile of the Bas-Saint-Laurent along a west-east transect outlines the transitional landscape between the St. Lawrence Lowlands in the west to the Gaspé high plateau toward the east, with a lower plateau between Lake Témiscouata and the Matane River

the west and the Luceville and Neigette moraines to the east (Hétu 1998). This geomorphological continuum is interrupted by the Trois-Pistoles delta (Lee 1962; Dionne 1968; Rappol 1993) that opens onto the Témiscouata–Madawaska Valley, which was occupied by glacial Lake Madawaska (Kiewiet de Jonge 1951; Lougee 1954; Kite 1983; Rampton et al. 1984; Kite and Stuckenrath 1989). Here, we report the opening of NDIC and describe the glaciated Appalachian landscape of the region by two local ice caps: the Lejeune Ice Cap (LIC) to the east of Témiscouata–Madawaska Valley and the Pohénégamook Ice Cap (PIC) to the west. Glacial Lake Madawaska influenced the processes of deglaciation in the Appalachian Highlands, including local ice cap margins and depositional assemblages.

17.2 Study Area

17.2.1 Topography

The regional physiography played an important role in the growth and decay of local ice caps originating from the NDIC. The flat coastal plain borders the steep piedmont of the northern Appalachian border. South of the piedmont, the Appalachian highlands reach 500 m asl, with only a few important valleys dissecting the landscape. During deglaciation, the ice margin of local ice caps responded to that topography (Gadd 1964). Remnants of these ice margins are revealed by moraine landform assemblages, forming an important heritage on the Quaternary landscape in the BSL.

17.2.2 Geology

The BSL covers an area of 28,401 km^2 with more than 6,000 km^2 located in the St. Lawrence Estuary. This region is delimited to the north by the St. Lawrence Estuary, with over 320 km of coastline between La Pocatière and Les Méchins. To the south, the BSL shares a common boundary with the state of Maine (USA) and the province of New Brunswick (Fig. 17.1).

The BSL is part of the Appalachians geological province. These eroded mountains were formed during three successive orogenic phases (Bourque et al. 2000; Lavoie 2008). The northern part of the Appalachians was formed during two major orogenies: the Taconian orogeny during the late Ordovician (475–450 Ma) and the Acadian orogeny in the middle Devonian (360 Ma) (Bourque et al. 2000). The Taconian orogeny is represented by the Humber and Dunnage zones, with different assemblages of Neoproterozoic Late Ordovician sedimentary rocks (Bourque et al. 2000). The Acadian orogeny is represented by the Gaspé belt, with an assemblage of sedimentary, volcanic and intrusive rocks from the Late Ordovician to the Middle Devonian (Bourque et al. 2000) (Fig. 17.2). At the end of the Devonian, the Acadian orogeny formed large folds and many faults in the bedrock (Bourque et al. 2000). Bedrock geology in the BSL consists of sandstones, mudrocks, conglomerates and limestones with extrusive igneous rocks such as basalt and diorite (Lavoie 2008) (Fig. 17.2). The final stage of the landscape construction is general erosion in cyclic step of the Appalachians that led to paleoplains and peneplains (Grant 1989). Three levels of this relict erosion surfaces are present in the eastern BSL.

17.2.3 Climate and Vegetation

According to the Köppen-Geiger classification, the western part of the BSL has a warm-summer/humid continental climate, while the climate of the eastern part and hinterlands is boreal (Peel et al. 2007). The average annual temperature is 2.5 °C (Deschênes et al. 2010) with strong variability, ranging between 2.5 and 5.0 °C in the west and nearly 0 °C in the east (MDDELCC 2017). The average temperature in January is −14.0 °C (min −19.0 °C/max −7.0 °C); in July it is 16.5 °C (min 11 °C/max 23 °C) (MDDELCC 2017). The mean total annual precipitation is 1,080.30 mm (Deschênes et al. 2010).

The balsam fir (*Abies balsamea*)—yellow birch (*Betula alleghanensis*) bioclimatic domain occupies 82% of the territory. The other bioclimatic domains are balsam fir—white birch (*Betula papyrifera*), sugar maple (*Acer saccharum*)–basswood (*Tilia americana*), sugar maple—yellow birch, and alpine tundra on the highest summits (Saucier et al. 2011).

17.3 Glacial History

17.3.1 Glacial Expansion and Erosion

Current knowledge of the Quaternary paleogeography in the BSL covers only MIS 2 (Late Wisconsinan) (Buffin-Bélanger et al. 2015; Veillette et al. 2017). Nevertheless, the moraines of the Appalachian piedmont provide much information on the process of deglaciation in southern Québec. At the Last Glacial Maximum, the BSL was completely occupied by the LISC (Chauvin et al. 1985; David and Lebuis 1985; Dyke and Prest 1987; Pronk et al. 1989;

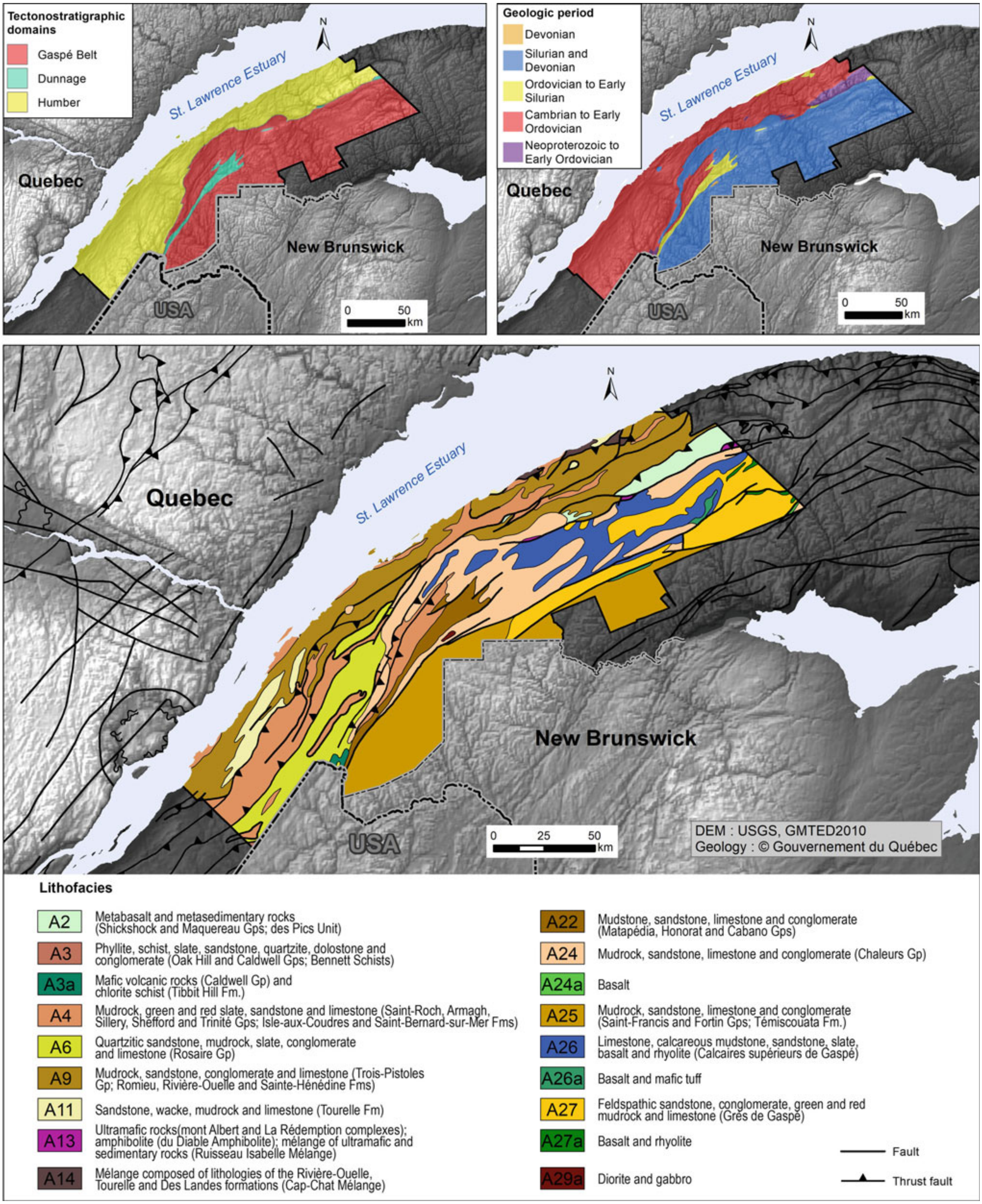

Fig. 17.2 Upper left: Tectonostratigraphic domains of the Appalachians in the Bas-Saint-Laurent. The Humber zone is outlined along the St. Lawrence Estuary; the Gaspé Belt is found toward the south and a narrow part of the Dunnage zone is present near Lake Témiscouata. Upper right: Geological periods of Appalachian orogenies in the Bas-Saint-Laurent. The Taconic orogeny in the north took place in the Cambrian to Early Ordovician period and in the south the Acadian orogeny occurred during Silurian and Devonian periods. A fault network exhumes substratum from the Neoproterozoic and Early Ordovician periods in the Chic-Choc Mountains. Bottom: Rock assemblages and lithofacies present in the Appalachians of the Bas-Saint-Laurent

