11 Geomorphology of the Great Lakes Lowlands of Eastern Canada

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Abstract

The Great Lakes Lowlands is Canada's most populated region. While landform distributions are mainly related to a legacy of Quaternary glaciation and pre-Quaternary bedrock erosion, many modern processes of sediment erosion and deposition are significantly influenced by human modifications to the landscape, including deforestation, agriculture, aggregate extraction and urbanization. Ice lobes and/or streams of the Laurentide Ice Sheet Complex have resulted in a complex arrangement of ice-contact, ice-marginal and pro-glacial sediment sequences infilling pre-glacial bedrock channels. End moraines and interlobate kame moraines are thick and their spatial arrangement records multiple ice-flow directions around the eroded Great Lakes. The "peninsula" of southern Ontario undergoes significant coastal modifications as wave energy from three of the lakes erodes and redistributes glacilacustrine and glacifluvial sediments along shorelines. Post-glacial isostatic uplift has resulted in entrenchment of both subsequent and consequent river systems exposing mixed channel boundaries of glacial sediments and bedrock. Modern infrastructure has developed on these surfaces that are still undergoing post-glacial adjustment.

Keywords

Lower Great Lakes • Landforms • Glacial • Coastal • Fluvial • Human impact

11.1 Introduction

The Great Lakes Lowlands, bounded to the south and west by lakes Ontario, Erie and Huron, and to the north and east by the Canadian Shield (including the Frontenac Axis of the Canadian Shield at Gananoque), is an area of relatively low relief (Fig. 11.1) that is heavily influenced by its bedrock origins, extensive glaciations, post-glacial fluvial and coastal activity and historical land use. Figure 11.1 shows the contemporary topography and river drainage. The region is densely populated with close to 9.5 million people. This is more than one quarter of Canada's entire population living in approximately 80,000 km^2, only 0.8% of the country's total surface land area. Southern Ontario is a rapidly growing region with a forecasted population of 13.5 million by 2041 (Ontario Ministry of Finance 2017). Therefore, the landscape seen today is primarily a composite of its geologic and geomorphic origins with substantial human impact on processes and landform changes over the past 200 years.

Since deglaciation, water and wind forces along river valleys and shorelines have shaped the surface morphology of the Great Lakes Lowlands. The temperate, mid-latitude, climate has not changed significantly over the Holocene (Edwards et al. 1996; McFadden et al. 2005) and thus the hydrology continues to be dominated by a modest precipitation regime with seasonal temperature contrasts (Colombo et al. 2007). Unlike other continental climate zones of central Canada, the Lower Great Lakes have significantly moderate seasonal temperatures and enhanced winter snowfall with prevailing westerly winds off the Great Lakes. A strong nival flood regime is dominant (Gingras et al. 1994; Javelle et al. 2003).

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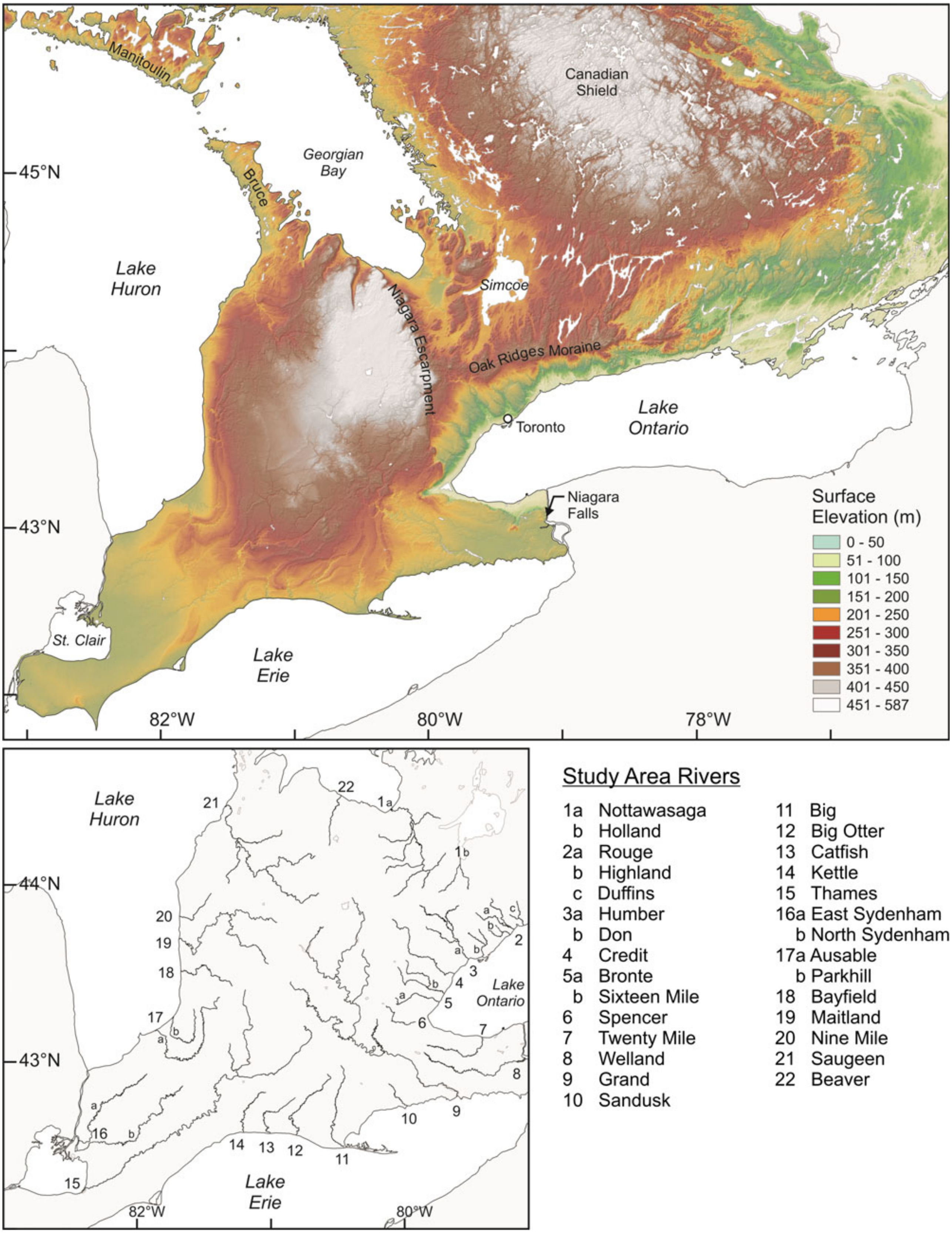

Fig. 11.1 Digital Elevation Model of the surface topography (m a.s.l) of southern Ontario with study streams used for classification of floodplains (Fig. 11.10). *Source* Ontario Geological Survey: https://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth

11.2 Bedrock

Geomorphic activity is, and continues to be, influenced by the lithological and structural make-up of basement and surface bedrock features. Extending outward from the margin of the Grenville-aged Canadian Shield (1.1 billion years), the Algonquin Arch (Fig. 11.2) forms a buried NE–SW trending topographic high of basement crystalline rocks (Carter et al. 1996). Granitic rocks are draped by a thick sequence of early Palaeozoic sedimentary units predominately comprising limestone, shales, dolostone and sandstones deposited in shallow marine and deltaic environments of the Michigan Basin between 450 and 375 million years ago (Catacosinos and Daniels 1991). Epeirogenic deformation of the surface crust resulted in shallow tilting of the sedimentary sequence to the southwest such that most formations of the eastern outer rim of the Michigan Basin were exposed to differential weathering over the Mesozoic and Cenozoic, ultimately forming the Niagara Escarpment. The escarpment, extending NW to form the Manitoulin Islands, is a major topographic feature separating Georgian Bay from Lake Huron (Tovell 1992). Along the southern margin, the Niagara River cuts across the escarpment between Lake Erie and Lake Ontario forming the largest waterfall (by volume) in Canada (Niagara Falls). The overlying Palaeozoic strata in southern Ontario have eroded to form a network of bedrock channels now buried by Pleistocene sediments (Fig. 11.2). Eyles et al. (1997) demonstrated that the bedrock channel orientation is correlated with the regional bedrock joint sets formed from mid-continent tectonic stresses and that these conditions have helped "pre-determine" post-glacial river alignment. Bedrock deformation in the form of pop-up structures and joint sets relate to glacial rebound processes (Adams 1989; Godin et al. 2002).

The spatial distribution and style of associated earthquake activity in eastern Canada is related to both tectonic and ice rebound stresses (Stewart et al. 2000). The southern Great Lakes (SGL) seismic zone has low to moderate levels of seismic activity compared to the rest of eastern Canada (Dineva et al. 2004). Evidence of past seismic activity, including small vertical and horizontal offset faults, can be found in the Late Glacial and Holocene sediments of these seismically active zones (Doughty et al. 2014).

