World Geomorphological Landscapes

Olav Slaymaker
Norm Catto *Editors*

Landscapes and Landforms of Eastern Canada

Springer

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Series Editor

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Series Editor Preface

Landforms and landscapes vary enormously across the Earth, from high mountains to endless plains. At a smaller scale, Nature often surprises us creating shapes that look improbable. Many physical landscapes are so immensely beautiful that they received the highest possible recognition—they hold the status of World Heritage properties. Apart from often being immensely scenic, landscapes tell stories which not uncommonly can be traced back in time for tens of million years and include unique events. In addition, many landscapes owe their appearance and harmony not solely to the natural forces. Since centuries, or even millennia, they have been shaped by humans who modified hillslopes, river courses, and coastlines, and erected structures which often blend with the natural landforms to form inseparable entities.

These landscapes are studied by Geomorphology—'the Science of Scenery'—a part of Earth Sciences that focuses on landforms, their assemblages, surface and subsurface processes that moulded them in the past and that change them today. Shapes of landforms and regularities of their spatial distribution, their origin, evolution and ages are the subject of research. Geomorphology is also a science of considerable practical importance since many geomorphic processes occur so suddenly and unexpectedly, and with such a force, that they pose significant hazards to human populations and not uncommonly result in considerable damage or even casualties.

To show the importance of geomorphology in understanding the landscape, and to present the beauty and diversity of the geomorphological sceneries across the world, we have launched a new book series *World Geomorphological Landscapes*. It aims to be a scientific library of monographs that present and explain physical landscapes, focusing on both representative and uniquely spectacular examples. Each book will contain details on geomorphology of a particular country or a geographically coherent region. This volume is the second among the two which show the geomorphology of the second largest country in the world—Canada. This one focuses on the eastern part of this enormous territory, which is often overshadowed by the majestic Rocky Mountains of the west and too hastily simplified to endless plains of the Laurentian Shield. How unjust such a view is, one will realize browsing through this book and reading its individual chapters. Not surprisingly, the theme of Quaternary glaciations features prominently as their impact can be demonstrated almost everywhere. But authors of specific stories included in the book show us much more: fascinating coastal sceneries, shaped in response to land and sea level change, permafrost-dominated tundra landscapes, big lakes, the legacy of long-term landform evolution which occurred at timescales much more protracted than glaciations, karst, devastating mass movements. In addition, various examples of interactions between humans and landforms are shown, in different cultural contexts.

The World Geomorphological Landscapes series is produced under the scientific patronage of the International Association of Geomorphologists—a society that brings together geomorphologists from all around the world. The IAG was established in 1989 and is an independent scientific association affiliated with the International Geographical Union and the International Union of Geological Sciences. Among its main aims are to promote geomorphology and to foster dissemination of geomorphological knowledge. I believe that this lavishly illustrated series, which sticks to the scientific rigour, is the most appropriate means to fulfil these aims and to serve the geoscientific community. To this end, my great thanks go to the Senior Editor, Professor Olav Slaymaker, Past President of the IAG, who enthusiastically responded to the invitation to coordinate both volumes, Western Canada that appeared a few years ago and now Eastern Canada, where he was joined by Professor Norm Catto as Co-Editor and assisted by Dr. Dori Kovanen. I am also grateful to all individual contributors who agreed to add the task of writing chapters to their busy agendas and delivered high-quality final products.

Piotr Migoń

Dedication

We dedicate this volume to the memory of Dr. Ian A. Brookes, former Professor of Geomorphology at York University, Toronto, who passed away in February 2015. Although Ian conducted geomorphological research in many parts of the world, much of his research, beginning with his M.Sc. in 1963, focused on the glacial geomorphology of Newfoundland. Ian's work generated much subsequent work throughout Western Newfoundland, as is evidenced by his co-authorship of Chap. 16 in this volume. His advocacy contributed to the development of research in Gros Morne National Park.

Ian's legacy to geomorphology includes scholarships in his name for undergraduate and graduate geographical field research offered through the Department of Geography, Memorial University of Newfoundland. Ian always considered undergraduate teaching as a core academic activity, blending his passion for geomorphology and his keen sense of social responsibility. His conviction that scientific investigation could never be completely separated from social and political concerns enlivened many of his discussions with colleagues, and finds an echo in the development of the concept of critical physical geography, as discussed in Chap. 26 of this volume.

From 1985 through 1993, Ian Brookes oversaw the publication of a succession of articles detailing 'Canadian Landform Examples' in *The Canadian Geographer*. These concise papers were used, and are still used, by geomorphologists across Canada and beyond to introduce students to the diversity of Canadian landforms and landscapes, several of which are examined in this volume.

—Norm Catto and Olav Slaymaker

Preface for Landscapes and Landforms of Eastern Canada

Olav Slaymaker first set foot on North American soil in Montréal in September, 1961, having set sail on the 'Empress of Canada' from Liverpool, UK 7 days earlier. The previous 2 days had been spent in Canadian waters, firstly skirting 'The Rock' of Newfoundland, then passing through the Gulf of St. Lawrence to the south of the karstic island of Anticosti, Québec, gradually getting squeezed into the estuary of the St. Lawrence River and finally docking at Montréal. Little could he guess that he was sailing past landscapes that would eventually be the subject of a co-edited book on Eastern Canada, almost 60 years later. The contrast between the steep Laurentian Highlands of the Canadian Shield backing the North Shore of the St. Lawrence River and the Gaspé Peninsula forming the gentler South Shore of a younger, folded Appalachian landscape was not lost on him. But the dominant impression was the extravagant welcome to North America provided by the majestic St. Lawrence River itself.

Norm Catto was born in Ottawa, on the Champlain Sea plain directly south of the Grenville front of the Gatineau Hills, in 1956. After spending time appreciating the landscapes of Central, Western and Northern Canada (and elsewhere), arrival in Newfoundland for the first time in 1989 provided a geomorphic and cultural contrast to everything that had gone before. After 30 years studying, publishing on and appreciating the landscapes of the seven provinces and territory discussed in our volume, there is still much to learn, from landscapes both majestic and subtle.

We continue to rely on a traditional definition of landscape as 'the total character of a region of the Earth's surface which includes landforms, vegetation (ecosystems) and fields and buildings (anthropogenically modified land)' (von Humboldt 1845). The landscapes and landforms of Eastern Canada form the subject of our volume, a companion to 'Landscapes and Landforms of Western Canada' (Slaymaker 2017). More than 5 million km^2 of Earth's terrestrial surface, including the provinces of Ontario, Québec, Newfoundland and Labrador, Nova Scotia, New Brunswick, Prince Edward Island, and northeastern Manitoba, and the territory of Nunavut are included. It is impossible to do justice to the varied individual landforms and landform assemblages of such a vast area, but we have endeavoured to provide at least an introduction to all the distinctive geomorphological landscapes of this region. Landscapes at this spatial scale are defined by (a) geological structure, (b) relief and (c) surrogates for geomorphic process. The presence or absence of meteorite craters, highly permeable lithologies, ice sheet cover at the Last Glacial Maximum, permafrost and vegetation are the surrogates for geomorphic process that are used in this volume.

The Canadian Shield contains some of the oldest rocks at the Earth's surface, up to 4 billion years old. However, there are no landscapes that have been preserved unchanged for such a long time. Indeed, only a tiny fraction of the rocks and landscapes that are visible today provides clues to the interpretation of palaeolandscapes older than a few hundred million years. Rocks that underlie the Canadian Shield have undergone numerous mountain building episodes, have been sutured along former plate collision zones and have experienced a series of erosion cycles. Today, such landscapes are topographically subdued and some have suggested that they are some of the most extensive planation surfaces that exist on the planet

(Ambrose 1964). However, they are certainly not featureless as many of the case studies in this volume demonstrate.

This volume is about landscapes that are larger than individual landforms and smaller than continental belts (Slaymaker et al. 2009). Landform assemblages of Eastern Canada that form distinctive landscapes include magnificent arctic fjords and glaciers; spectacular coastlines adjacent to the Arctic and Atlantic oceans; a high incidence of meteorite craters that have been preserved preferentially in the ancient Shield terrain of Québec; youthful, glaciated karst in Ontario, Newfoundland, Québec and Nova Scotia; urban karst in Montreal and Ottawa; wetlands of five subtly distinct varieties with an extent second only to those in Russia; the ubiquitous permafrost terrain (>3 million km^2) in Nunavut, Labrador and northern Québec; and the unique Great Lakes-St. Lawrence basin, that sustains one of North America's largest rivers, is co-managed by Canada and the USA and whose seaway allows modest-sized ships to penetrate into the heart of the continent. Eastern Canada also contains the cradle of the European settler society from which the present-day national governance structure has evolved. Complications that have arisen in relations between First Nations, Inuit, Metis and the more recent ′settlers′ have become so urgent in the past few decades that land use, land claims and land governance have become issues that are strongly colouring the landscape, both physical and cultural.

Part I (Chaps. 1–3) is a general overview of Eastern Canadian geomorphological landscapes in relation to geological structure, relief and dominant processes of change.

Part II (Chaps. 4–20) consists of case studies of outstanding representative landscapes from which original, field-based research is reported.