Rappol 1993; Hétu 1998; Occhietti et al. 2004, 2011; Shaw et al. 2006; Veillette et al. 2017). The GIC occupied the eastern Gaspé peninsula (David and Lebuis 1985; Charbonneau and David 1993; Olejczyk and Gray 2007). In the BSL, ice flows toward the east-southeast are revealed by the dispersal of Precambrian erratics (Rappol 1993; Veillette et al. 2017). The LISC in the BSL affected the landscapes differently than did the local ice cap in the Gaspé highlands (Lebuis and David 1977; Hétu and Gray 1985). The local Gaspé ice cap had a cold-based thermal regime while the LISC was a temperate-based glacier (David and Lebuis 1985).

Lake basins were formed in part by glacial erosion, and thus can be used as a proxy for scour depth and efficiency (Sugden 1978; Hétu 1998; Principato and Johnson 2009). The number of lakes in the territory and their total area indicate the intensity of glacial erosion (Fig. 17.3). The BSL contains 35 lakes/100 km^2, occupying areas of more than 700 ha/100 km^2. On the Gaspé Peninsula, there are fewer than 25 lakes/100 km^2, covering areas of about 100 ha/100 km^2. In the centre of the Gaspé Peninsula, several areas are devoid of water bodies. These indicators allow an evaluation of the intensity of glacial erosion and the thermal regime at the base of the glaciers (Sugden 1978; Principato and Johnson 2009).

The territory that had been covered by the local cold-based thermal regime of the Gaspé ice cap has fewer and smaller lakes than does the territory covered by the temperate-based LISC. The BSL landscapes dotted with lakes are a Quaternary heritage of the higher glacial erosion intensity by LISC. The glacial erosion also accentuated the structural notches (Shilts et al. 1992; Allen et al. 2009) of the trans-Appalachian valleys by forming valleys that cut into BSL landscapes (Fig. 17.1).

17.3.2 The St. Lawrence Ice Stream: Calving and Notre-Dame Ice Cap

The St. Lawrence ice stream (Rappol 1993; Shaw et al. 2006; Margold et al. 2015; Stokes et al. 2016) contributed to the initiation and acceleration of deglaciation in the last glacial period by opening a calving-bay in the axis of St. Lawrence River valley when the ice stream slowed down (Thomas 1977) (Fig. 17.4). This situation led to the splitting of the LISC and development of the NDIC.

The reversal of ice flows from east-southeast to north (Pronk et al. 1989) is one of the most important consequences of the growth of the NDIC. This ice cap occupied the Appalachians between the last phases of MIS 2 and the beginning of the Holocene. At the front of the ice margin a morainic belt is present containing the Luceville-Neigette ice-front deposits to the east, and the St. Antonin-St-Jean-Port-Joli ice-front deposits to the west. This morainic system was produced by the Notre-Dame Ice Cap, formerly incorrectly associated to the LISC Highland Front Moraine (Gadd 1964). Many moraine segments (Lee 1962; Martineau and Corbeil 1983; Hétu 1998) reveal frontal position of the NDIC (Martineau and Corbeil 1983; Rampton et al. 1984).

17.3.3 Notre-Dame Ice Cap: Lejeune Ice Cap and Pohénégamook Ice Cap

According to Rampton et al. (1984), the NDIC split into several small local ice caps (Fig. 17.4) that were anchored on middle and high plateaus. The two main trenches of the Appalachian ice in the BSL correspond to the Témiscouata–Madawaska and the Matapédia valleys. Openings in the NDIC were occupied by glacial lakes (Chalmers 1884; Kiewiet de Jonge 1951; Rampton et al. 1984; Prichonnet 1995), which were responsible for the acceleration of the deglaciation in these areas by increasing iceberg calving at the ice margin.

Morainic systems indicating the presence of local ice caps in the Appalachian Highlands are limited. An important discontinuity in the morainic system occurs near Trois-Pistoles along the Témiscouata–Madawaska axis, where a delta occupies the mouth of the modern river. The assemblage of ice margin landforms and glacifluvial deposits is one of the most important Quaternary heritage features of the BSL.

17.4 Quaternary Heritage and Landscape in Bas-Saint-Laurent

17.4.1 Luceville and Neigette Ice-Front Moraines

In the segments of the Highland Front moraine (Gadd 1964), also named the Appalachian Piedmont moraine (Fig. 17.5), northward ice flows and lithology (Martineau and Corbeil 1983; Chauvin et al. 1985; Hétu 1998) provide clear evidence for the existence the NDIC. However, other than this ice front, knowledge on local Appalachian ice cap dynamics is scarce (Hétu 1998; Buffin-Bélanger et al. 2015), except for ice-flow direction (Rappol 1993; Veillette et al. 2017).

The Luceville moraine segment, deposited around 15 ka cal. BP, and the Neigette moraine segment, deposited around 14 ka cal. BP, represent Appalachian ice margin