The bedrock surface topography was largely in place until the beginning of the Quaternary period (Fig. 11.2). Highest bedrock terrains are over the Algonquin Arch and Niagara Escarpment exposures forming a bedrock island surrounded by lower bedrock terrain. Connecting present-day Georgian Bay of Lake Huron with Lake Ontario is the Laurentian bedrock channel that would have been a significant part of the pre-glacial drainage network in the region (Fig. 11.2).

11.3 Glacial Landforms and History

Quaternary continental-scale glaciations resulted in extensive sedimentary sequences (glacial drift) in the region, including a broad range of glacial landforms and a post-glacial legacy of isostatic rebound. The glacial drift covering much of southern Ontario averages about 40 m in thickness (median thickness $\sim$30 m) and is locally up to 262 m deep (Fig. 11.3). Greatest fill depths to bedrock are at the crest of the Oak Ridges Moraine (ORM) and under the Simcoe Uplands (Fig. 11.3) associated with infill of bedrock channels (Mulligan et al. 2016). The total volume of overburden in southern Ontario is approximately 2500 km^3 (estimated from Gao et al. 2006), which is roughly the combined volume of the Lake Ontario and Lake Erie basins.

Major surface landforms and glacial deposits with local names are shown in Fig. 11.4 based on the original physiographic mapping of Chapman and Putnam (1951, 1984) and digital data from the Ontario Geological Survey (Chapman and Putnam 2007). Differential rates of glacial erosion into less resistant shale formations left residual outcrops of dolomitic limestone as topographic highs—namely the Niagara Escarpment (see 1 in Fig. 11.4a)—and as alvar limestone plains with thin to no overburden along the Niagara Escarpment and to the east along the fringes of the Michigan Basin. MIS 2 (Late Wisconsinan) lodgement till, drumlinized till plains and other mega-scale glacial lineations (Fig. 11.5) blanket large areas of the region. Older glacial drift recording ice advance, interglacial and Illionian-age sediments are documented in outcrops and subsurface borehole and seismic data (Karrow 1967; Sharpe et al. 1997). Subglacial eskers and drumlins (Fig. 11.4b), formed under separated lobes of the Laurentide Ice Sheet, record evidence of ice flow directions (Boyce and Eyles 1991; Brennand 1994, 2000; Eyles and Doughty 2016), with major streamlines associated with ice moving out of Lake Huron (Teeswater (see 14 in Fig. 11.4b) and Arran (see 16 in Fig. 11.4b) drumlin fields) and Lake Ontario (e.g. Peterborough Drumlin Field; see 18 in Fig. 11.4b and 11.5). With respect to the dominant processes of drumlin formation, the role of glacial erosion and bed deformation by fast-moving ice-streams (Eyles et al. 2016) and the role of deposition by subglacial meltwater floods (Shaw 2002) have been presented in the literature.

With the onset of MIS 2 (Late Wisconsinan) deglaciation, a succession of kame moraines, recessional till moraines (the "Horseshoe Moraines") and associated outwash channels were formed roughly surrounding the central uplands (Fig. 11.4c)—the central upland area has been aptly referred to as the *Ontario Island* as it was briefly surrounded by glacial ice lobes and proglacial lakes during the early stages of deglaciation around 13 ka BP (Chapman and Putnam 1951). To the east of the Niagara Escarpment is the

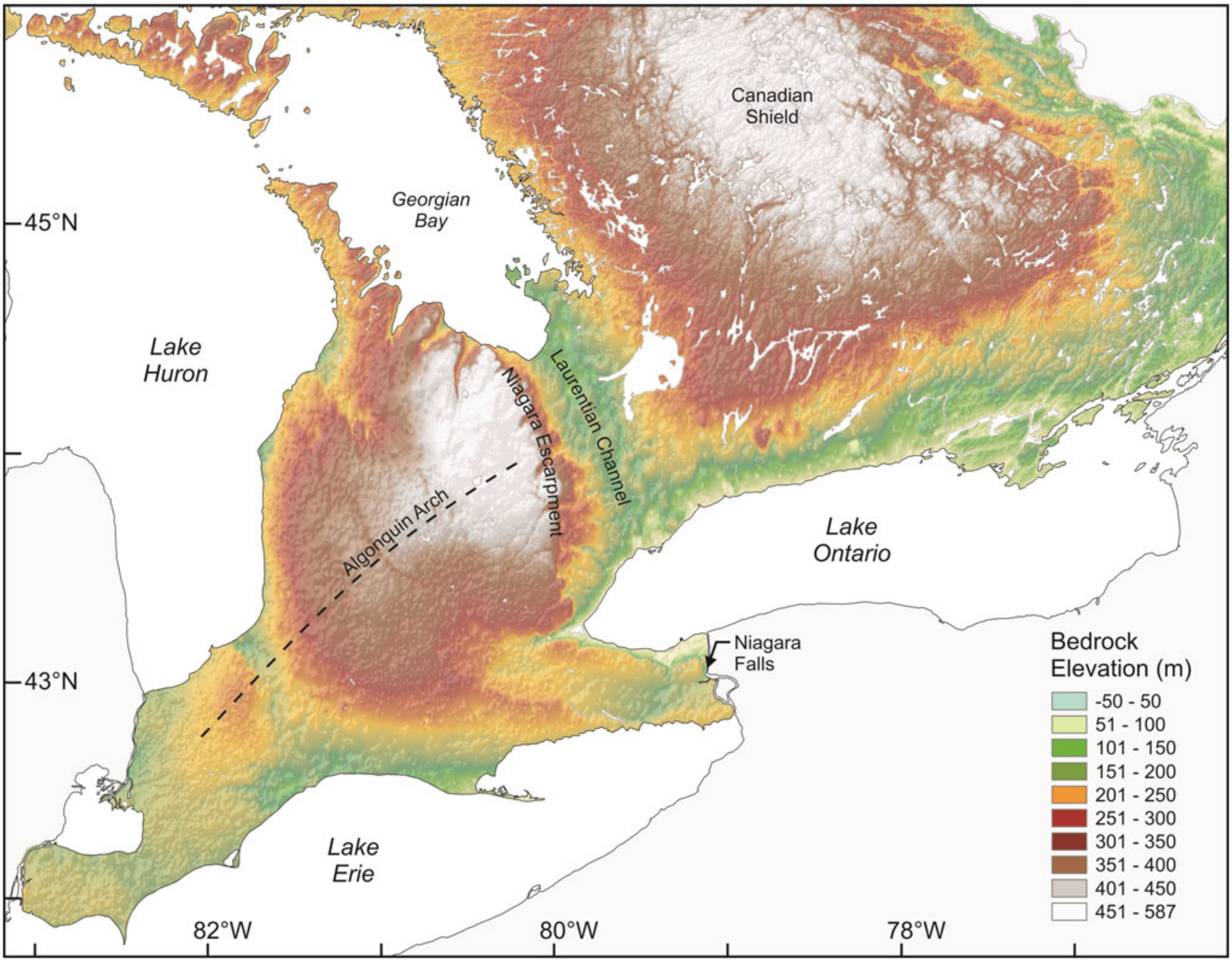

Fig. 11.2 Digital Elevation Model of the bedrock topography of southern Ontario, highlighting key features such as the Algonquin Arch, Niagara Escarpment, Laurentian Channel and Canadian Shield. *Source* Ontario Geological Survey: https://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth

prominent ORM, a stratified interlobate moraine (dominantly sand and gravel, kame-type) formed within a complex sequence of subglacial, ice-contact and proglacial depositional environments (Gilbert 1997; Barnett et al. 1998). The ORM is a major groundwater reservoir discharging into drainages that flow north and south off the moraine crest (Gerber and Howard 2000). The Dummer Moraine north of the Peterborough Drumlin Field is a hummocky ridge of limestone-clast debris along the transition between the surface Palaeozoic limestone and Precambrian crystalline bedrock of the Canadian Shield (Eyles and Doughty 2016).

Within the greater Great Lakes Basin, meltwater during deglaciation ponded in a series of large proglacial lakes leaving behind beach deposits of gravel and glacilacustrine plains of sand, silt and clay (Fig. 11.6; Larsen and Schaetzl 2001; Lewis et al. 2008). The proglacial lake shorelines tend to be tilted across each basin due to greater glacial isostatic rebound to the northeast of the Great Lakes Basin (Fig. 11.7; Lewis et al. 2005).