Part III (Chaps. 21–26) provides examples of human impact on, stewardship of, and human perceptions of Anthropocene landscapes in eastern Canada.

This book could not have been completed without the outstanding technical skills of Dori Kovanen, Research Associate in the Department of Geography at UBC. Eric Leinberger, Cartographer in the Department of Geography, UBC should also be acknowledged for emergency assistance. The Book Series Editor, Piotr Migon, provided valuable advice at all stages during the process of book preparation, and Robert Doe and Marielle Klijn of Springer Verlag were consistently supportive. The following expert reviewers gave freely of their time to ensure the scientific quality of the text: Tracy Brennand, Frank Brunton, Evan Edinger, Don Forbes, Derek Ford, Konrad Gajewski, Krister Jansson, Patrick Lajeunesse, Pascale Roy-Leveillee, Dave Liverman, Piotr Migon, Martin Roy, Martin Sharp, and Wendy Sladen. To all these colleagues we extend our warmest thanks.

Vancouver, Canada — Olav Slaymaker
St. John's, Canada — Norm Catto
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References

Ambrose JW (1964) Exhumed paleoplains of the Precambrian Shield of North America. Am J Sci 262: 817–857

Humboldt A von (1845) Kosmos: a sketch of a physical description of the universe (translated from the German by Otté EC), vol 1, Harper and Brothers, New York

Slaymaker O, Spencer T, Dadson S (2009) Landscape and landscape scale processes as the unfilled niche in the global environmental change debate: an introduction. In: Slaymaker O, Spencer T, Embleton-Hamann C (eds) Geomorphology and Global Environmental Change. Cambridge University Press, Cambridge, UK, pp 1–36

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About the Editors

Olav Slaymaker is a Member of the Order of Canada, and Professor Emeritus of geography in the Department of Geography at the University of British Columbia, Vancouver, B.C. His 20+ co-authored and edited monographs and 160+ refereed papers reflect three different styles of work. First, he has pursued original field research for 40 years on sediment systems in the Canadian Cordillera and the European Alps, strongly supported and enhanced by his stellar doctoral and postdoctoral students and international colleagues. Second, he has produced papers and books summarizing trends in land use and environmental change in mountain regions worldwide. Third, he has edited monographs with invited international contributions on major environmental and geomorphological themes. He is former President of the Canadian Association of Geographers and former President of the International Association of Geomorphologists.

Lead author of Chaps. 1, 3, 25 and 26.

Norm Catto joined Memorial University in July 1989 and is now the Head and Professor of Geography at that university. His research and teaching interests include coastal landforms, natural hazards, sea level change and impacts in coastal environments; response of river systems to climate and weather events, and flood risk assessment; aeolian geomorphology and response to climate and human factors in boreal and coastal environments; mass movements and slope failures; loess deposition; palaeosol formation; emergency measures policies and effectiveness of human adaptations to climate and weather events; the impacts of climate and weather events on agriculture, transportation, fisheries, and communities; and the relationships among landscapes and people. His research has included projects and investigations in landscapes and environments in 16 countries, and in all Canadian provinces and territories, particularly in Eastern Canada. For 18 years, he served as Editor-in-Chief for *Quaternary International*, a professional international journal dedicated to the study of landscape evolution and climate variation throughout the past 3 million years. He has taught more than 50 different undergraduate and graduate courses focused on numerous aspects of geomorphology, landscape analysis, Quaternary research, natural hazards, ocean sciences, environmental science, climate and climate change, soil science, geoarchaeology, and palaeontology. Study of landscapes forms his central focus for an understanding of the various areas of Eastern Canada, the combination of physical and cultural constituents that contribute to its identities. For most species, and for all human occupants, life in Eastern Canada has been heavily influenced by geomorphology since deglaciation.

Lead author of Chaps. 2, 7, 15, 18, and 21.

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Part I

Introduction to the Geomorphological Landscapes of Eastern Canada

1 Eastern Canadian Landscapes as a Function of Structure, Relief and Process

Olav Slaymaker, Norm Catto, and Dori J. Kovanen

Abstract

Eastern Canada's landscapes are investigated as a function of structure, relief and process. Eastern Canada can be divided into four roughly concentric megaregions whose boundaries are controlled exclusively by geological structure. These megaregions are (a) the Canadian Shield, which is the craton or core of North America; (b) the surrounding plains arranged in a broken ring around the Shield together with an inlier of similar lithology stratigraphically above the Shield; (c) a broken ring of two mountainous regions that surrounds the plains: Innuitia in the far north and Appalachia in the southeast; (d) two widely separated low-relief continental shelves and coastal plains of Quaternary sediments marginal to the Arctic and Atlantic oceans. These four megaregions are further subdivided into 29 subregions that are sensitive to variations in structure, relief and process. The most spectacular landscapes are arranged around the periphery of Eastern Canada: the magnificent glaciers and snow-capped mountains of the Arctic, the fascinating Atlantic coastline and the unique Great Lakes and St. Lawrence River basin.

Keywords

Landscape • Geological province • Physiographic region • Geomorphological region • Structure • Relief • Process

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1.1 A Word About Landscape

Given that landscapes and landforms are the phenomena of central interest in this volume, a few words about the word 'landscape' are in order. Landscape is a contested word linking the morphology of land with its longer geological past as well as with the man-made features that contribute to the roughness of Earth's boundary (von Humboldt 1845). Landscapes are often envisaged as analogous to palimpsests or medieval parchments on which texts of many different historical time periods are superimposed. Geomorphological landscapes incorporate the aggregate effects of past and present Earth surface processes, and at this point in time the challenge is for us to expose landscapes formed in the geological past; to interpret their relationship with contemporary landscapes and to be aware of the extent to which human activity has transformed Earth's boundary. Human activities have become an integral part of the way that geosystems function. In the context of Eastern Canada we can perhaps be permitted the broadest of generalizations by noting that human activity in its northern regions has left little mark on the morphology of the land, but indigenous people's place names demonstrate that the land is far from empty; by contrast, southeastern Canada has been modified by human activity to such an extent that pristine landscapes are hard to find.

In this chapter and Chap. 2, human impact is excluded from consideration for obvious reasons. But there is a role for humans that affects our understanding of these ancient landscapes, specifically in relation to place names in the Arctic. The term Inuit refers to a group of indigenous peoples of the circumpolar regions of Alaska, Canada and Greenland. The term is also used for the continuum of language varieties spoken by the Inuit people. Three of these languages spoken in Canada and Greenland, are referred to as Inuktitut. The last decade has seen the emergence of a stronger indigenous presence in Canadian place names (Tyman 2008; Inuit Heritage Trust 2015; Canadian

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Geographic 2018). This long-overdue acknowledgment of the reality of Canadian indigenous culture complicates place name recognition for English speaking readers, as indicated in a partial list of equivalences between English and Inuktitut names (Table 1.1).

This chapter and Chaps. 2, 3 and 21 deal with landscapes at four different spatial and temporal scales, namely, total geological time scale and very large spaces (chapter 1); Quaternary time scale and moderately large spaces (Chap. 2); Holocene time scale and smaller spaces (Chap. 3); and finally an Anthropocene scale and generally quite small spaces (Chap. 21). The latter chapter is needed to explore the role of human activity in landscape change.

At the largest spatial and longest temporal scales (this chapter), Eastern Canada can be divided into four roughly concentric regions that are controlled exclusively by geological structure. These regions are firstly the central Canadian Shield, which is the craton or core of North America (Stearn 1975). It is by far the oldest and largest of the regions and has a complex history. The shield was formed one to four billion years ago and consists of highly resistant crystalline rocks and planation surfaces. The surrounding stable platforms form a second region, which is characterized by flat-lying and gently sloping Palaeozoic and Mesozoic sedimentary rocks, arranged in a broken ring around the shield as well as an inlier of similar lithology on top of the shield around the margins of Hudson Bay. Thirdly, there is a broken ring of two relatively unstable mountainous regions that surrounds the plains: Innuitia in the north and Appalachia in the southeast. These Phanerozoic orogens consist of highly folded and faulted sedimentary and metamorphic rocks. Finally, there are two widely

Table 1.1 English place names and their Inuktitut equivalents. *Source* Inuit Heritage Trust (2015)