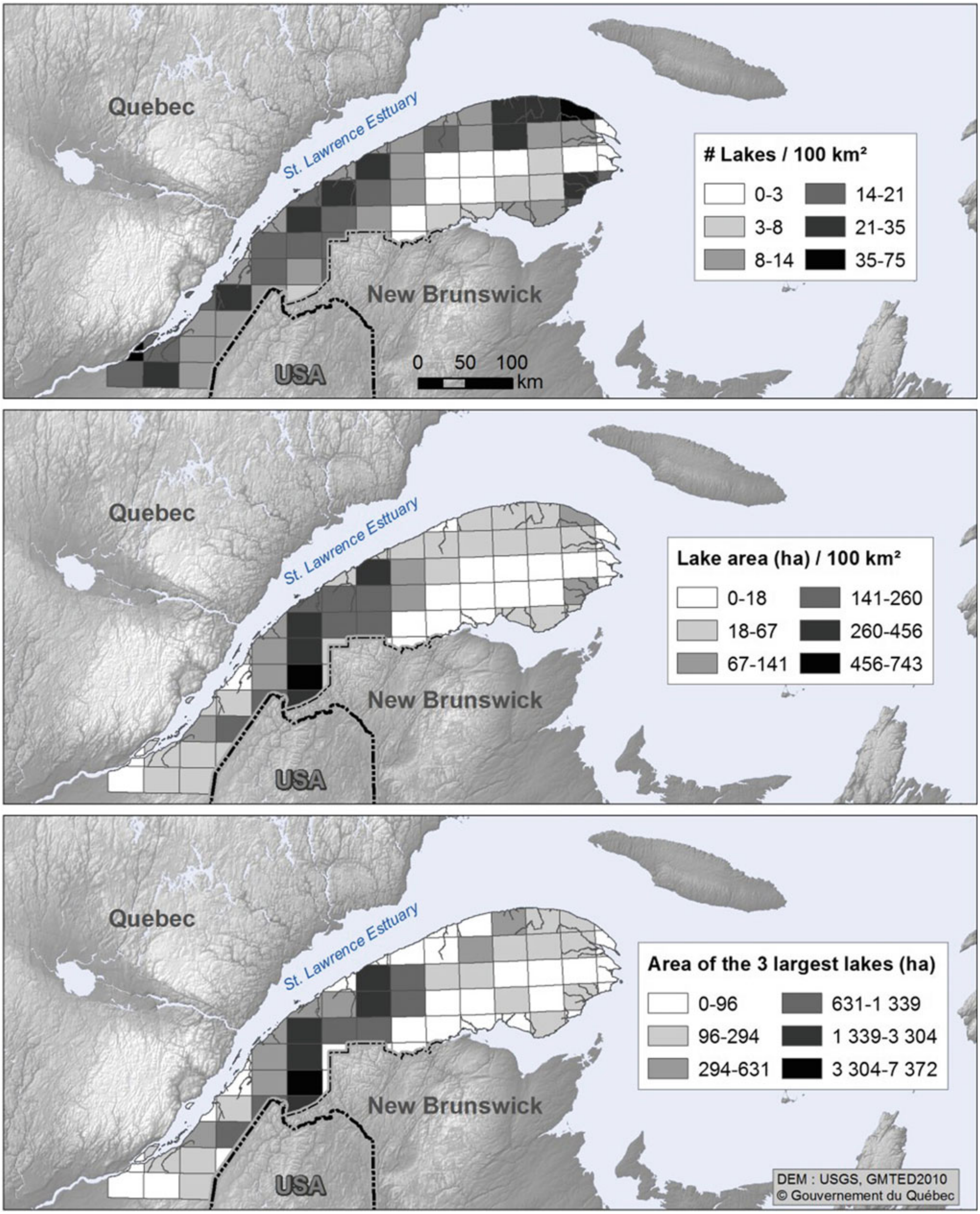

Fig. 17.3 Top: Number of lakes per 100 km^2 determined from 1:50,000 map of eastern Québec. The Bas-Saint-Laurent and the north of the Gaspé Peninsula have the largest number of lakes whereas several areas in the center of the Gaspé Peninsula are devoid of bodies of water. Middle: Lake area in hectares per 100 km^2 determined from 1:50,000 maps of eastern Québec. The largest lakes represent more intense glacial erosion that accentuated structural notches in the Appalachian bedrock structure. Bottom: Area of the three largest lakes in hectares determined from 1:50,000 maps of eastern Québec. The larger lakes also represent more intense glacial erosion

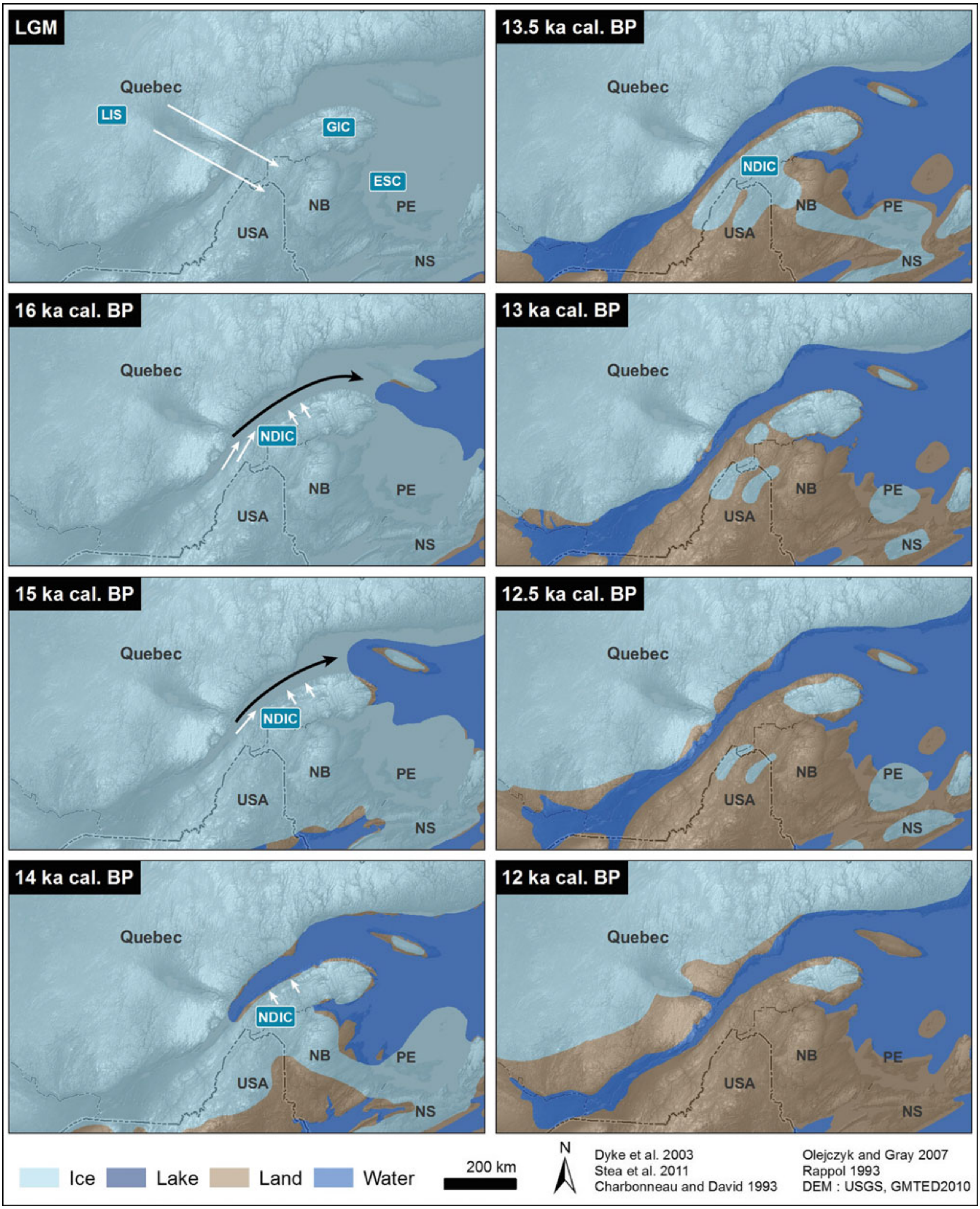

Fig. 17.4 Evolution of deglaciation in eastern Québec from the LGM to the Holocene. In white, ice; dark blue, lakes; light brown, land; light blue, sea. Black arrows outline the St. Lawrence ice stream and white arrows correspond to the direction of ice flow. At the LGM the ice sheets present in eastern Québec were the Laurentide ice sheet (LIS), the Gaspé ice cap (GIC) and the Escuminac ice center (ESC). From LGM to 14 ka cal. BP, the St. Lawrence ice stream was active and then a calving-bay opened the St. Lawrence Estuary, allowing the development of the NDIC. From 13.5 ka cal. BP to 12 ka cal. BP, the NDIC grew and decayed until their final melting. The postglacial seas followed the retreat of ice sheets