Given the low-relief topography and large-scale ice-sheet dynamics of the region, the geomorphic expression of glacial landforms viewed from the ground is subtle. However, the extensive glacial sedimentary sequences are frequently cut and exposed along river valleys (Fig. 11.6) and coastal bluffs as the post-glacial surface has been reworked by Holocene fluvial, coastal and aeolian processes.

11.4 Coastal Geomorphology in Southern Ontario

Glacial erosion, extensive late Pleistocene glacial lakes and post-glacial lake level adjustment (including isostatic tilting, Fig. 11.7) have led to the modern configuration of the lower

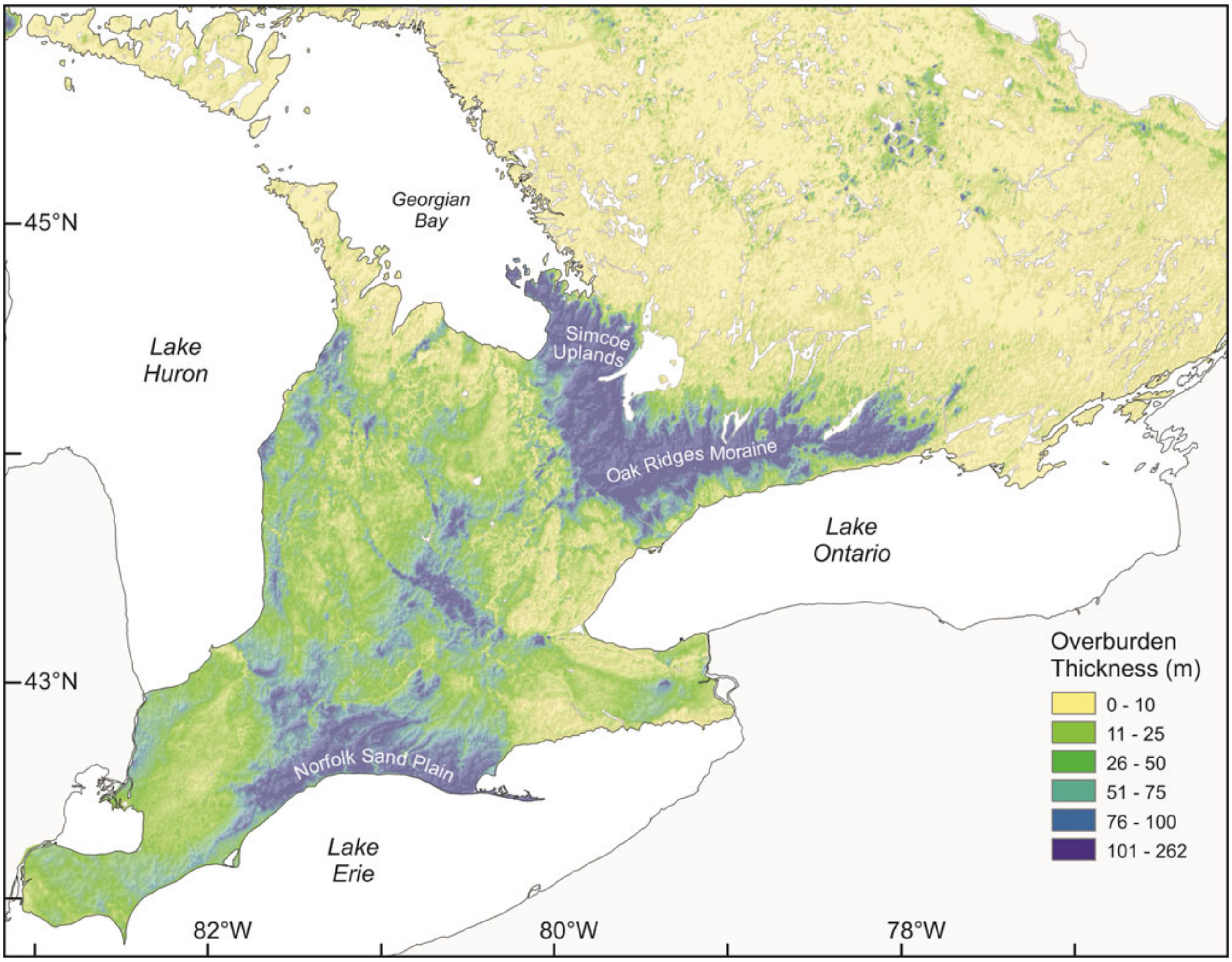

Fig. 11.3 Sediment overburden thickness in the Lower Great Lakes, with the thickest deposits within the Oak Ridges Moraine and Simcoe Uplands. *Source* Ontario Geological Survey: https://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth

Great Lakes shorelines (Fig. 11.8). Shoreline length of lakes Erie, Ontario and southern Huron on the Canadian side exceeds 1400 km. Contemporary wave and current processes are strongly influenced by variations in lake water levels on a seasonal and long-term basis (Quinn 2002; Rao and Schwab 2007; Department of Fisheries and Oceans 2016). Seasonal signatures of high water are associated with spring melt and low water with late summer/fall temperature induced evaporation. Long-term high lake levels result in higher rates of shoreline erosion and higher rates of sedimentation within the lakes.

11.4.1 Lake Erie

Lake Erie is comprised of three basins—Western, Central and Eastern—with shoreline features reflecting the configuration of each. The Western Basin is associated with bluffs bordering the Essex Clay Plain, with narrow beaches and a depositional sink that makes up Point Pélée. It is shallowest and receives inflow from the Detroit River. The land bordering the north side of the Western Basin is characterized by clay-rich till with bluffs along the north shore that range in height from a few metres above the lake level in the west to over 20 m above the lake level in the east. Narrow beaches border the bluff toe in an overall erosional environment that has resulted in various approaches to shoreline protection (e.g. Lawrence 1994). The national park at Point Pélée is a large cuspate foreland composed of beach ridges, dunes and marshland (Coakley 1976; Trenhaile et al. 2000), and marks the eastern end of this basin. The pre-European contact processes active in this area resulted in a tenuous balance of erosion and deposition along the shoreline and the development of Point Pélée. Post-European contact settlement and development resulted in sediment starvation of the coastal system and a resulting increase in erosion