English Canadian names	Inuktitut names (roman type)	English Canadian names	Inuktitut names (roman type)
Arctic Bay	*Ikpiarjuk*	Makkovik	*Marruuvik*
Baffin Island	*Qikiqtaaluk*	Mealy Mountains	*KakKasuak*
Baker Lake	*Qamanituaq*	Melville Peninsula	*Sanirajak*
Bathurst Inlet	*Kingoak*	Meta Incognita Peninsula	*Katannilik*
Bathurst Island	*Qausuittuq*	Mount Asgard	*Sivanitirutinguak*
Belcher Islands	*Sanikiluaq*	Mount Thor	*Qaisualuk*
Boothia Peninsula	*Kingngailap Nunanga*	Nain	*Nunajnguk*
Broughton Island	*Qikiqtarjuaq*	Navy Board Inlet	*Nalluata imanga*
Cambridge Bay	*Iqaluktuuttiaq*	Nouveau Québec	*Nunavik*
Cape Chidley	*Killiniq*	Oliver Sound	*Kangiqluruluk*
Cape Dorset	*Kinngait*	Ottawa Islands	*Arviliit*
Chesterfield Inlet	*Igluigaarjuk*	Pelly Bay	*Kugaaruk*
Clyde River	*Kangiqtugaapik*	Pond Inlet	*Mittimatalik*
Coppermine	*Kugluktuk*	Poste-de-la-Baleine (Whale River)	*Kuujjuaraapik*
Coral Harbour	*Salliq*	Postville	*Qipuqqaq*
Devon Island	*Tatlurutit*	Prince of Wales Island	*Kingailik*
Eclipse Sound	*Tasiuja*	Rankin Inlet	*Kangiqtiniq*
Ellesmere Island	*Umingmak Nuna*	Repulse Bay	*Naujaat*
Gjoa Haven	*Usqsuqtuuq*	Resolute	*Qausuittuq*
Grise Fjord	*Ausuiktuq*	Rigolet	*Kikiak*
Hall Beach	*Sanirajak*	Schwartzenbach Falls	*Qulitasaniakvik*
Hopedale	*Aqvituq*	Somerset Island	*Shugliaq*
Bay Hudson	*Wînipekw*	Southampton Island	*Shugliaq*
Inoucdjouac (Port Harrison)	*Inukjuak*	Spence Bay	*Taloyoak*
Keewatin (part of)	*Kivalliq*	Ungava Bay	*Ungava kangiqluk*
King William Island	*Qikiqtaq*	Victoria Island	*Kitlineq*
Lancaster Sound	*Tallurutiup Timanga*	Wales Island	*Shartoo*

separated low-relief continental shelves and coastal plains of Quaternary sediments marginal to the Atlantic and Arctic oceans. They are the youngest and smallest of the four regions. At Quaternary scale (Chap. 2), the focus of interest is the role of ice sheets and location in relation to those expanding and contracting ice covers. Such features cut across the boundaries created by geological structure. At Holocene scale (Chap. 3), paraglacial processes (non-glacial processes conditioned by glaciation) are emphasized and the gradually increasing importance of human activity is traced. And finally at Anthropocene scale (Chap. 21) environmental change induced by direct and indirect human activity holds centre stage.

1.2 Structure, Relief and Process

1.2.1 The Geological Provinces of Eastern Canada

A geological province is defined as an extensive region characterized by rocks that are relatively homogeneous in type and age in comparison with neighbouring regions. Wheeler et al. (1996) identified 14 geological provinces in Eastern Canada (Fig. 1.1).

The geological assembly of Eastern Canada has resulted from the convergence, collision, and separation of distinctive continental and oceanic fragments at various times over the last four billion years. Canada's geological architecture is dominated by its central foundation—the Precambrian shield—the largest area of Archaean rocks (>2.5 billion years ago) in the world and containing its oldest rocks, dated at 4.0 billion years. The shield consists of several Archaean fragments comprising granitic rocks and gneiss surrounded by greenstone volcanic belts and broader tracts of sedimentary rocks. Orogenic belts between the Archaean fragments, such as those flanking the Superior Province or Slave Province, contain younger, Palaeoproterozoic (2.5–1.6 billion years ago) rocks representing continental, oceanic, and collisional deposits and exotic fragments. Although most of the Precambrian shield was consolidated by the end of Palaeoproterozoic time, its southeast portion (the Grenville Province) was stabilized about one billion years ago. The addition of Mesoproterozoic (1.6–1.0 billion years old) and older gneisses and granitic rocks in the Grenville orogenic belt thus completed the assembly of the Precambrian shield. Two younger deformed belts, mainly of Phanerozoic rocks (<545 million years old) surround the shield. The Appalachian belt, in the southeast, contains large tracts of continental and oceanic fragments that were attached to ancestral North America in early- and mid-Palaeozoic times, about 475 and 375 million years ago, respectively. By contrast, in the Innuitian belt in the Arctic Islands, only a small foreign fragment was attached in the mid-Palaeozoic about 400 million years ago. After these belts were deformed, they were superimposed by extensive less deformed basins dominated by sedimentary rocks in the Appalachian and Innuitian belts. Large parts of the Precambrian shield are covered by a thin veneer of undeformed sedimentary rocks which are mainly of early Palaeozoic age. Locally, where the Palaeozoic rocks are overlain by Cretaceous strata, they form basins, as in Hudson Bay, and fault-bounded troughs in and near Hudson Strait and north of Baffin Island, related to the rifting and opening of Labrador Sea and Baffin Bay. Crustal spreading and ocean opening, east of the passive eastern continental margin, ceased west of Greenland in the early Cenozoic, nearly 40 million years ago (Hodgson 1989), but still continues in the mid-Atlantic Ocean (Wheeler et al. 1996).

1.2.1.1 The Canadian Shield

The Canadian Shield includes seven geological provinces, namely, Bear, Churchill, Grenville, Nain, Slave, Southern and Superior (Fig. 1.1). Each geological province is distinguished by its unique internal structural trend and style of folding. Collectively, they are the Earth's most extensive area of exposed Archaean rock, covering >70% of Eastern Canada. Major rock types of the shield are intrusive and metamorphic (blue and mustard in Fig. 1.2) by contrast with the dominance of sedimentary rocks in the platforms and orogens (purple in Fig. 1.2).

This vast area of stable Precambrian rocks is largely the end product of many orogenies or mountain-building episodes that occurred prior to 500 million years ago. The scenery is uniform for great distances, nevertheless, within this large area there is considerable variety at local and regional scales. The exceptional uniformity of the shield landscape occurs because 80% of the surface of the shield is underlain by granitic gneissic rocks. The remaining 20% consists of folded and deformed metasediments and metavolcanics which produce ridge and valley scenery in southeastern Ontario and Québec, the Nouveau Québec Orogen, the Povungnituk Hills and the Belcher Islands (Sanikiluaq). In the Nouveau Québec Orogen glacial scouring of the landscape eroded remains of an ancient mountain chain that once extended from Ungava Bay almost as far south as the Gulf of St. Lawrence (now folded and faulted) (Fig. 1.3a).

Three major factors account for such variability of landscape as does exist: warping of an ancient land surface; major faulting both defining the edge of the shield and grabens within the shield; and regional joint patterns giving strong linear patterns (Fig. 1.4). In general, the north to northeastern sector of the shield is occupied by the mountains of southern Ellesmere Island, Devon Island, Baffin Island and Labrador. This is some of the most spectacular