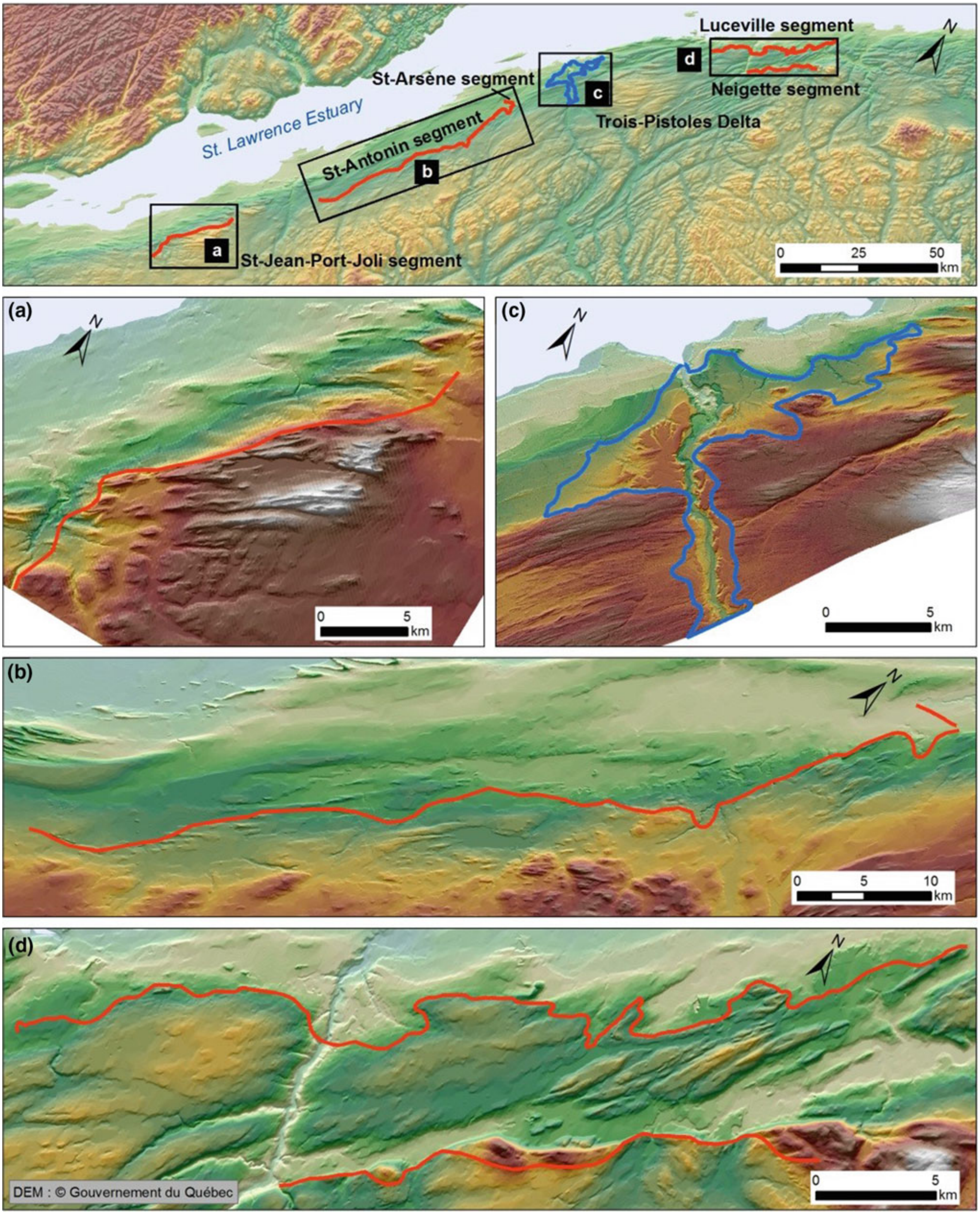

Fig. 17.5 Red line: Moraine segments in the Appalachian piedmont of the Bas-Saint-Laurent determined from Gadd (1964), Martineau and Corbeil (1983), Hétu (1998). Blue line: The Trois-Pistoles delta presents a discontinuity between moraine segments of the western Bas-Saint-Laurent and moraine segments to the east determined from Dionne (1966)

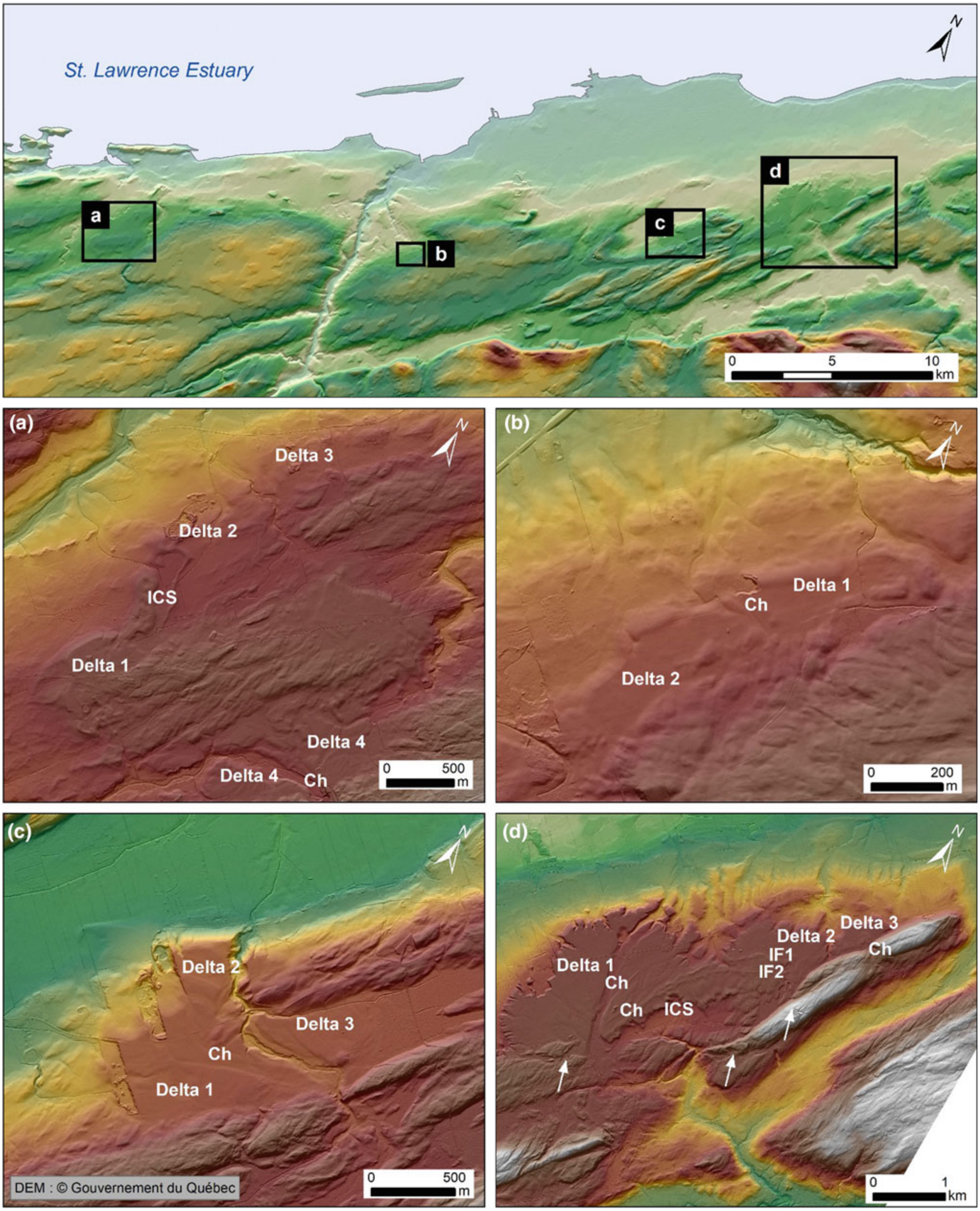

Fig. 17.6 Landform assemblage of the Luceville moraine segment. **a** Bic ice-contact delta. ICS: Ice-contact slope. Ch: Channels. Deltas 1–4 show the time evolution of the deltaic form. **b** St. Odile ice-contact delta. Ch: Channels. Deltas 1 and 2 show the geomorphological parts of the deltaic form. **c** St. Anaclet delta. Ch: Channels. Deltas 1–3 show the time evolution of the deltaic form. **d** Luceville ice-contact delta. ICS: Ice-contact slope; IF: Ice front; Ch: Channels. Glacial fluting in bedrock is shown by white arrows in the bedrock. Deltas 1–3 show the time evolution of the deltaic form (Buffin-Bélanger et al. 2015)

positions in the eastern BSL at the transition between coastal plain and Appalachian piedmont (Hétu 1998). These frontal moraines consist of an assemblage of ice-contact landforms and glacifluvial deposits. In Québec, the term "moraine" includes landforms representing ice-front positions, which may contain a variety of glacial and glacifluvial sediments and features. The Luceville moraine (Fig. 17.6) is composed of the Luceville delta, the St-Odile delta, the Bic delta, and the St-Fabien kames, all of which are ice-contact deposits (Locat 1977, 1978; Rappol 1993; Hétu 1998). The St-Anaclet delta (Fig. 17.6) is also part of this moraine segment, despite no clear evidence of ice-contact (Hétu 1998). The Neigette moraine (Fig. 17.7) is an assemblage of sandur, glacifluvial outwash, kames, esker and an ice-contact delta (Hétu 1998).