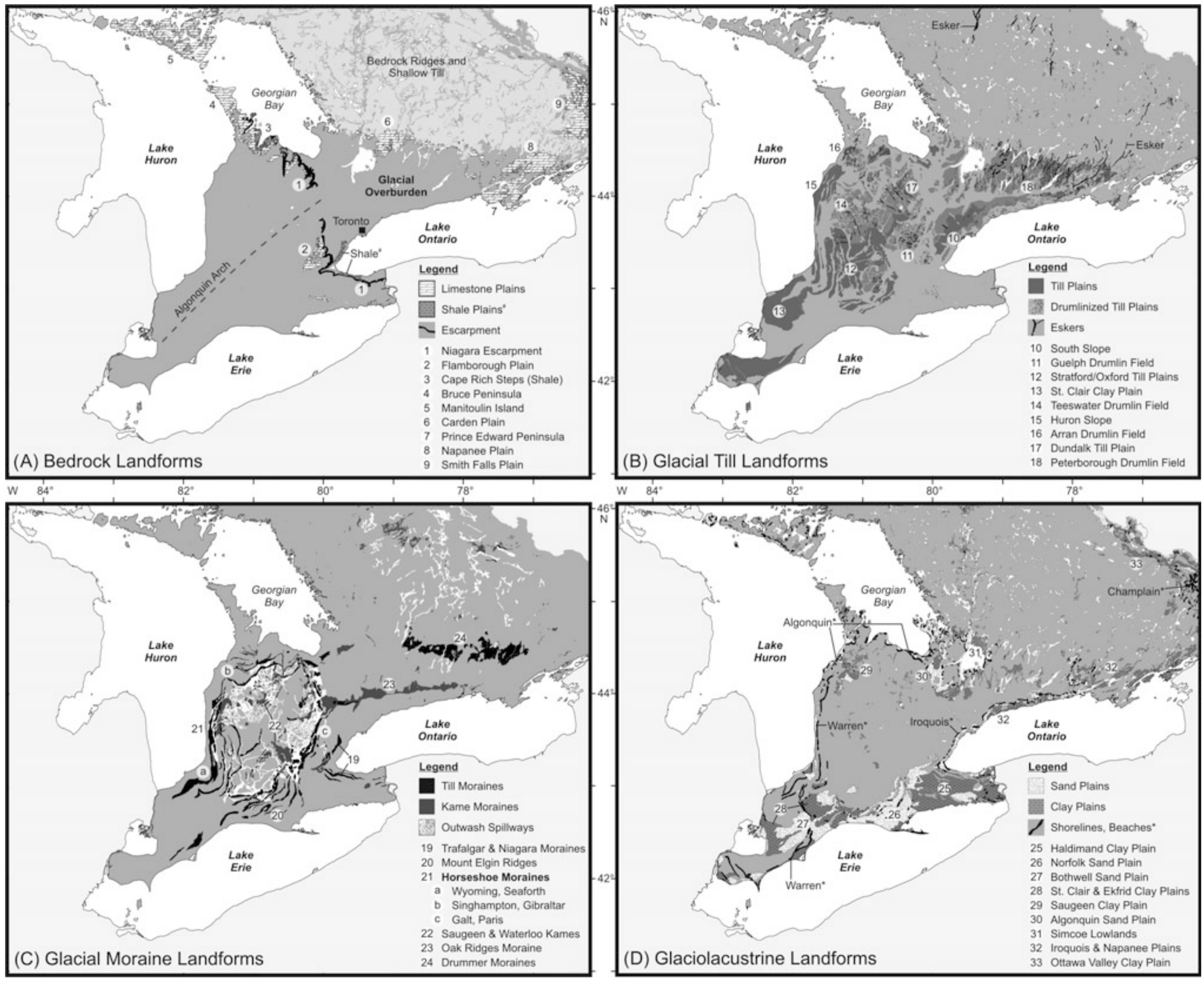

Fig. 11.4 Glacial landforms of southern Ontario. **a** Bedrock landforms; **b** glacial landforms—till plains drumlin fields, eskers; **c** glacial landforms—moraines; and **d** glacilacustrine landforms with post-glacial lakeshores identified with an asterix (Warren (Erie and southern Huron), Iroquois (Ontario), Algonquin (Bruce Peninsula), Champlain (eastern edge of the map)). After Chapman and Putnam (2007)

(BaMasoud and Byrne 2011) and thus the need for shoreline protection or sediment nourishment to maintain beaches. Point Pélée National Park provides a good example of both shoreline protections with the armouring of some beaches to arrest the rate of erosion and recent sediment nourishment on others (Dobbie, pers.com).

The Central Basin, extending eastward and terminating in Long Point and the Long Point Spit (Fig. 11.8b), is bordered to the north by sand plains overlying till. Several small streams drain the Norfolk and Bothwell Sand Plains (see 26, 27 in Fig. 11.4d) and the Ekfrid Clay Plain emptying into the Central Basin. Two sediment depositional sinks mark the shoreline—first is Long Point and the second is the Pointe aux Pins complex, composed of the Erieau and Rondeau spits. Between these two sinks are erosional bluffs that range in height from just a few metres to over 30 m. Sections of thick sand in the Norfolk Sand Plain are highly erosive (Fig. 11.8e) with shoreline retreat rates varying from 0.2 to 4.9 m per year (Boyd 1981). Rukavina and Zeman (1987) noted that most of this eroded material is removed from the coastal system and lost to offshore basins.

The Eastern Basin is the deepest and is bordered on the north shore by a low sloping coast associated with the Haldimand Clay Plain (25, Fig. 11.4d) with wetlands and pocket beaches between limestone headlands. A present-day delta to the Grand River (9, Fig. 11.1) is marked by sand accumulation and a minor depositional sink with active sand dunes.

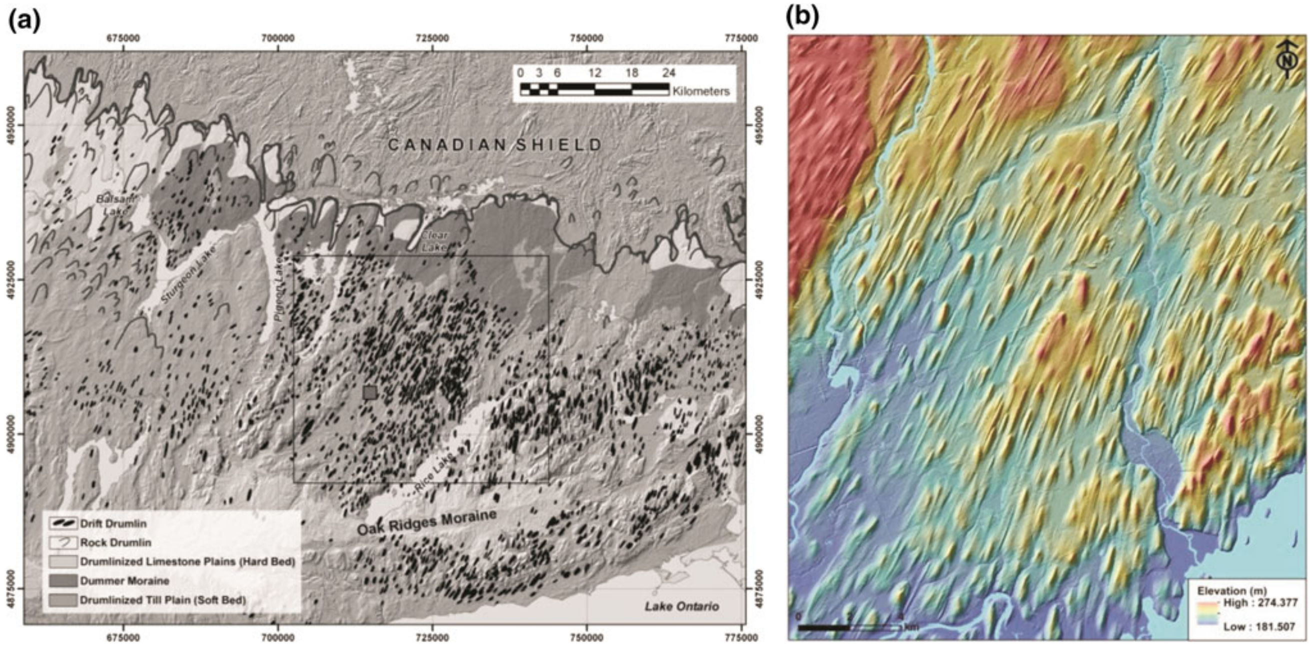

Fig. 11.5 Drumlins and megaridges: **a** centred on City of Peterborough; **b** drumlins and mega-scale glacial lineations of dissected drumlins near Rice Lake. From Eyles and Doughty (2016)

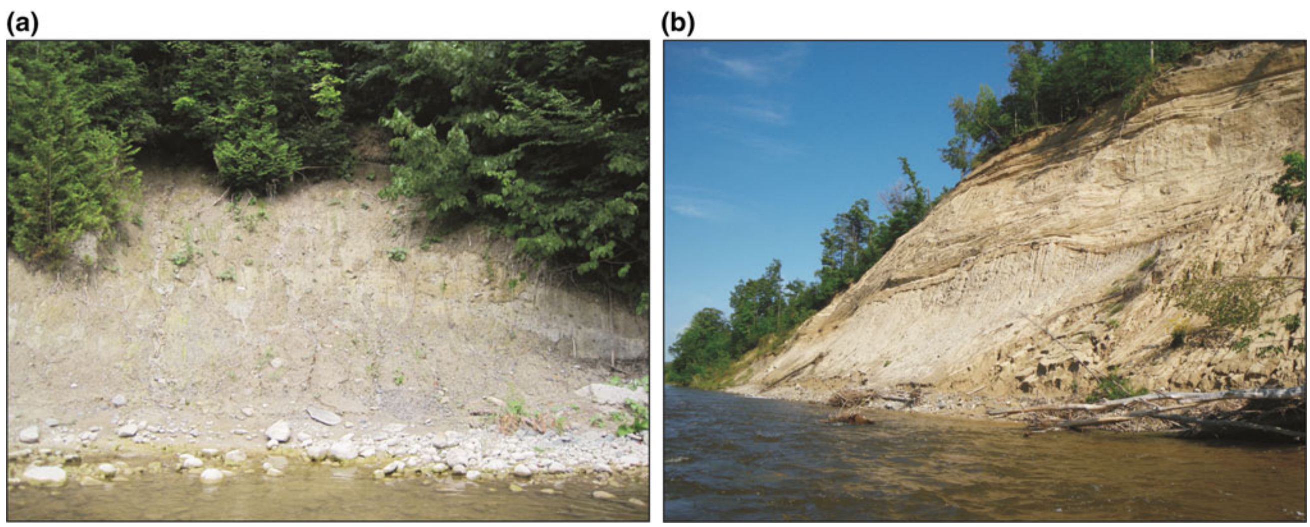

Fig. 11.6 **a** Glacial till bluff along Little Rouge River (43°48′29″ N′ 79°08′09″ W) showing contribution of cobble and gravel till clasts supplied to the fluvial channel. *Photograph* James Thayer, with permission. **b** 45 m high valley bluff of exposed glacilacustrine sand over till along Saugeen River (see 21 in Fig. 11.1) near Walkerton, Ontario (44°10′33″ N′ 81°10′51″ W)