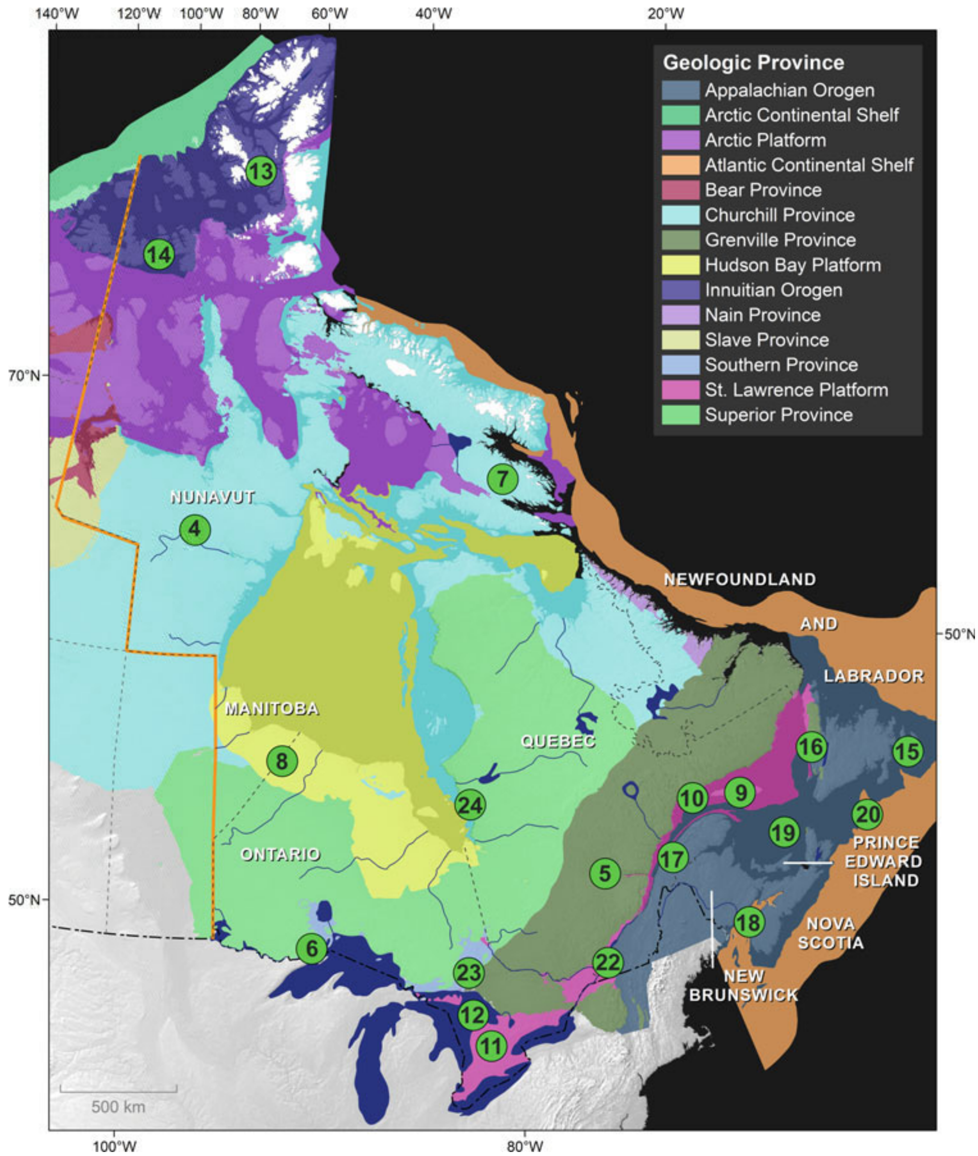

Fig. 1.1 The geological provinces of Eastern Canada (adapted from Wheeler et al. 1996). Numbers correspond to the chapters in which case studies are presented in this book. *4* Mainland Nunavut, Churchill Province; *5* Lake Saint-Jean Lowlands, Grenville Province; *6* Thunder Bay region, Superior Province; *7* Baffin, Labrador, and the Strait of Belle Isle, Churchill, Grenville, Nain provinces and Appalachian Orogen; *8* Hudson Bay Lowlands, Hudson Bay Platform; *9* Anticosti Island landscapes, St. Lawrence Platform; *10* North Shore, St. Lawrence River, St. Lawrence Platform; *11* Great Lakes Lowlands, St. Lawrence Platform; *12* Bruce Peninsula, St. Lawrence Platform; *13* Arctic Archipelago, Innuitian Orogen; *14* Melville, Bathurst and Cornwallis islands, Innuitian Orogen; *15* Avalon Peninsula, Appalachian Orogen; *16* Long Range Mountains, Appalachian Orogen; *17* Témiscouata-Madawaska Valley, Appalachian Orogen; *18* Atlantic coastlines, Appalachian Orogen; *19* Magdalen Islands landscapes, Atlantic Continental Shelf; *20* Submarine geomorphology, Atlantic Continental Shelf; *22* Urban caves in Montréal, St. Lawrence Platform; *23* Sudbury mining landscapes, Southern Province; *24* Wemindji Cree environment, Superior Province. Not shown are Chap. 1, 2, 3, 21, 25 and 26 that deal either with introductory or broad scale issues from more than one location. The orange line is the boundary between western and eastern Canada

scenery in Canada, with glaciers and 2,000 m cliffs rising almost vertically out of the sea. The southern margin of the shield is generally lower but along the north shore of the gulf and estuary of the St. Lawrence the shield rises to 1,000 m directly from the water. For a distance of nearly 1,500 km the edge of the shield is broken by deep valleys and gorges. Between Ottawa and Sault Ste. Marie, the edge of the shield dips gently under the younger sedimentary rocks and the general relief is moderate. Further west along the north shore of Lake Superior the edge of the shield is higher (La Berge 1994). However, in general the west and southwest edges of the shield are relatively low compared with the north and northeast. The scenery of the northern arctic boundary of the shield is rather different. Several fingers of Precambrian

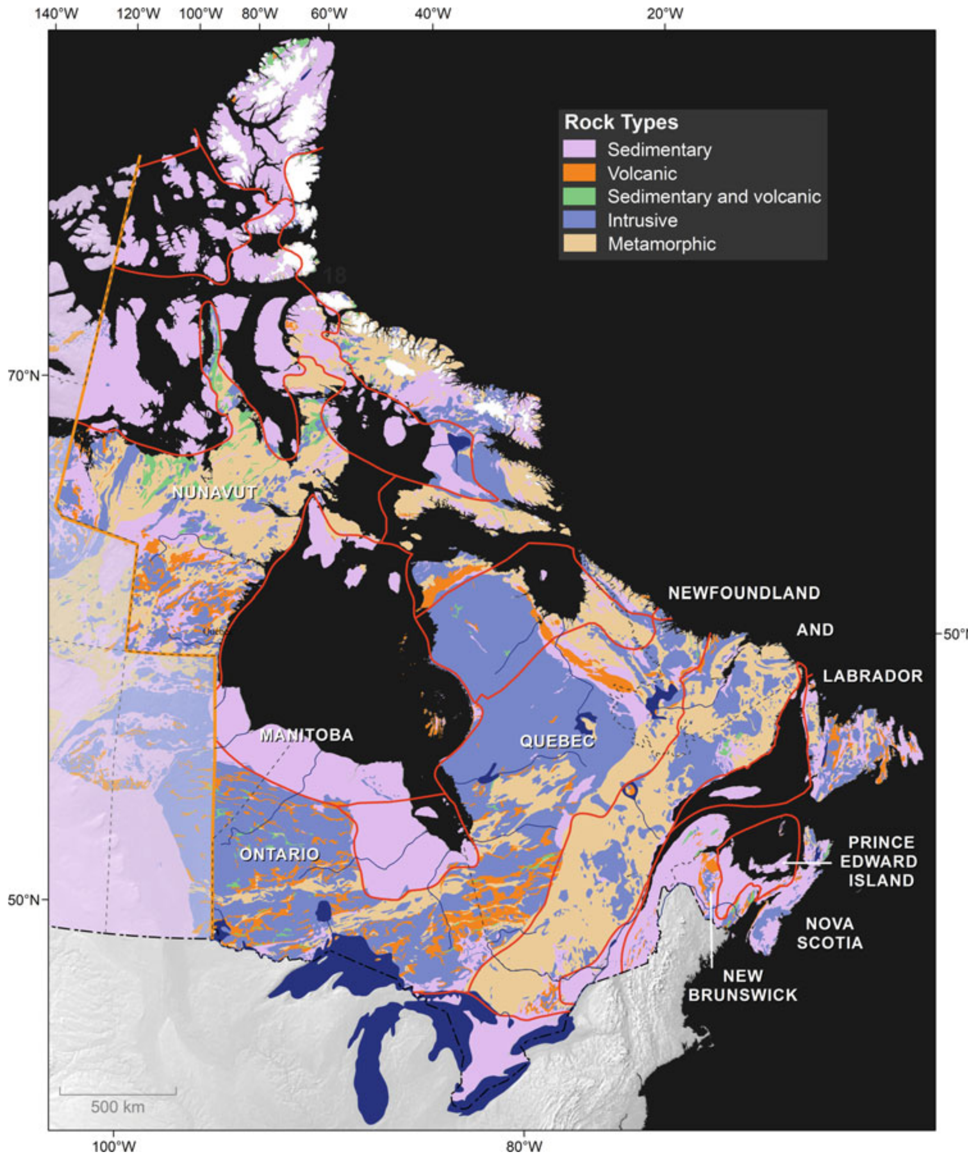

Fig. 1.2 Distribution of major rock types in Eastern Canada (after Wheeler et al. 1996). The red lines represent geomorphological landscape regions and the orange line is the boundary between western and Eastern Canada

rocks penetrate northwards into the arctic islands, making more variable scenery.

1.2.1.2 Platforms

The Arctic, Hudson, and St. Lawrence platforms are underlain by a basement of Precambrian shield rocks, overlain by beds of much younger, unmetamorphosed Palaeozoic and Proterozoic rocks. Sediments were deposited in shallow seas in the intervening areas between the shield and the mountains. Large areas of the interior of the Canadian Shield were depressed below sea level and marine sediments were deposited over parts of Québec, Ontario, Manitoba and NWT between 450 and 350 Ma. The Arctic Platform extends under the islands of the arctic archipelago, between the Innuitian Orogen and the Canadian Shield. The St. Lawrence Platform consists of three geographically disjunct parts separated by two southward extensions of the Canadian Shield. The Hudson Platform surrounds and extends beneath Hudson Bay (Tasiujarjuak).

1.2.1.3 Orogenic Belts

Orogenic belts are areas that have undergone relatively recent (post-Proterozoic) mountain-building episodes accompanied by volcanic eruptions and metamorphism. The rocks in these belts have also undergone folding (Fig. 1.3), faulting and uplift. Eastern Canada has two orogens, namely, Appalachia and Innuitia. Appalachia extends south of the St. Lawrence River, through the Atlantic Provinces. Innuitia extends from Ellesmere Island (Umingmak Nuna) through the Queen Elizabeth Islands in Nunavut and is underlain by highly deformed sedimentary, metamorphic and volcanic rocks.