The Luceville and Neigette moraines are paleogeographically significant (Hétu 1998). They are the only evidence of the NDIC margin in the eastern BSL. The Luceville moraine, deposited in the Goldthwait Sea around 15 ka cal. BP, is strong evidence of the opening of St. Lawrence River followed by the stabilization of the NDIC on the Appalachian piedmont. This ice generated forms and deposits of mainly glacifluvial origin during glacial decay (Fig. 17.8). Thereafter, the ice retreated from the Neigette Valley and grounded on the escarpment of the Neigette fault around 14 ka cal BP.

The landforms and deposits indicate an episode of glacial recurrence, likely of climatic origin. The short distance between these two morainic segments indicates a slow deglaciation between 15 and 14 ka cal. BP in the eastern part of the BSL. These two morainic segments are the only known positions of the Appalachian ice margin in the eastern BSL (Hétu 1998). At the present time, no other ice front south of the Neigette moraine in the Appalachian Highlands has been reported. Therefore, the regional deglaciation model remains speculative after 14 ka cal. BP.

17.4.2 St. Antonin and St-Jean-Port-Joli Ice-Front Moraines

Although early studies associated segments of the Appalachian piedmont moraine observed in the western BSL with the LISC (Lee 1962; Gadd 1964; Lasalle et al. 1976, 1977a, b), recent studies have associated these moraine segments with Appalachian glaciation (Martineau and Corbeil 1983; Chauvin et al. 1985), specifically with the local ice cap of the BSL, the NDIC. The paleocurrents measured in glacifluvial deposits of the morainic belt show northward sediment transport originating from the NDIC to the south. These glacifluvial deposits belong to the NDIC's frontal moraine system (Martineau 1977; Martineau and Corbeil 1983; Chauvin et al. 1985).

The St. Antonin moraine (Fig. 17.5) consists of ice-contact glacifluvial deposits consisting of a series of fans and deltas aligned parallel to the St. Lawrence over 40 km (Martineau and Corbeil 1983). In some sectors, it is composed of glacial deposits such as till and flowtill (Chauvin et al. 1985). The St. Arsène segment at its northeastern end is a frontal moraine that precedes the deposition of the St. Antonin moraine (Martineau and Corbeil 1983). This segment is built on an Appalachian ridge at marine limit (Fig. 17.9). Part of the sedimentation of this deposit occurred in the Goldthwait Sea (Martineau and Corbeil 1983). It is a glacifluvial outwash with regular sand and gravel stratification. This moraine segment is the same age as the Luceville moraine while the St-Antonin moraine was formed at the same time as the Neigette ice margin deposits.

The St-Jean-Port-Joli moraine extends nearly 50 km between Ste. Louise and Montmagny (Chauvin et al. 1985). It mainly consists of ice-contact stratified drift and flowtill expressed geomorphologically by isolated kames and glacifluvial hills. This moraine is almost devoid of Precambrian clasts. Measurements of paleocurrents towards the north show that this moraine segment is associated with Appalachian ice. This moraine is a dynamic equivalent of the St. Antonin moraine and the Neigette moraine despite its later deposition due to the lag in the opening of St. Lawrence valley (Thomas 1977).

17.4.3 Glacial Lake Madawaska Complex

During the retreat of the NDIC, a network of glacial lakes formed at its margin (Nicholas et al. 1981; Dumais et al. 1998). In the BSL, Glacial Lake Madawaska was a former glacial lake that occupied a larger area during the late-glacial and the early Holocene. This glacial lake was formed by the coalescence of several lakes, such as Lake Témiscouata, Lake Touladi, and Lake des Aigles (Fig. 17.10) (Kiewiet de Jonge 1951; Lougee 1954; Mott 1975; Kite 1983; Rampton et al. 1984; Kite and Stuckenrath 1989). Glacial Lake Madawaska occupied the Témiscouata–Madawaska Valley at the end of MIS 2 for a maximum of 4 ky, starting at marine invasion around 14 ka cal. BP and ended with final draining around 11 ka cal. BP. Radiocarbon dating provides an estimate of the duration of the lake: basal peat over silts along the St. John River gave a maximum age of 11.9 ± 0.5 ka cal BP (I(GSC)-2) and a minimum age of 10.8 ± 0.5 cal ka BP (W-2927) (Kite and Stuckenrath

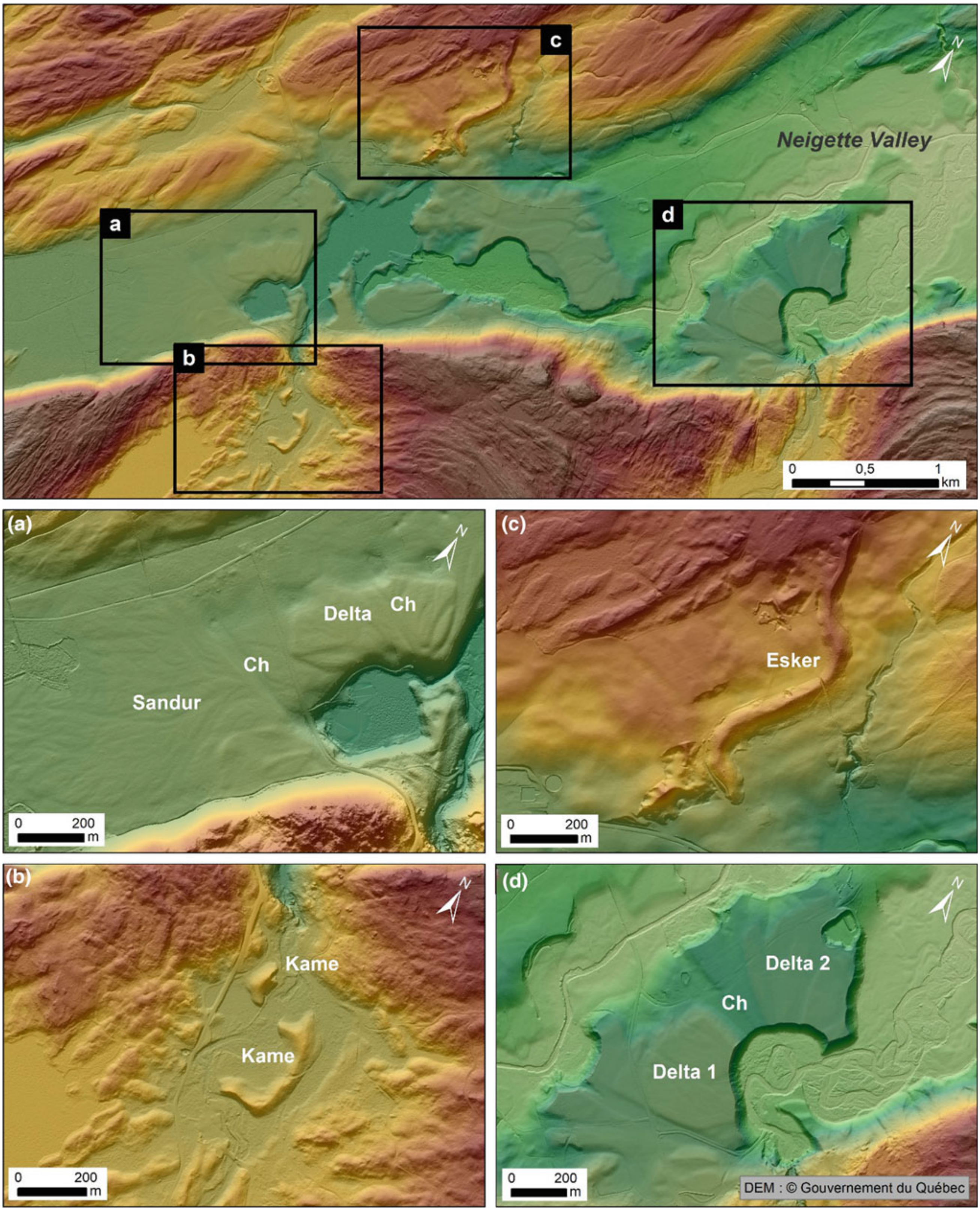

Fig. 17.7 Landform assemblages of the Neigette moraine segment. **a** Neigette ice-contact delta and sandur. Ch: Channels. **b** Ice decayed forms. **c** Neigette esker. **d** Neigette ice-contact delta. Ch: Channels. Deltas 1 and 2 show the time evolution of the deltaic form (Buffin-Bélanger et al. 2015)