11.4.2 Lake Ontario

This lake is characterized by the Iroquois Plain (see 32 in Fig. 11.4d), a relatively flat, low-lying former lake bottom that contrasts with the undulating surface of the till plains that it borders. The Iroquois Plain extends over 300 km from the Niagara River around the western end of Lake Ontario and then eastward to the Trent River. The Iroquois Plain contains the Niagara fruit belt, Lake Ontario's lake-head including a large and productive wetland complex—Cootes Paradise, and the sands, gravels and shale plains of the Hamilton to Toronto shoreline. This landscape was so

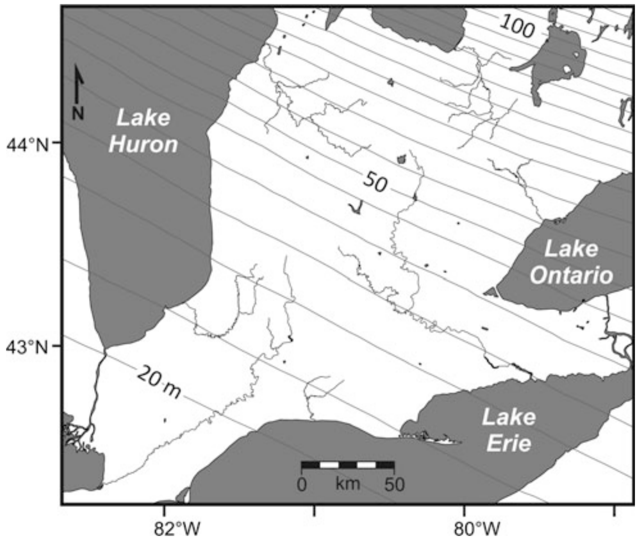

Fig. 11.7 Isoline map of southern Ontario for isostatic rebound since 10.6 ka BP (uncalibrated ^{14}C, glacial Lake Algonquin phase) (after Lewis et al. 2005). Contour interval is 5 m with reference area of zero uplift southwest of Lake Michigan beyond the limit of the last glaciation

desirable for settlement that it is now almost completely developed. The Iroquois Plain is very narrow in the eastern part of Toronto (Fig. 11.1). Here the Scarborough Bluffs tower over 100 m above the lake level. Eyles and Eyles (1983) interpreted these deposits to be the preserved stratigraphy of a large Pleistocene lake (Fig. 11.8f). Eastward, the Iroquois Plain continues with former shoreline sand and gravel complexes now nearly invisible beneath modern urban and rural development. Other notable features of Lake Ontario's coastal geomorphology include Toronto Islands, the Limestone Plains of Prince Edward County with the sand spits and the drumlinized clay plains at the east end of the lake.

11.4.3 Lake Huron (South)

The southern part of Lake Huron is marked by a series of moraines that parallel the present-day lakeshore. The Huron Slope (15, Fig. 11.4b) marks the recessional shorelines of glacial Lake Warren (Fig. 11.4d) and glacial Lake Algonquin (Fig. 11.4d). Bordering this slope is the Huron Fringe that is comprised of glacial Lake Algonquin and Lake Nipissing shorelines and the modern Lake Huron. On the Bruce Peninsula, the fringe is characterized by scoured limestone plains just metres above present-day lake level, interspersed with small beaches and wetlands. A large sand accumulation at Sauble Beach is relict from the post-glacial supply of material by the Saugeen River (see 21 in Fig. 11.1). Southward from the Bruce Peninsula to Grand Bend, the shoreline is marked by shore bluffs 15–30 m tall that are highly erosive (Fig. 11.8c). Sediment is carried in the littoral system to be deposited from Grand Bend northward as active beaches and dune complexes (Fig. 11.8d).

11.5 Fluvial

Holocene fluvial systems have carved river drainage networks into the deglaciated surfaces forming valleys typically in the range of 10–50 m deep—30 m being a reliable average. Longitudinal river profiles retain topographic and sedimentary signatures from glacial landforms (Fig. 11.9), with fluvial systems incorporating a large range of materials through incision (Phillips and Desloges 2014). Channel materials tend to reflect local sediment sources, resulting in longitudinal variations in floodplain alluvium that are systematically coupled with the surrounding glacial landforms within each watershed (Phillips and Desloges 2015a, b).

Given the dominance of silt and clay from till and glacilacustrine deposits in the region, variations in the alluvial floodplain sequences and channel morphologies tend to be most strongly influenced by the local sources of cobble-gravel (from moraines and outwash) and of sand (from lake bottom, delta and beach deposits). The continuum of alluvial floodplain types (Fig. 11.10) tend to statistically cluster—providing a useful classification tool (Phillips and Desloges 2015a, b)—based on stream power (correlated with bed grain size and boundary resistance) and floodplain sedimentology (based on sand availability and floodplain thickness).

The glacial conditioning of fluvial systems in southern Ontario is also revealed in the comparison of specific stream power mapped over the glacial landforms (Fig. 11.11). However, the correlation between stream energy and bed grain size may be mismatched in some cases resulting in oversteepened or understeepened reaches (Phillips and Desloges 2014). For example, slope-driven changes in grain size are obscured by the continual recruitment of coarse sediment from incision into glacial moraine sediments that supply a relatively constant grain size even as slope increases or decreases downstream (Thayer et al. 2016). Not only is the typical Holocene response of the fluvial systems confounded by numerous and distinct glacial landform assemblages, rivers in the lower Great Lakes region are also affected by base-level changes associated with water-level fluctuations (±100 m) and post-glacial isostatic rebound (Phillips and Desloges 2015b).