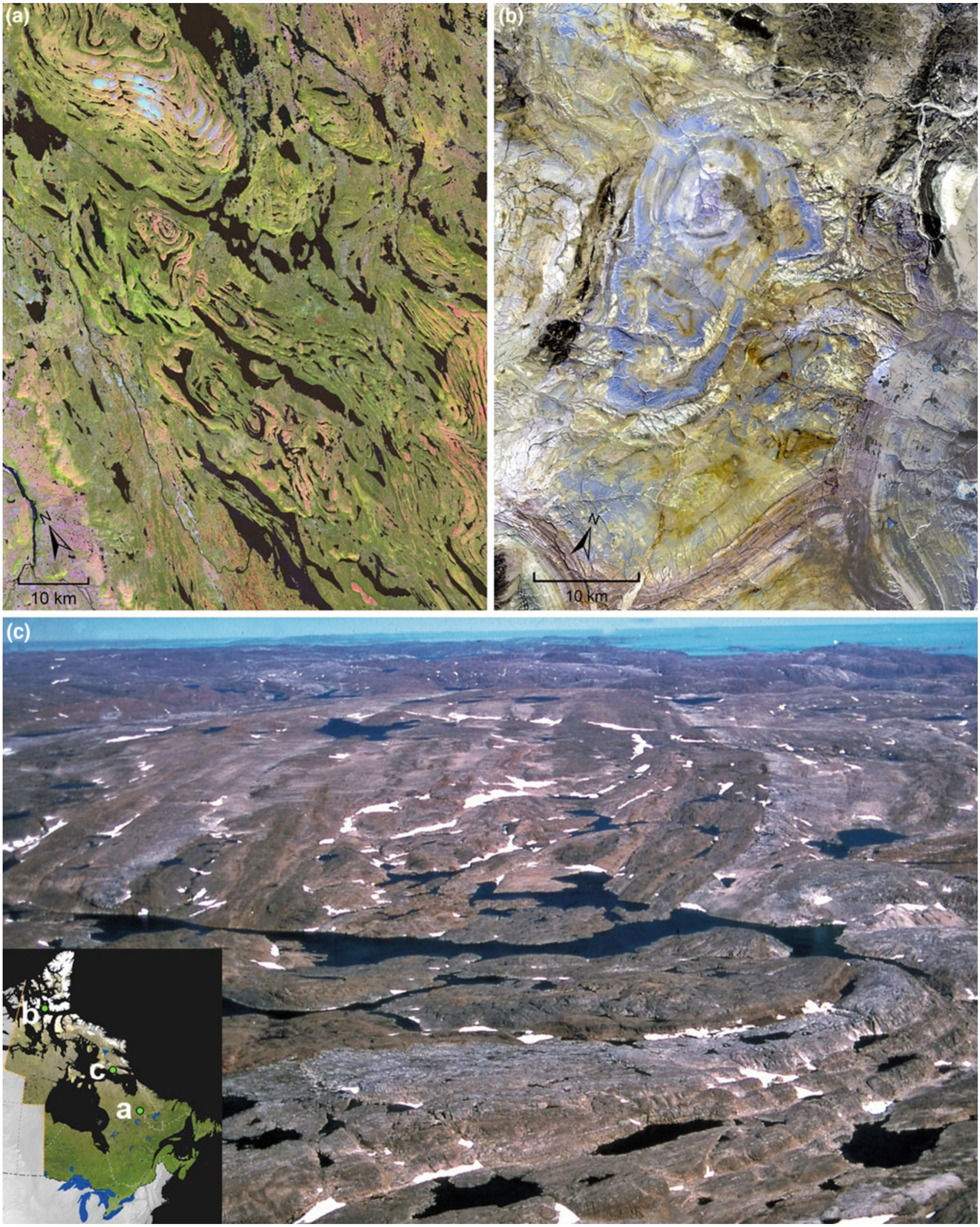

Fig. 1.3 Surface expression of folded Precambrian and Upper Devonian strata. Precambrian covers 'a' and 'c', but not 'b'. The Arctic Fold Belt in Innuitia, including Cornwallis Island, includes younger orogenies. **a** Complex folded rock layers that represent the Nouveau Québec Orogen, Québec. **b** Part of the Arctic Fold Belt, Innuitia, Cornwallis Island, Nunavut. **c** Folded mafic sill (dark) emplaced in psammite (light) of the Lake Harbour Group, Meta Incognita Peninsula, Baffin Island, Nunavut. *Source* a—Mosa_landsat_qc-2015-lcc-MFFP. b—Government of Canada; Natural Resources Canada (2007). Contains information licensed under the Open Government License—Canada. c—NRCan 2001-017 by M. R. St-Onge/Natural Resources Canada. Inset image here and elsewhere in this chapter is extracted from NASA Visible Earth (Stöckli et al. 2005)

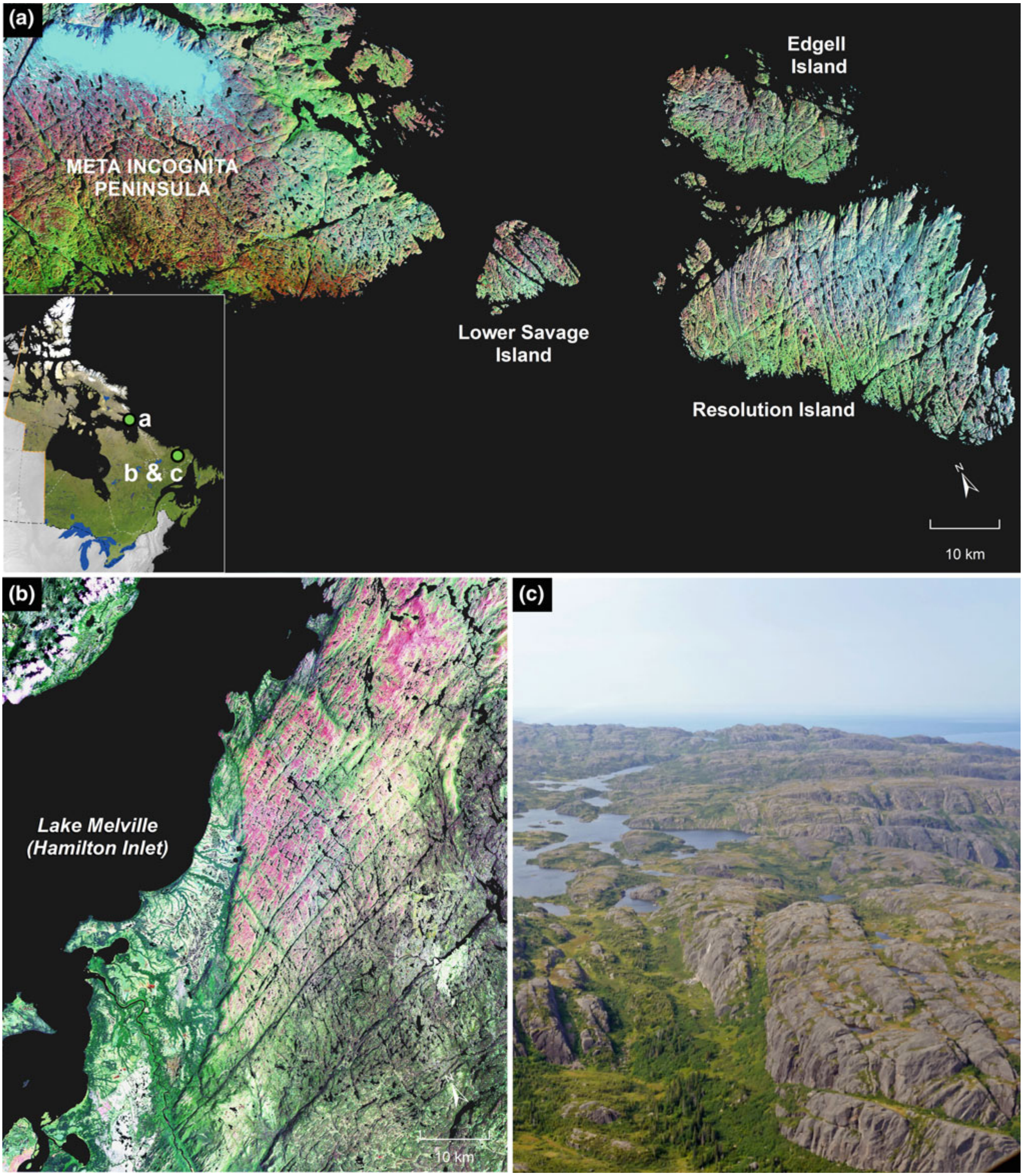

Fig. 1.4 Fractures and lineaments; long, straight, topographic alignments carved by erosion. **a** Meta Incognita (Katannilik) Peninsula, southern tip Baffin Island, Nunavut. **b** Happy Valley-Goose Bay, Labrador. The rugged terrain of the Mealy Mountains is visible in the right third of the image. The Churchill River flows into Lake Melville, lower left. **c** Mealy Mountains, Labrador. Locations are shown in the inset image. *Source* a and b—MDA Federal (2004). c—P. Gierszewsk/Wikimedia Commons, CC BY-SA 4.0

1.2.1.4 Continental Shelves

The Arctic and Atlantic continental shelves are two geological provinces that extend below the Arctic and Atlantic oceans and have experienced multiple cycles of sedimentation and erosion during the glacial and interglacial cycles of the past 2.59 million years.

1.3 Physiography

Physiographic subdivision of Canada is based on a system summarized by Bostock (1970, 2014; see also Graf 1987; Fulton 1989). Eastern Canada has been divided into eight physiographic regions. Whereas the geological provinces are defined by structure and lithology alone, the physiographic regions are defined by structure, lithology and relief and do not extend to submarine areas as shown in Fig. 1.5. These are Canadian Shield, Arctic, Hudson Bay and St. Lawrence lowlands, Innuitia, Appalachia, Arctic Coastal, and Maritime plains.