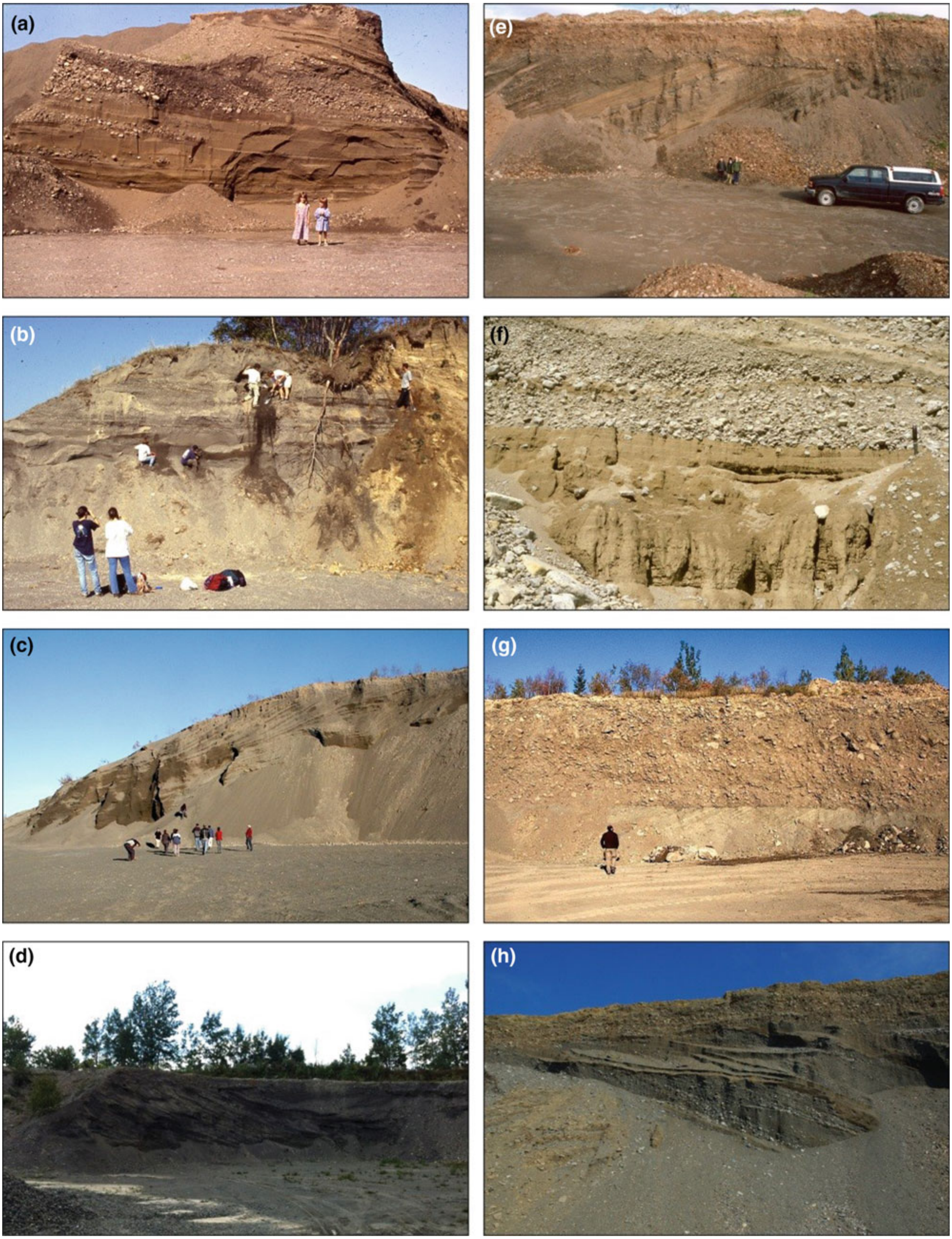

Fig. 17.8 Landform and deposits of the moraine segments in the Appalachian piedmont of the Bas-Saint-Laurent. **a** Bic glacifluvial deposits. *Photograph* B. Hétu. **b** Neigette kame. *Photograph* B. Hétu. **c** St. Antonin ice-contact delta. *Photograph* B. Hétu. **d** Trois-Pistoles glacifluvial delta. **e** Luceville ice-contact delta. *Photograph* B. Hétu. **f** Neigette glacifluvial deposit. *Photograph* B. Hétu. **g** St. Antonin ice-contact delta. *Photograph* B. Hétu. **h** Trois-Pistoles glacifluvial delta (Buffin-Bélanger et al. 2015)

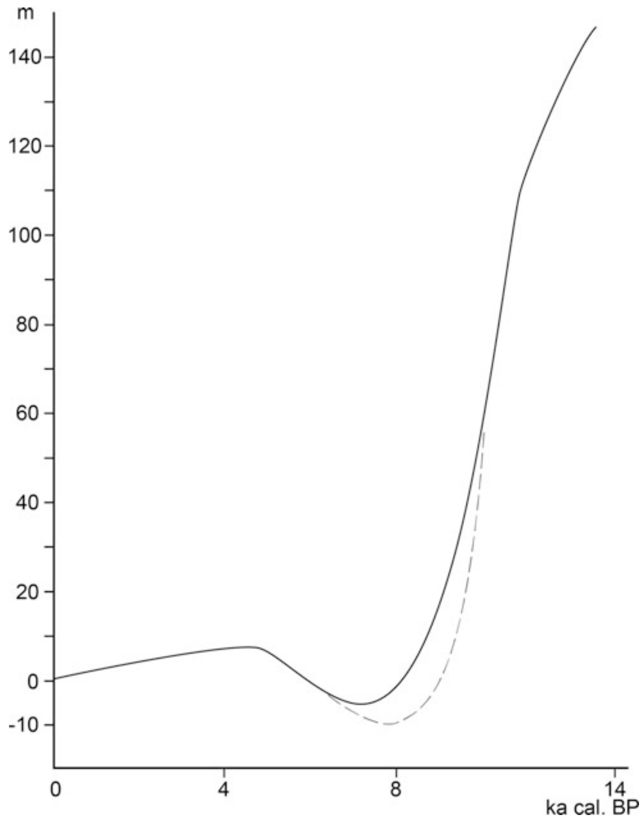

Fig. 17.9 Relative sea-level curve for Rivière-du-Loup area (adapted from Dionne (2002)). See Fig. 17.13 for location

1988). Varves observed in the BSL (Fig. 17.11) confirmed the presence of this lake.

During its maximum extent phase, Glacial Lake Madawaska covered over 500 km^2 in the southern BSL and New Brunswick (Fig. 17.10). During the early stage (proto-Madawaska) at the beginning of deglaciation, the lake drained northward in the St. Lawrence watershed (Nicholas et al. 1981; Rampton et al. 1984). In the first phases, outlets were located toward the north, to the Trois-Pistoles River, and toward the northeast, to the Rimouski River (Fig. 17.10) (Rampton et al. 1984). Formation of the Trois-Pistoles River outlet is consistent with the first stage of formation of the Trois-Pistoles glacifluvial delta. Lake Madawaska, which was in sporadic contact with the NDIC margin (Lougee 1954; Seaman 2004), played a key role in the regional deglaciation (Gadd et al. 1972; Chauvin et al. 1985). The Témiscouata–Madawaska Valley was deglaciated around 13 ka cal BP (Burke and Richard 2010) and was gradually occupied by a lake as the ice margin was retreating. This glacial lake contributed to the complete opening of this valley by increasing ablation through iceberg calving and thus to the opening and separation of the NDIC into local ice caps (PIC and LIC) on the plateaus of the interfluve of the Témiscouata–Madawaska Valley.