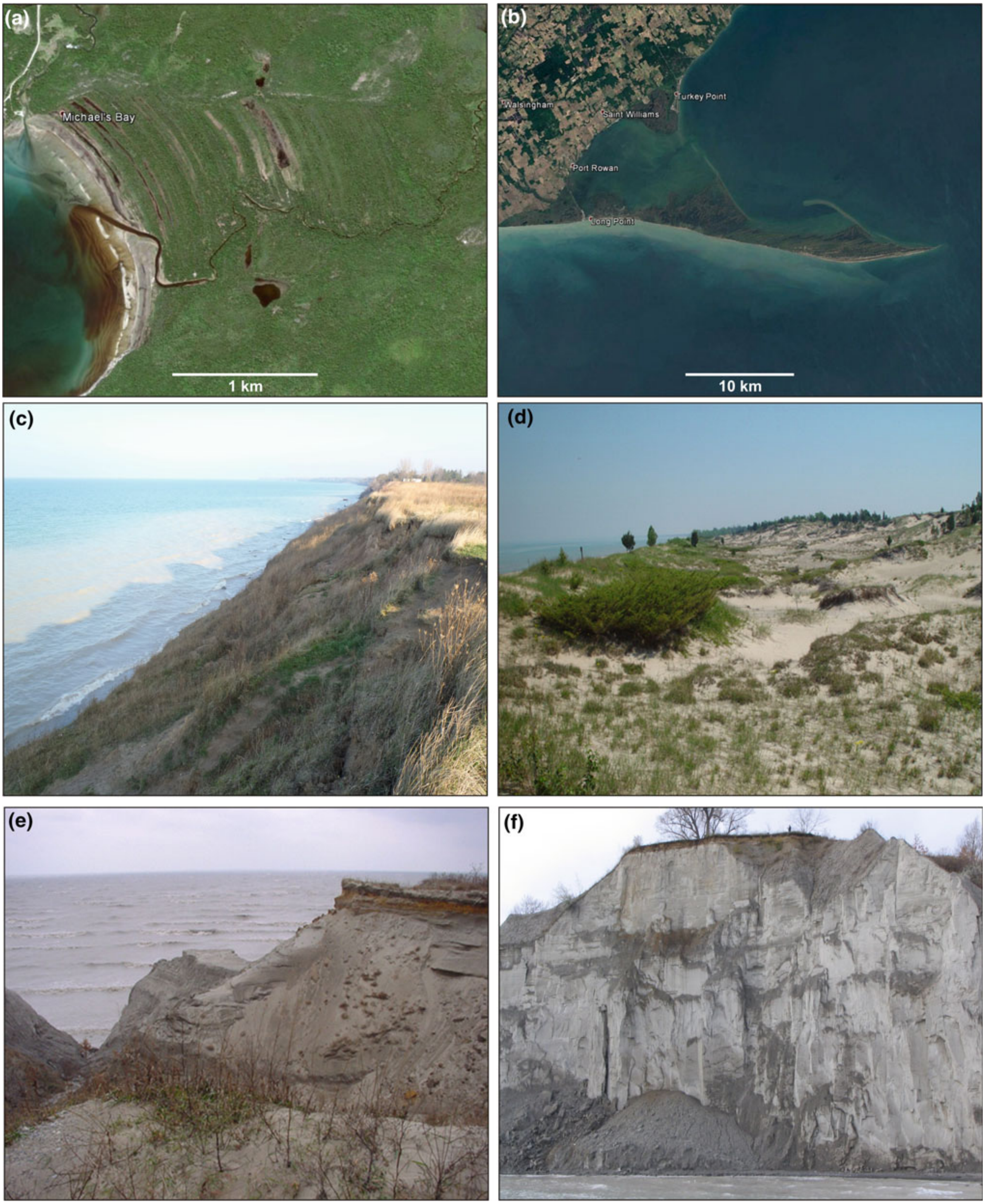

Fig. 11.8 **a** Beach strandlines due to Holocene isostatic rebound and tilting at Michael's Bay, Manitoulin Island (see 5 in Fig. 11.4a); **b** Long Point in Lake Erie developed by prevailing longshore currents; **c** Glacial Lake Warren shoreline above modern day Lake Huron (Fig. 11.4d); **d** sand dunes at Pinery Provincial Park—This depositional sink has been receiving sediment since the Lake Algonquin stage. Modern coastal processes still deliver sand to this location; **e** eroding bluffs of the Central Basin, north shore Lake Erie—Sediment removed by subaerial and coastal processes is removed from the coastal system and carried to offshore basins; and **f** eroding Scarborough Bluffs east of Toronto on the north shore of Lake Ontario in 2008—the bluffs have since been protected from further erosion with engineered rip-rap at the base of the slopes

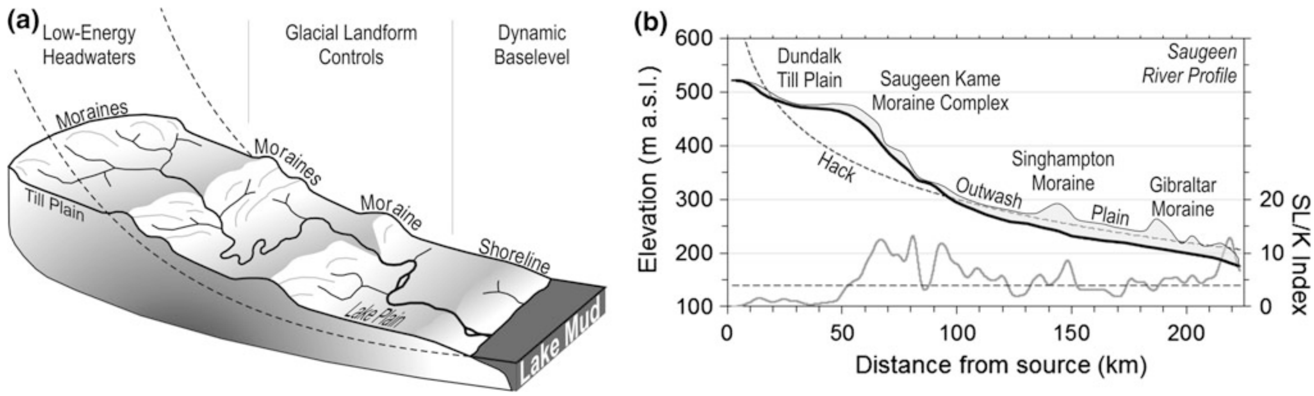

Fig. 11.9 Longitudinal river profiles retain topographic and sedimentary signatures from glacial landforms. **a** Generalized fluvial landscape model for southern Ontario; and **b** example longitudinal profile for Saugeen River (see 21 in Fig. 11.1; Phillips and Desloges 2014, 2015b), including local names for glacial landforms and the stream length-gradient (*SL/K*) index relative to an exponential best-fit Hack profile

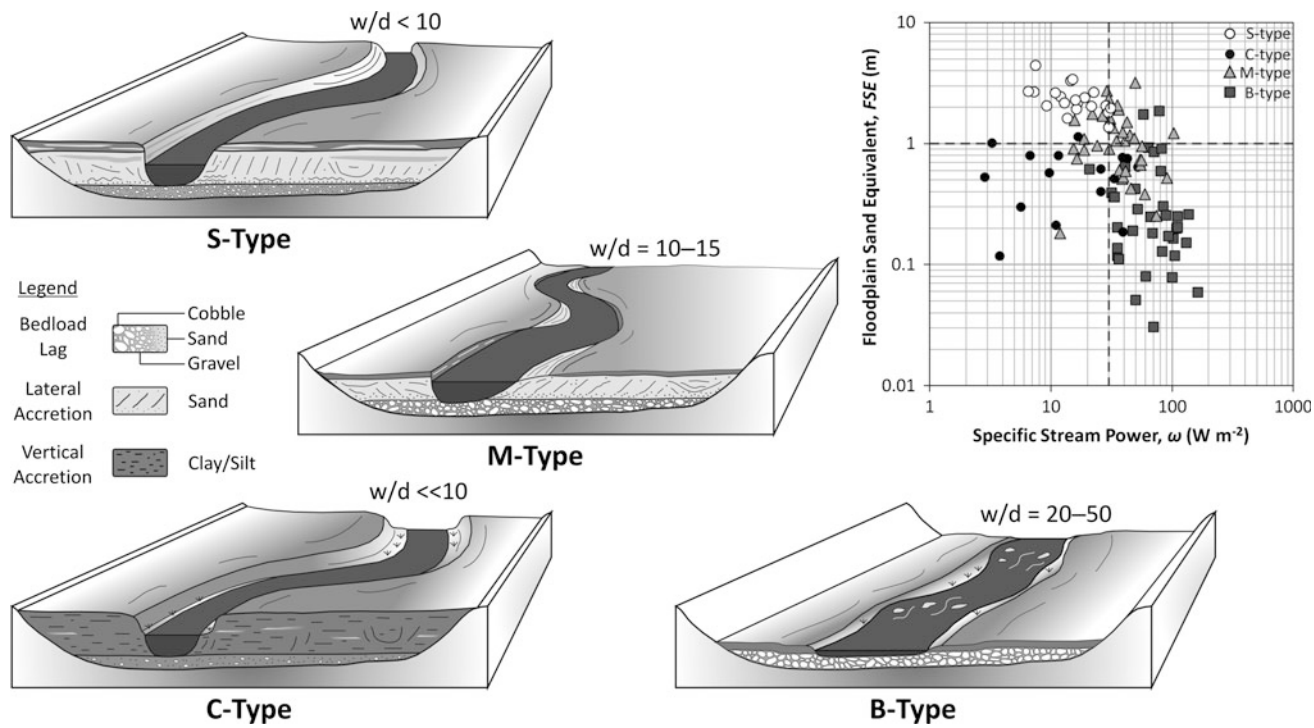

Fig. 11.10 Alluvial floodplain types for low-relief, glacially conditioned rivers (labelled in Fig. 11.1 lower map) as end-members in a continuum of stream power and floodplain sedimentology, with graph in upper right corner showing clustering of the four types by specific stream power and sand availability (defined as floodplain sand equivalent, *FSE*) as per Phillips and Desloges (2015a, b)

11.6 Human Influences in the Lower Great Lakes

European settlement in the seventeenth and eighteenth centuries dramatically altered the lower Great Lakes region, but early horticulture started more than a few millennia before European settlement (Hart and Lovis 2013) including on fertile river floodplains (Crawford et al. 1998). Extensive deforestation for agriculture across southern Ontario, and subsequent land development in urban areas, has resulted in significant changes in land cover and watershed hydrology. Cleared agricultural and urban land cover currently account for about 62 and 9%, respectively, with the balance of 29% making up the remaining forests, wetlands, and shorelines (from SOLRIS 2000 v1.2 dataset, Ontario Ministry of