1.3.1 Canadian Shield

Seventy percent of Eastern Canada is underlain by the Canadian Shield. The present surface of that shield appears to be an exhumed pre-Palaeozoic erosion surface. The shield was eroded and the valley system cut into the bedrock before the Palaeozoic. The Precambrian surface has been little changed since the removal of the Palaeozoic cover, and glaciation has only superficially modified it (Ambrose 1964). The sequence of events envisaged is that first there was the development and partial dissection of an erosion surface on the Archaean rocks in pre-Proterozoic time, then the burial and exhumation of this surface once or perhaps twice during the Proterozoic, followed by the exhuming of these several surfaces from beneath the cover of Palaeozoic strata, and finally the scouring of the surface during the surges of Pleistocene glaciation (see Chap. 2).

During the evolution of the Canadian Shield, many cycles of erosion and sedimentation reduced generations of mountain ranges to low relief such that the direct control of

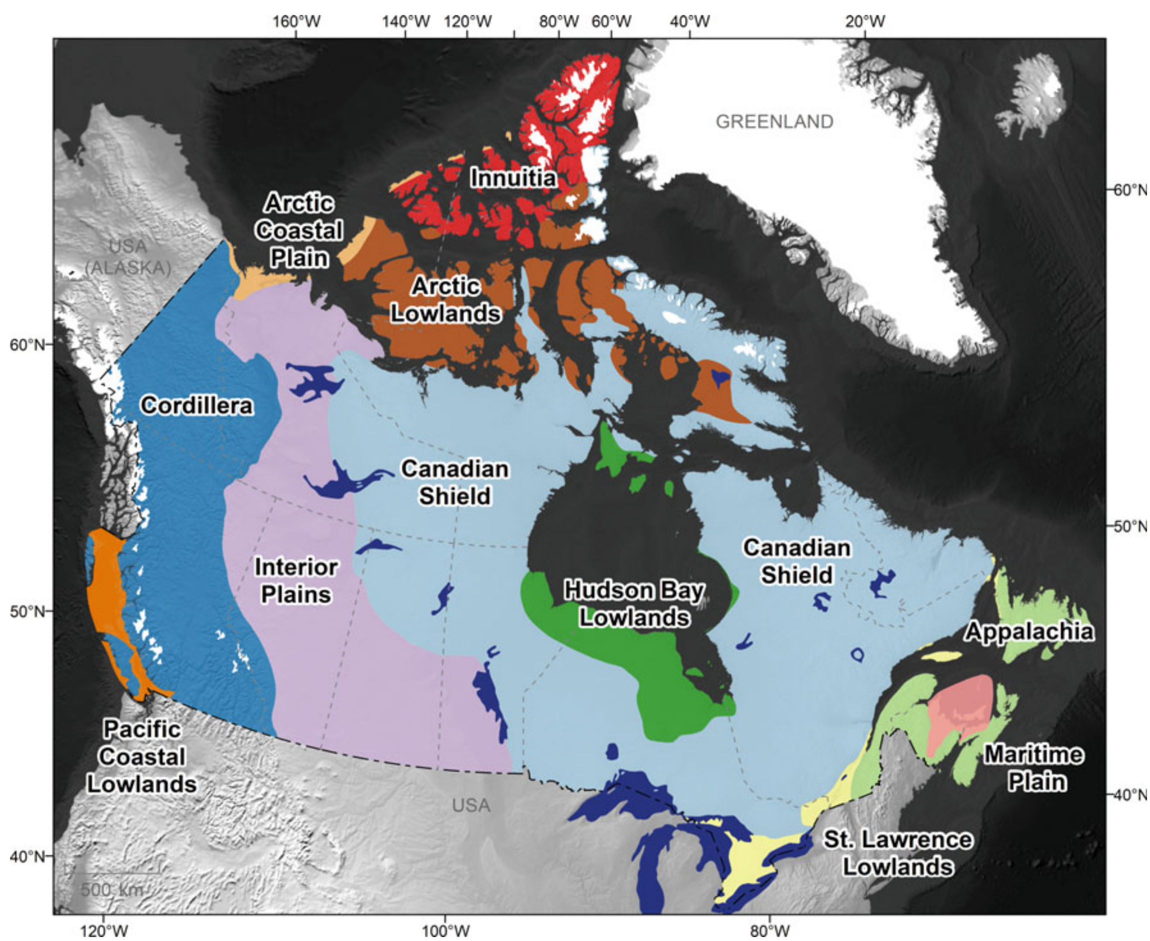

Fig. 1.5 Physiographic regions of Canada (adapted from Bostock 2014)

lithology on these landforms and landscapes is rarely seen. Over the greater part of the shield local relief is less than 100 m. In spite of its overall low relief, a number of different terrains can be identified in the shield. Plains have formed on areas of unmetamorphosed rocks, more or less flat lying, such as the sandstone and conglomerate terrains of the Cobalt Plain, Ontario, and the terrain of flat-lying gabbro sills of Nipigon Plain, northwestern Ontario. Low to moderate relief hills are associated with low grade metamorphic rocks and generally tilted or gently folded sediments or sills such as the Port Arthur, Penokean and Labrador hills (Ontario and Québec). Moderate to high relief uplands are present in the Laurentian Highlands, Québec. High relief mountains are associated with particularly resistant massive rocks, such as the anorthosites of the Mealy Mountains of Labrador and stand high above the surrounding terrain. Highlands formed of broad uplifted areas of deeply incised massive crystalline rocks characterize the Torngat Mountains and glacier-capped Baffin Island, where the greatest relief of up to 1,800 m is found.

1.3.2 Lowlands

Fourteen percent of Eastern Canada comprises lowlands and plateaus: Arctic, Hudson Bay and Great Lakes-St. Lawrence lowlands.

1.3.2.1 Arctic Lowlands

These lowlands are formed on the flat lying or nearly flat Palaeozoic and late-Proterozoic sedimentary rocks, lying between the Canadian Shield and the Innuitian Orogen.

1.3.2.2 Hudson Bay Lowland

The Hudson Bay Lowland is a low, swampy, marshy plain with subdued glacial features and a belt of raised beaches that border the bay. Palaeozoic strata mantle the massive or stratified Precambrian rocks and slope gently northeastward and eastward into Hudson and James bays.

1.3.2.3 Great Lakes-St. Lawrence Lowlands

These lowlands border the Canadian Shield on the southeast, extending from the west end of Lake Huron and the head of Lake Erie northeasterly to the Strait of Belle Isle. Three separate parts can be distinguished: (a) The Gulf of St. Lawrence, that includes Anticosti Island, the Mingan Islands, and several small areas bordering the Gulf of St. Lawrence, the Strait of Belle Isle, and western Newfoundland (see Fig. 9.1). Most of the area is lower than 100 m asl; (b) The St. Lawrence-Ottawa Valley subregion which straddles the St. Lawrence River from Pembroke to Québec City. The land is rarely higher than 150 m asl, except for the Monteregian Hills formed of intrusive igneous rocks; and (c) The Great Lakes Lowland subregion, which has at its centre the Niagara Escarpment cuesta that varies in elevation from 200 m asl at Niagara Falls in the southeast to 500 m asl at Manitoulin Island in the northwest.

1.3.3 Mountains

Sixteen percent of eastern Canada is underlain by the hilly to mountainous areas of Innuitia and Appalachia-Acadia. They are the sites of two great geosynclines, the Franklinian and Appalachian-Acadian geosynclines where orogenesis occurred during the Palaeozoic and Mesozoic eras. The sedimentary rocks are highly folded and faulted with a dominant southwest to northeast strike, locally becoming north-northeasterly.

1.3.3.1 Innuitia

The highest summits of northwest Ellesmere Island and central and western Axel Heiberg Island reach 2,500 m asl and are nearly buried by ice caps with projecting nunataks. Northeastern Ellesmere Island is a second major mountain belt. Eureka Upland extends the length of Innuitia from northeastern Ellesmere Island to the west end of the Parry Islands and is developed on Palaeozoic carbonates, shales and sandstones. Altitudes in this upland are generally less than 1,000 m asl. Low dissected plateaus and gently rolling low uplands have developed on soft late Mesozoic and Palaeogene sandstone and shale.

1.3.3.2 Appalachia

Appalachia consists of three subregions in Newfoundland, Québec and Nova Scotia/New Brunswick. (a) a Newfoundland subregion consists of highlands, up to 850 m asl; uplands between 200 and 300 m asl; and central lowlands extending from sea level to 150 m asl.; (b) a Québec subregion, which includes the Notre Dame Mountains, exceeding 1,200 m asl, the Sutton Mountains that reach 1,000 m asl, and a variety of hills and uplands that reach about 300 m asl; and (c) a Nova Scotia and New Brunswick subregion, consisting of alternating uplands and highlands along the Bay of Fundy to Cape Breton Island to the northeast.

1.3.4 Plains

1.3.4.1 Arctic Coastal Plain

The Arctic Coastal Plain is remarkably flat and uniform. Included are parts of Meighen Island, Ellef Ringnes Island, and Borden Island.

1.3.4.2 Atlantic Maritime Plain

The Atlantic Maritime Plain stretches along the coast of New Brunswick and Nova Scotia from Chaleur Bay to Cape George. It includes Prince Edward Island and the Magdalen Islands.