17.4.4 The Trois-Pistoles Delta

The Trois-Pistoles delta (Fig. 17.5) is the largest delta on the south shore of St. Lawrence (Buffin-Bélanger et al. 2015). It occupies more than 60 km^2. Despite its size and importance in the BSL landscape, only two authors have documented this large-scale depositional landform (Lee 1962; Dionne 1966, 1968). The construction of this delta overlaps the formation of the Luceville, St. Arsène, Neigette, St. Antonin and St-Jean-Port-Joli moraines, indicating that it was deposited over a long period, overlapping the late-glacial and the Early Holocene.

The upper level of the Trois-Pistoles delta is a glacifluvial delta consisting of coarse beddings of sand and gravel dipped towards the north (Dionne 1966). Deltaic sediments with thicknesses varying between 30 and 50 m (Dionne 1966) were deposited in the Goldthwait Sea from 14 ka cal BP (Lee 1962). The deltaic surface is incised with many marine terraces, which provide evidence for the forced regression of the Goldthwait Sea (Dionne 1966, 1977, 2002). The three main stratigraphic units found in this delta are, from base to top: (1) Goldthwait Sea clays at the base; (2) deltaic beds reworked by coastal processes; and (3) littoral deposits at the top (Dionne 1966). There is no evidence of ice-contact deposits over the entire delta; the deposits are rather associated with ice-distal margin glacifluvial sediments (Fig. 17.8).

17.5 Conclusions

The opening of the St. Lawrence Estuary during the calving phase (Thomas 1977) at the end of MIS 2 led to the formation of an autonomous ice in the Appalachians (Prest 1984), the Notre-Dame Ice Cap. Among the Quaternary heritage landforms and deposits observed in the BSL, the complex of frontal moraines of the Appalachian piedmont (Martineau and Corbeil 1983; Chauvin et al. 1985; Hétu 1998) is undoubtedly the most important. These moraines reveal the position of the northern NDIC margin during the late glacial period, when it had stabilized on the first escarpments south of the Goldthwait Sea.

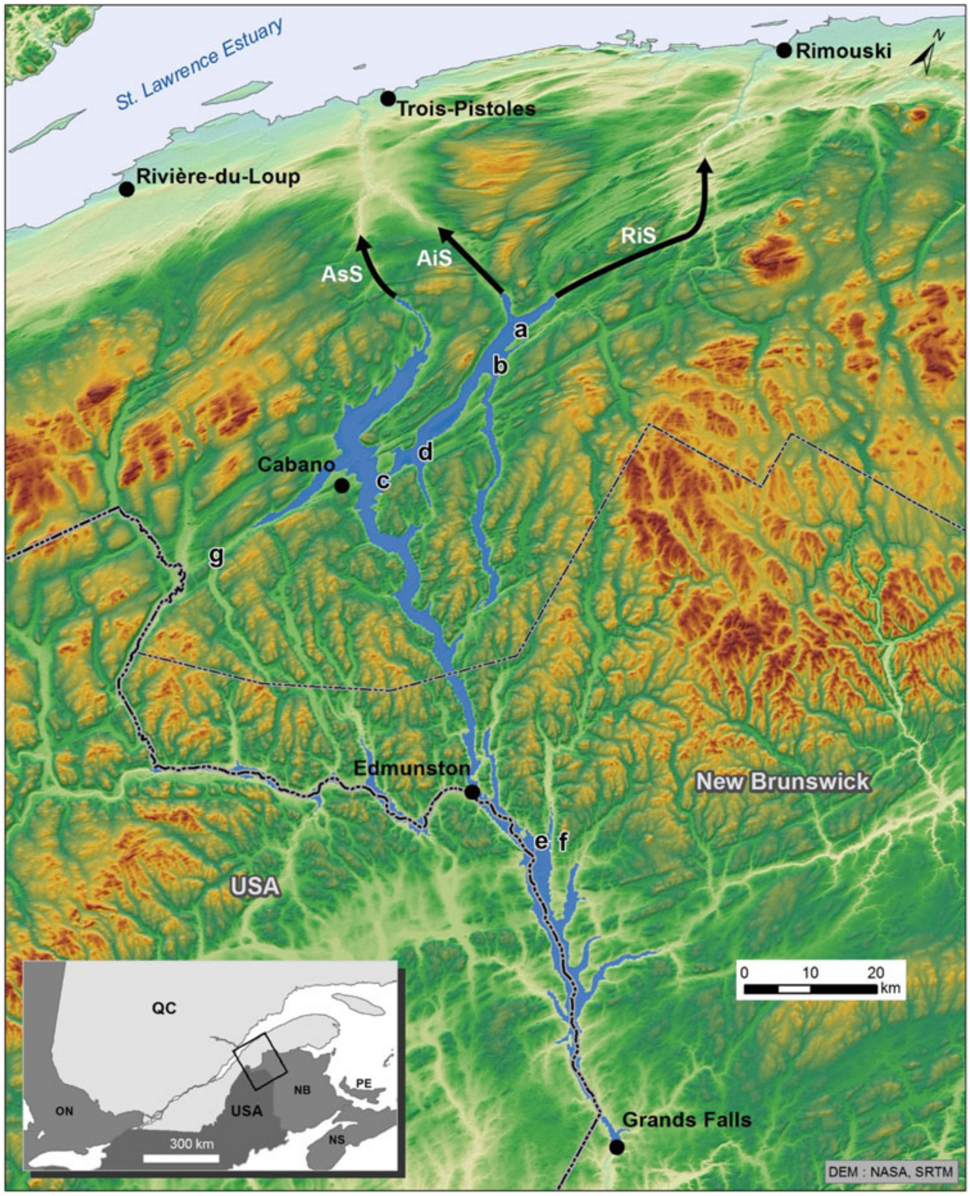

Fig. 17.10 The maximum extent of Lake Madawaska (Kiewiet de Jonge 1951; Rappol 1989). Spillways are shown by black arrows: AsS: Ashberish spillway, AiS: Aigles spillway, RiS: Rimouski spillway. Letters represent the location of photos in Fig. 17.11

There is a geomorphological continuity in landform and deposits assemblages of frontal moraine complex of the Appalachian piedmont between the St. Arsène and Luceville moraine segments and between the St-Jean-Port-Joli, St. Antonin and Neigette moraine segments (Fig. 17.12). These moraines, however, are not geographically connected, because the Trois-Pistoles delta represents a significant discontinuity in the landform assemblage. This delta was supplied by glacial Lake Madawaska in the Témiscouata–Madawaska Valley (Fig. 17.12). Glacial Lake Madawaska contributed to the early opening of this valley and to the rapid separation of the NDIC into two local caps—the Lejeune Ice cap (LIC) and the Pohénégamook Ice cap (PIC)—along the axis of the Témiscouata–Madawaska Valley (Fig. 17.13).

This paper, based on a review of existing research work and field observations, provides new insights on the model of the deglaciation of the Québec Appalachian Highlands.

Fig. 17.11 The varve complex of Lake Madawaska. Location on Fig. 17.10. **a** Lac-des-Aigles. **b** Squatec. **c** Témiscouata. **d** Touladi. **e** Rivière St-Jean. **f** Rivière Verte. **g** Rivière Bleue. *Photographs* A. Morissette