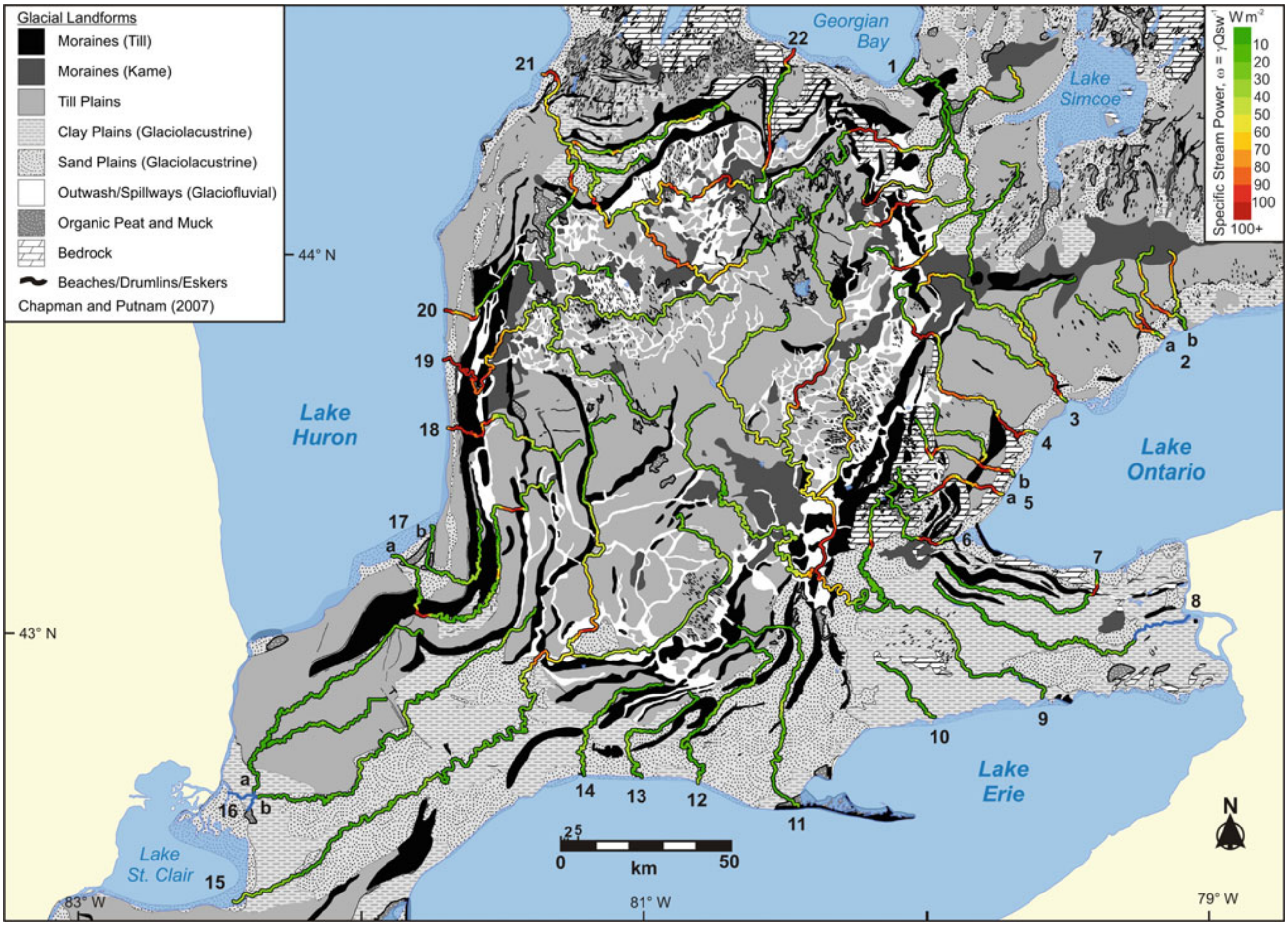

Fig. 11.11 Specific stream power conditioned by glacial landforms, numbers correspond to streams labelled in Fig. 11.1 (Phillips and Desloges 2014)

Natural Resources 2008). Land development and road construction have also driven aggregate resource extraction across the landscape, with provincial records for more than 8,000 open pits and quarries (Ontario Ministry of Natural Resources 2013), covering over 800 km^2 and accounting for about 1% of the land area in southern Ontario (Fig. 11.12). Aggregate mining opportunities have tended to focus on glacifluvial gravel and sand deposits or near-surface limestone formations in the region. Sand mining of the Great Lakes shorelines also occurred in the past. On average, about 130 Mt of aggregate (sand and gravel; crushed stone) are mined and moved in this region each year (Altus Group Economic Consulting 2009). This is equal to ~1600 t/km^2/year. Clubine et al. (2010) showed that the average suspended sediment yield for southern Ontario drainages are in the range of 200–300 t/km^2/year, indicating that human movement of aggregates is 5–8 times river sediment discharge from the region.

The hydrological cycle is modified by anthropogenic activities, which has led to changes in watershed and fluvial processes (e.g. Campo and Desloges 1994; Allan 2004; Chin 2006; Gregory 2006). With European settlement and intensified agricultural practices, stream channels were moved and in some cases filled, while subsurface drainage was augmented through tile-drain networks (e.g. Macrae et al. 2010; Molder et al. 2015). Over 68% of wetlands were drained (Ducks Unlimited Canada 2010) and the overall watershed hydrology has changed because of water use and extraction (Mao and Cherkauer 2009). As agricultural land use around urban centres evolved to allow urban expansion (e.g. in the form of suburban communities, road networks, aggregate extraction, etc.), impervious surface area increased and further modified hydrological processes and aquatic ecosystems (Paul and Meyer 2001; Conway and Hackworth 2007). River engineering practices have also directly impacted the stream channels with a long history of dam and

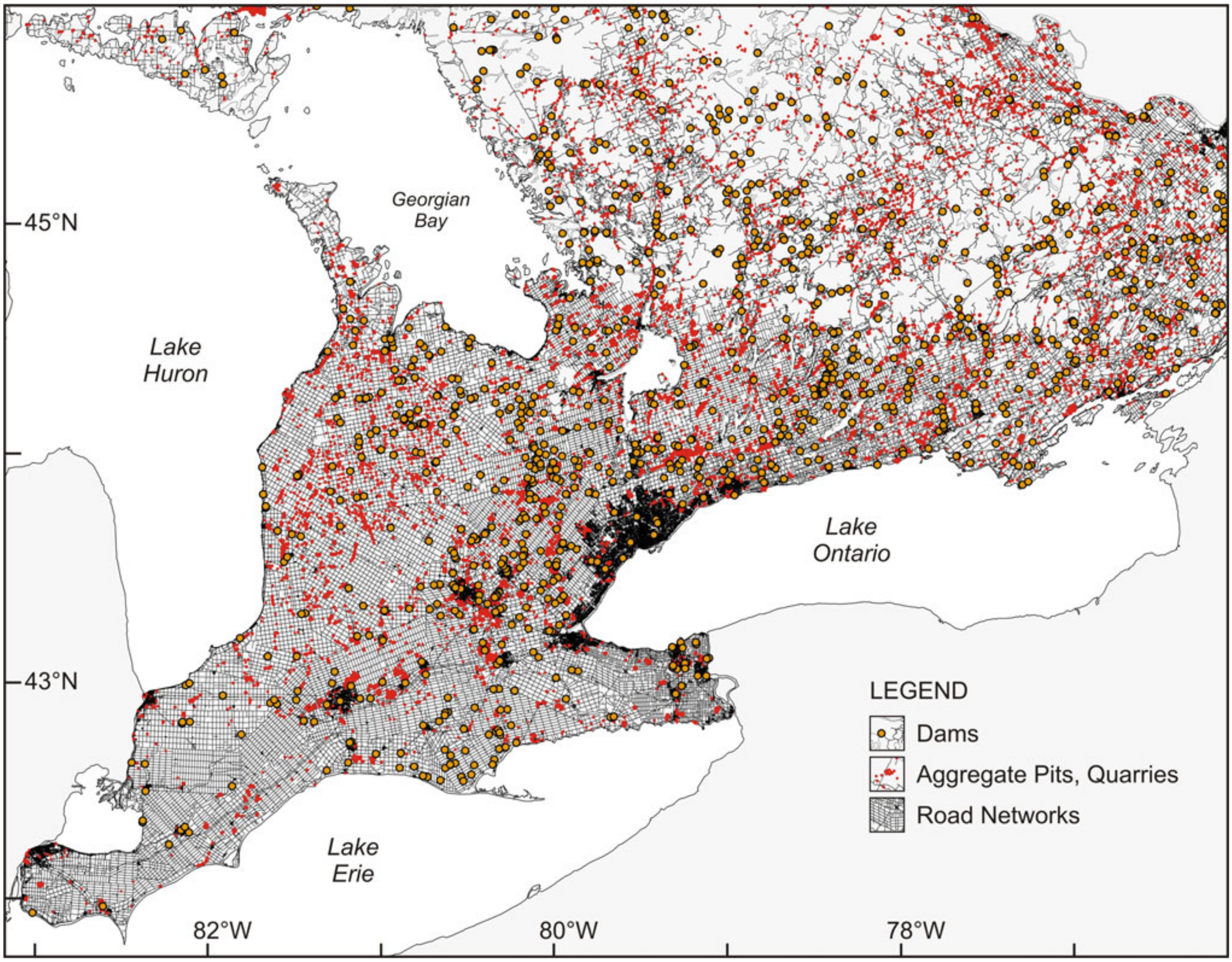

Fig. 11.12 Regional human impacts illustrated with location of dams, aggregate pits and quarries, and road networks. The increasing density of road networks provides a graphical representation of development intensity from low density in the northern portion of the figure (Canadian Shield), to moderate density in southern Ontario (rural agriculture), to high density urban areas. Dams tend to cluster in areas of higher relief and aggregate activities cluster based on source deposits and development intensity and history

road construction, including generations of erosion and flood mitigation measures that tend to deteriorate within a few decades resulting in further degradation of "natural" stream functions.