1.4 Permafrost and Vegetation Cover as Geomorphic Drivers

Much of the 'big picture' landscape regions can be defined in terms of structure and relief. But some account of process is also necessary in order to incorporate a sense of the dynamism of geomorphological landscapes. At the macro-scale we have to look to surrogates for agents of change. We have chosen two such surrogates, namely, presence or absence of vegetation and permafrost, when considering the geomorphological landscape regions of Eastern Canada. Subaerial geomorphic processes, which will be considered more fully in Chap. 3, are greatly influenced by presence/absence and type of vegetation cover. There is also a delicate interplay of vegetation and permafrost which strongly influences the sensitivity and resilience of individual landscape regions to environmental change. Hence the need to define geomorphological landscape regions taking into account ecozones and permafrost zones.

1.4.1 Permafrost

Permafrost is a thermal condition defined as 'ground that remains below 0 °C for two successive summers or longer'. The thermal condition of the ground should be known in order to identify accurately the presence of permafrost. Unfortunately, the thermal condition of the ground is not widely monitored, and surrogate parameters commonly have to be employed. A further problem is that the nature of the materials in the ground (whether massive ground ice, inter-particulate ice, bedrock or snow) has substantial influence on the thermal condition of the ground. This means that there is no simple formula to predict the presence or absence of permafrost. The whole of Nunavut and substantial portions of Labrador and northern Québec are underlain by continuous permafrost. The most serious effects of recent climate change leading to landscape instability are, in general, found in the discontinuous permafrost zones, where the ground is closer to melting and/or thawing. But engineering in the continuous permafrost zone presents its own distinctive challenges.

Four permafrost regions are commonly recognized in Canada (Fig. 1.6). The regions are defined by the proportion of the landscape that is underlain by permafrost.

1.4.1.1 Continuous Permafrost

Continuous permafrost is defined as a region where >90% of the land is underlain by permafrost (Smith et al. 2001). All of Nunavut, Nunavik (Ungava, Québec), the Torngat Mountains (Labrador) and a coastal strip on the western side of Hudson Bay are the areas of eastern Canada that are included.

1.4.1.2 Extensive Discontinuous Permafrost

Extensive discontinuous permafrost is defined as a region where 50–90% of the land is underlain by permafrost. A narrow strip of land south of Ungava, the Torngat Mountains and the Hudson Bay continuous permafrost zone is included.

1.4.1.3 Sporadic Discontinuous Permafrost

Sporadic discontinuous permafrost is defined as a region where 10–50% of the land is underlain by permafrost. Northern Québec, northern Ontario and northeastern Manitoba are included.

1.4.1.4 Isolated Patches of Permafrost

Isolated patches of permafrost are defined as regions where <10% of the land is underlain by permafrost. Such patches are common in central Québec, the Chic-Choc Mountains of Gaspésie, southern Labrador, the Great Northern Peninsula of Newfoundland and a thin strip of northern Ontario (Fig. 1.6).

Geomorphological landscapes with permafrost are radically different in terms of response to changing climate from those that have no permafrost. They display different landforms (discussed in Chap. 3) and experience different processes of change simply because of the presence of permafrost.

1.4.2 Ecozones

A terrestrial ecozone map is presented in Fig. 1.7. In this map, Southern and Northern Arctic ecozones are not differentiated. The importance of ecozones, especially the distinction between arctic and alpine tundra and the forested ecozones, is primarily in terms of the associated processes of landscape change.

1.4.2.1 Arctic Cordillera, Northern Arctic and Southern Arctic Ecozones

The Arctic Cordillera Ecozone consists of glaciers and ice caps, marked by extreme cold, and high winds. The regolith is thin and plants are scarce. Frost-shattered materials in soils are characteristic. At lower elevation, tundra meadows are present, dotted with arctic flowers and prostrate or stunted shrubs.

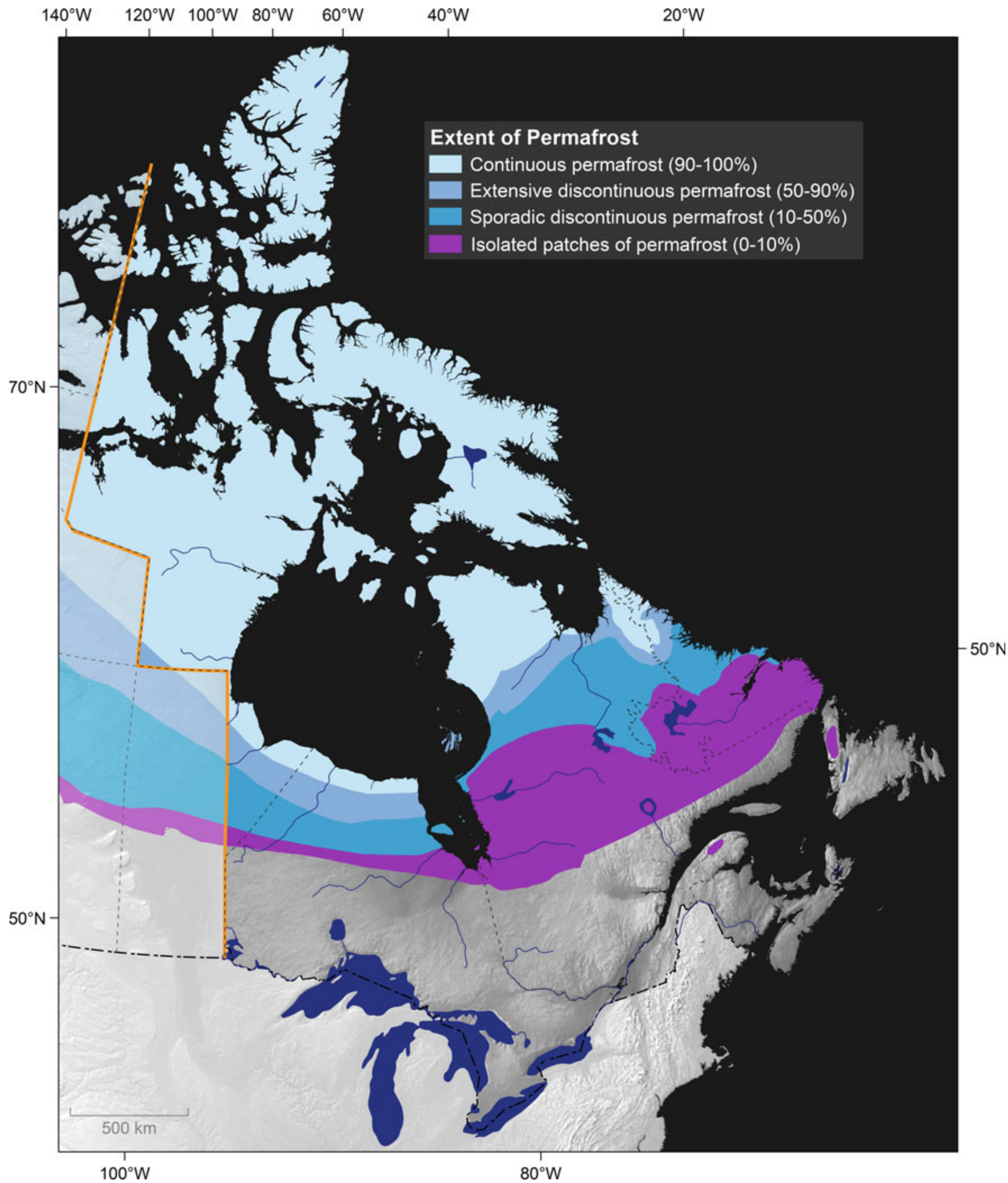

Fig. 1.6 Distribution and extent of permafrost in Eastern Canada (adapted from Smith et al. 2001; Government of Canada 2008). % in legend refers to percentage of land underlain by permafrost

The Northern Arctic Ecozone includes most of the non-mountainous areas of the arctic islands, western Baffin Island, and northern Québec (Nunavik). When not covered in snow, it is typified by barren plains covered by frost-controlled patterned ground and scattered rock outcrops. Moss and lichens are abundant. *Salix arctica* (Dwarf Arctic willow) and prostrate and cushion plants or mats are characteristic. The Southern Arctic Ecozone contains shrublands, wet sedge meadows and other wetlands (Zoltai 1988). Superimposed are the patterned ground, and frost-controlled soils. It is known as the barren lands and demarcates the northern limit of treeline (Bliss et al. 1981).