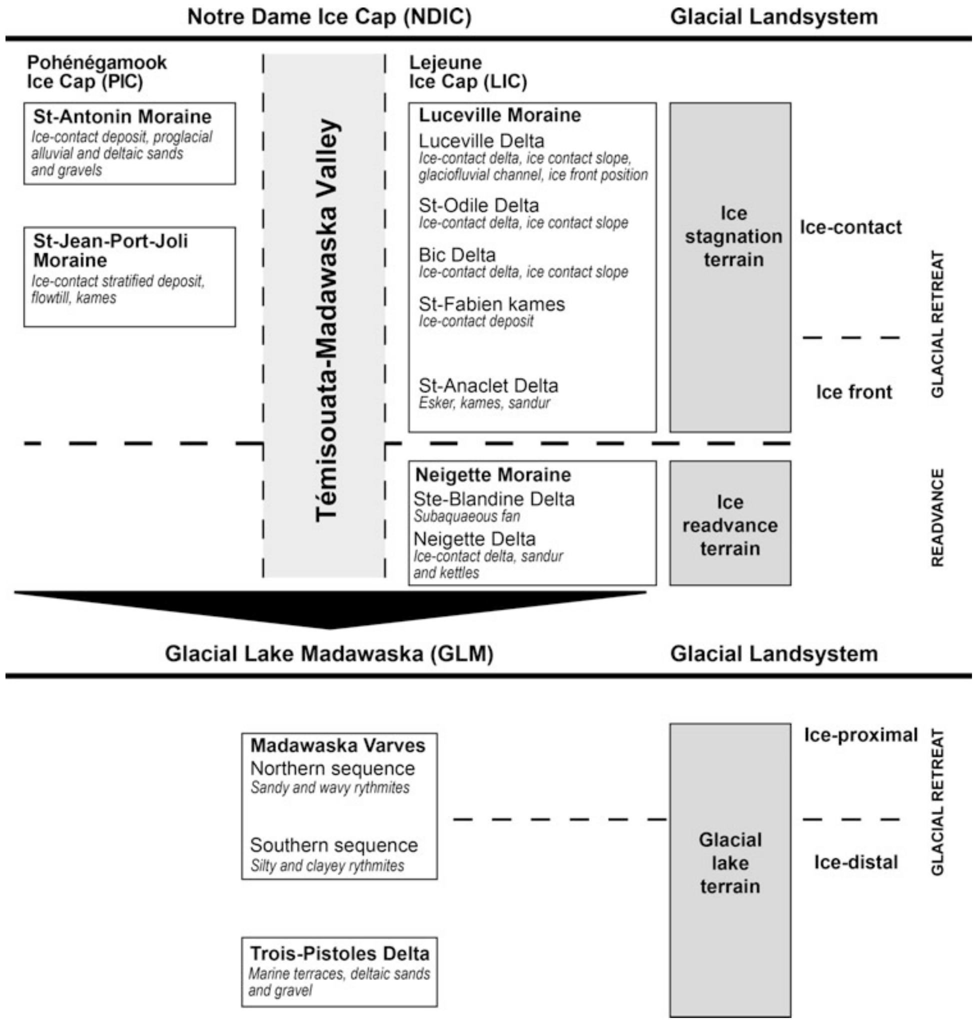

Fig. 17.12 Landform assemblages model accounting for the NDIC and glacial Lake Madawaska. The Témiscouata–Madawaska Valley splits the geomorphologic continuum between moraine segments of the western the Bas-Saint-Laurent belonging to the Pohénégamook Ice Cap (PIC) and moraine segments of the eastern Bas-Saint-Laurent belonging to the Lejeune Ice Cap (LIC). Glacial Lake Madawaska and the Trois-Pistoles delta developed between these two local ice caps

The St. Lawrence Ice Stream and its associated calving-bay contributed to the growth of the NDIC. In the Témiscouata–Madawaska valley, the fault in the Gaspé rift zone, exploited by glacial erosion, allowed rapid flooding by glacifluvial water. The resulting large glacial lake contributed to early deglaciation of this Appalachian valley. These processes activated the disintegration of NDIC into smaller local ice caps, the Lejeune Ice Cap and Pohénégamook Ice Cap, centered on the high plateaus of Notre-Dame Mountains. The Témiscouata–Madawaska valley was the first to be deglaciated due to the development of Glacial Lake Madawaska, while the Lejeune and Pohénégamook plateaus were still occupied by ice centers. The valleys at 90° to the Appalachian folds aided in the initiation and acceleration of deglaciation processes before the top of plateaus.

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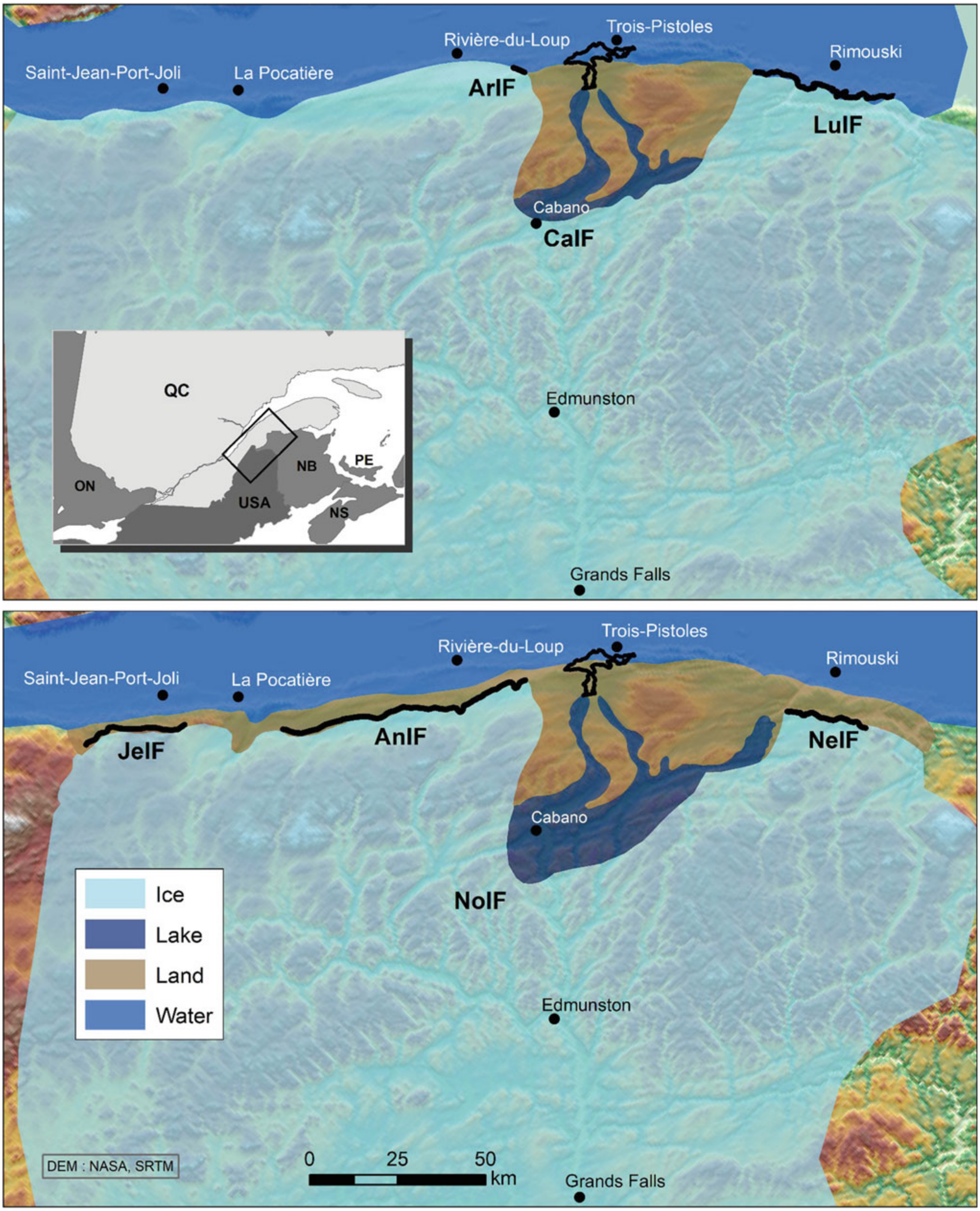

Fig. 17.13 Evolution of deglaciation in the Témiscouata–Madawaska Valley. In white, ice; dark blue, lakes; light brown, land; light blue, sea. ArIF: St. Arsene ice front. CaIF: Cabano ice front. LuIF: Luceville ice front. JeIF: St-Jean-Port-Joli ice front. AnIF: St. Antonin ice front. NoIF: Notre-Dame-du-Lac ice front. NeIF: Neigette ice front. The two phases correspond to the opening of the Notre-Dame Ice Cap by the Témiscouata–Madawaska Valley and the development of the early proglacial Lake Madawaska

field work: M. Boivin, E. Brouard, P.-O. Couette, D. Deschênes, G. Joyal, M. Joyal-Fortier, A.-P. Trottier, and V. Roy

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