For example, the provincial dam inventory has in the order of 1000 medium and large dams on record in southern Ontario (Fig. 11.12), about 100 km of stream per dam, with many more small dams not in the current database (Ontario Ministry of Natural Resources and Forestry 2015). Given the approximately 100,000 km of existing stream channels, and a drainage density of about 1.2 km/km^2 in the region, there is on average a road crossing for each 1.8 km of stream ($\sim$0.6 crossings/km), which is just slightly less than the distance of 2 km between the concession roads of the 1,000 acre sectional system used in the survey layout in many counties of southern Ontario. To highlight river engineering for erosion and flood control, Highland Creek—one of Toronto's most urbanized watersheds—has had over 50% of the stream banks hardened including treatments like concrete and rip-rap stone, with some reaches as high as 89% (Aquafor Beech Ltd. 2010). Dams, road crossings and river engineering practices in southern Ontario have contributed significantly to fluvial discontinuity and habitat fragmentation in hydrological, geomorphological and ecological terms.

The results of the anthropogenically modified hydrological cycle and history of channel engineering are evident in the degraded forms and functions of freshwater streams throughout the lower Great Lakes (Stanfield 2012). Baseflow dynamics, runoff-response relationships and fluvial processes have changed, in turn impacting sediment transport

Fig. 11.13 Stream restoration and river engineering (before and after photos); a–a′ stream restoration within formerly agricultural lands in the headwaters of Fletcher's Creek, Brampton a tributary to Credit River (see 4 in Fig. 11.1); b–b′ river engineering to protect sanitary sewer pipe within Highland Creek (see 2b in Fig. 11.1), Toronto (white arrows for common reference point; black arrow and dashed line indicate exposed trunk sewer pipe in before photo); c–c′ slope restoration and channel realignment within Amberlea Creek, Pickering

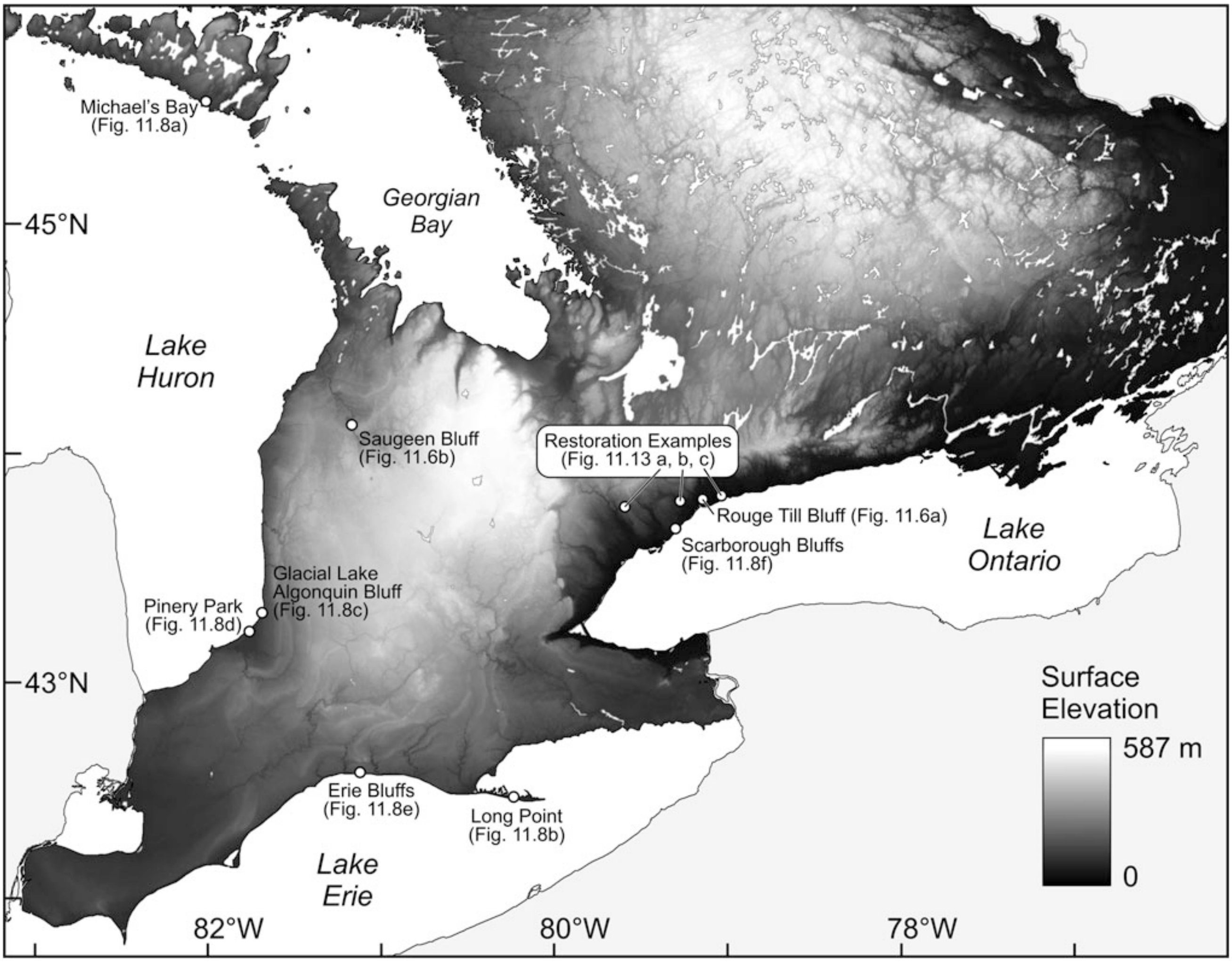

Fig. 11.14 Locations of images displayed in Figs. 11.6, 11.8 and 11.13

and sediment function (e.g. effective stream power; Vocal Ferencevic and Ashmore 2012). This has necessitated a highly active stream rehabilitation and restoration industry (Fig. 11.13; e.g. Wohl and Merritts 2007; Ashmore 2015). A prominent challenge to stream restoration and renaturalization in the region is existing infrastructure and therefore space constraints. Designed stream channels are often engineered within confined corridors, but with planning objectives that still expect flexibility for flood attenuation and aquatic habitat (Walsh et al. 2005). With these design challenges for restoring urban watercourses, projects often attempt to implement "hybrid" approaches that mimic stream functions with static features rather than restore dynamic fluvial processes that addresses sediment supply connectivity within the watershed (Cockburn et al. 2016; Thayer et al. 2016; Wohl et al. 2017). Sustainable long-term management policies for stream restoration are largely restrained by practical, social and economic limitations. Ecological restoration initiatives in the region tend to be most strongly driven by environmental regulations at multiple levels of government, including watershed conservation authorities, and provincial and federal agencies, under legislation for fisheries and endangered species habitat protection (e.g. Committee on the Status of Endangered Species in Canada (COSEWIC 2007)) (Fig. 11.14).

11.7 Conclusion

Geomorphic processes and surface landforms in the lower Great Lakes region have undergone significant change over a relatively short time in Earth's history (<25 ka). These changes have been accelerated substantially in an even shorter time span of less than 200 years. Predicting landscape response to regionally and globally influenced climate change in a context of significant human impacts on surface form will be a critical challenge for future geomorphic research in this region.

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Jackie Cockburn grew up in the interior of British Columbia, and before she even knew what they were, was fascinated by the glacilacustrine deposits in her backyard. It would all come together while completing her degrees at Queen's University, with the help of Bob Gilbert and Scott Lamoureux; the secret is in the sediments. The work at Queen's was focused on palaeoclimatology. Her interest in the complex story between water and sediment developed further with a keen lens to human modification within the landscape, focused on disruptions to sediment cascades (dams, landslides, agriculture). In 2011, she moved to the University of Guelph, and has continued the work started in the USA as well as working in areas closer to home. Her research interests are centred on understanding the impacts of environmental and climate changes on surface processes. Specifically, issues related to sediment mobilization, transport and deposition as a result of these changes. In addition to working with excellent colleagues in the Department of Geography, Environment and Geomatics at the University of Guelph, her research also involves environmental consultants at GEO Morphix Ltd in Milton, ON, in particular Paul Villard.