Baffin Island comprises Arctic Cordillera and Northern Arctic ecozones, all of which lie within the continuous permafrost zone. There are two distinctive vegetation communities that characterize the inland flanks of the mountains:

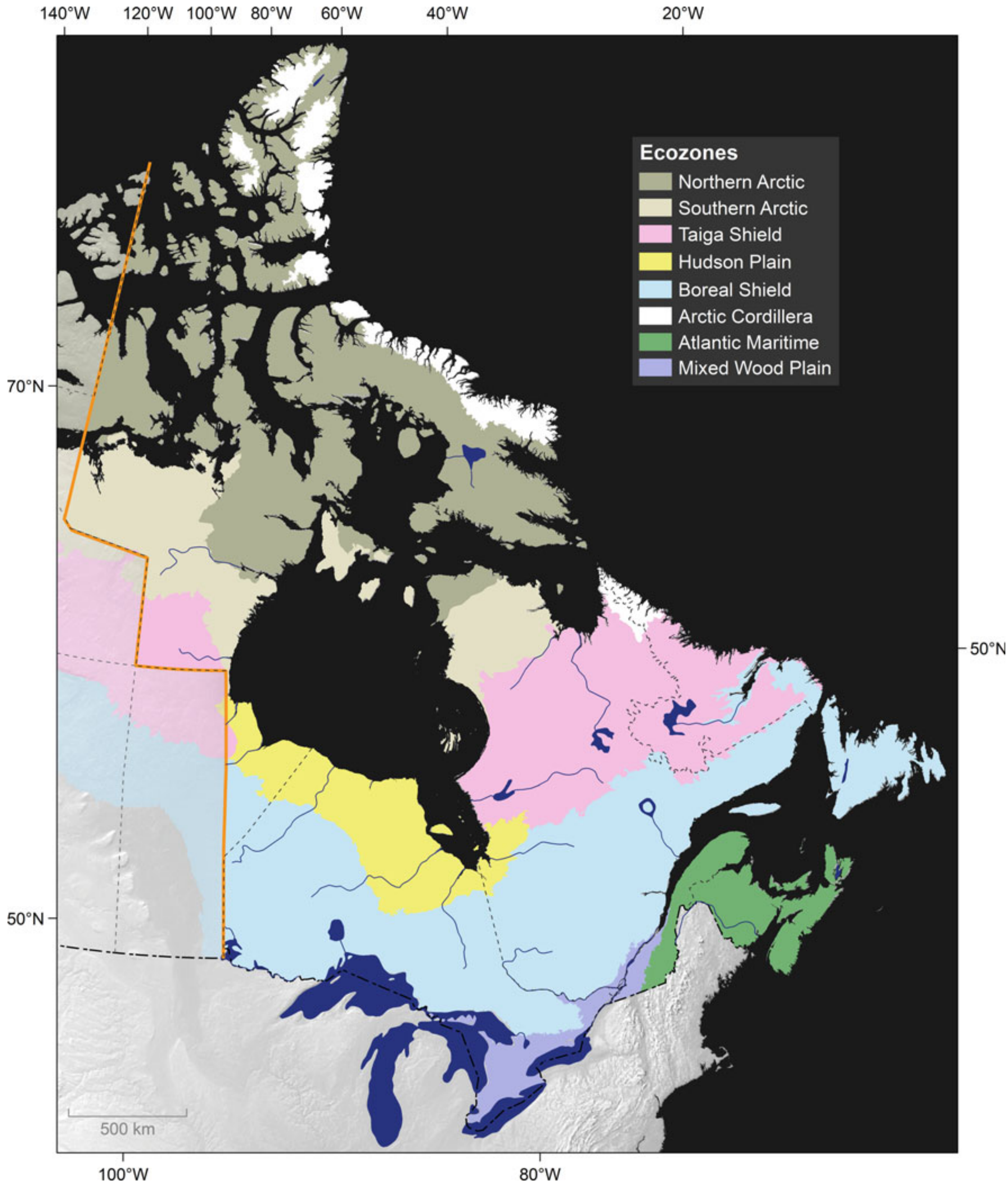

Fig. 1.7 Terrestrial Ecozones of eastern Canada (derived from Environment Canada 1995)

fell-field and tundra. Fell-field assemblages develop in areas where frost heaving has disturbed the surface of the land, producing areas of shattered and thrusted felsenmeer, and areas of cryogenic hummocks developed in Quaternary sediment. The most noticeable plants are *Silene* (campion) and *Papaver nudicale* (arctic poppy), along with scattered lichens and bryophytes. Poorly developed regosols and turbic cryosols are present. Tundra communities are commonly encountered throughout Auyuittuq National Park below approximately 1500 m asl, and in Sirmilik National Park below 1000 m asl. Woody shrubs include *Salix* (willow), *Betula glandulosa* (dwarf birch), and *Betula nana* (arctic birch), all of which commonly do not exceed 60 cm in height but may survive more than 100 years. *Salix* leaves were important supplements to the traditional Inuit diet, as they are rich in Vitamin C. Although *Salix* and *Betula glandulosa* are common in the low- and mid-arctic, in Canada *Betula nana* is confined to Baffin Island. Many of the tundra plants are edible, and some are of great medicinal value, especially sorrel, which prevents scurvy and was known to European visitors as 'arctic salad'.

1.4.2.2 Taiga Shield, Boreal Shield and Hudson Plains Ecozones

The open stunted forests of the Taiga Shield Zone are dominated by *Picea mariana* (black spruce) and *Pinus banksiana* (jack pine), innumerable bogs and wetlands (Halsey et al. 1997), scattered stands of *Betula papyrifera* (paper birch) and *Populus tremuloides* (trembling aspen), lichens and ground-hugging shrubs (Table 1.2). 'Drunken forests' emphasize the role of permafrost gradual subsidence on fringes of bogs as opposed to central heave. The Hudson Plains Ecozone, which lies mostly in Ontario, Manitoba and Québec, is where the boreal forests and the tundra merge and vegetation resembles that of the arctic tundra. Treeless areas extend about 30 km from the coast but stands of trees can penetrate further north in sheltered sites. Vegetation includes willow shrubs and tussocks of sedges, including *Eriophorum* (cottongrass). The Boreal Shield Ecozone largely corresponds with the Canadian Shield between Newfoundland and Alberta. *Picea mariana*, *Picea glauca* and *Abies balsamea* (balsam fir) are the dominant species, and wetlands are also common. In its southern regions, larger wetlands have been converted to cranberry and blueberry farms.

1.4.2.3 Mixed Wood Plains and Atlantic Maritime Ecozones

These southernmost ecozones were largely deciduous forests before the arrival of European settlers. The Mixed Wood Plains Ecozone lies adjacent to the St. Lawrence River and the Great Lakes and has fertile soils that are agriculturally highly productive. Very little of the original forest (*Pinus strobus* (eastern white pine), *Tsuga Canadensis* (eastern hemlock), *Betula alleghaniensis* (yellow birch) and *Pinus resinosa* (red pine) remains today, and farms, woodlots, urban forests and protected areas have taken their place. The Atlantic Maritime Ecozone contains mixed wood Acadian forests, sand dunes, and coastal islands. There are few pockets of old growth forest, as centuries of forestry, agriculture and natural disturbance have produced dominantly secondary and tertiary growth.

1.4.3 The Significance of Arctic Treeline and Alpine Timberline

The distribution of the ecozones of Eastern Canada (Fig. 1.7) provides a sense of the north-south gradation of vegetation. At local scale, however, the presence of the arctic treeline or the alpine timberline can be of greater significance than the north-south gradation of vegetation.

1.4.3.1 Arctic Treeline

The arctic treeline in Eastern Canada can be divided into two parts (Hare and Ritchie 1972). The northern of these is the 'forest tundra zone' consisting of scattered patches of stunted trees set in a matrix of tundra. The forest tundra zone extends across northern Québec from the Hudson Bay coast to the Atlantic Ocean where it is largely cut off by the coastal tundra of the Torngat Mountains. The lichen woodland zone extends south from the arctic tree line to the open boreal forest or 'lichen woodland'. The proportion of trees to lichen mat gradually increases southward towards the forest line where trees cover >50% of the landscape (Larsen 1980). East of Hudson and James bays, the ground lichens often make up the most conspicuous understory vegetation near forest line. The open boreal forest or lichen woodland is a very extensive zone in Québec and central Labrador. At its northern extreme, long stringers of lichen woodland stretch north along the major rivers, while intervening uplands are entirely without trees. Farther south in the main lichen woodland, *Picea mariana*, *Picea glauca*, *Larix laricina* (tamarack), and *Abies balsamea* stand several metres apart in a sea of lichens. A muskeg of stunted *Picea mariana*, *Rhododendron groenlandicum* (Labrador tea) and sphagnum covers the intervening wet sites. The boreal forest zone consists of closed crown conifer forests with a conspicuous deciduous element (Ritchie 1987). The proportions of the dominant conifers *Picea glauca*, *Picea mariana*, *Pinus banksiana*, *Larix laricina* and *Abies balsamea* vary greatly in response to climate, topography, soil, fire and pests.

1.4.3.2 Alpine Timberline

In the highlands of southern Labrador and eastern Québec, there is an alpine timberline at around 1,000 m asl, upslope from the open boreal forest. In southeastern Québec, the Laurentians have some 1,000 m asl peaks that also have treeline communities. In the Long Range Mountains of Newfoundland and the Cape Breton Highlands, *Picea mariana*, *Picea glauca* and *Abies balsamea* form a dense krummholz called 'tuckamore' at about 600 m asl. Although the highest summit in the Cape Breton Highlands reaches barely 500 m asl, several of the ridge tops are covered with caribou lichen. The Notre Dame Mountains extend along the Gaspé Peninsula, with a dozen peaks above 900 m asl.

Geomorphological landscapes above timberline or north of the treeline are radically different in terms of response to changing climate than those that have forest cover. They