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Introduction

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Geomorphology has a distinguished history in Canada, as old as the country itself. Initially, the science of geomorphology of Canada drew on rich British and French scientific traditions, but later it developed its own character, strongly influenced by the richness and diversity of the Canadian landscape, the strong imprint of glaciation, and the importance of periglacial processes, permafrost, and sea ice.

Canada is the second largest country in the world. Its coastline is longer and more varied than that of any other country. Nearly one-third of Canada is underlain by permafrost, some up to 700 m thick. The country's physiography ranges from nearly flat coastal and interior plains to the glacierised mountains of Baffin and Ellesmere Islands, British Columbia, and the Yukon. Its climate and vegetation are equally diverse, ranging from the cold semiarid tundra of the high Arctic to the temperate rainforest of the Pacific coast. Given this diversity, it is not surprising that Canada is active in many areas of geomorphic research. An incredible spectrum of landforms and geomorphic processes has fostered world-class research in Canada, both by Canadians and by scientists from other countries. Much of this research is field-based and empirical, rooted in field observation. In recent decades, however, there have been important advances in inductive, laboratory and field experiment-based research, which have greatly broadened the contribution that Canadian geomorphologists are making to the science. Geomorphic research in Canada has both basic and applied elements, although the distinction between the two has become increasingly blurred in a science that is so inherently practical. This is particularly true in Canada, where the landscape, the heritage of Pleistocene glaciation, and geomorphic processes have profoundly influenced the country's development and continue to affect people's lives.

This issue of *Geomorphology* is a sampler of Canada's recent and continuing research in geomorphology. It is not encyclopaedic; space limitations preclude coverage of all fields in which Canadians are active contributors. Rather, it includes a selection of contributions in fields in which Canadians have been leaders. Each of the nine papers is written by a leading Canadian geomorphologist. Some of the papers are reviews, others present results of recent research. They are organised in the following temporal sequence:

1. Tertiary landform evolution (Bouchard and Jolicoeur)
2. Quaternary landforms and sedimentation (Hickson, Brennand, Gilbert)
3. Late-glacial and postglacial crustal processes and landform evolution (Dyke and Peltier, Hétu and Gray)

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4. The Little Ice Age (Luckman)
5. Contemporary hillslope and fluvial erosion (Bryan and Buffin-Belanger et al.)

Below, we briefly discuss these papers in the context of their contributions to Canadian geomorphology.

1. Chemical weathering studies in southeastern Canada

Mireille Bouchard and Serge Jolicoeur direct our attention to three kinds of studies that have a bearing on long-term chemical denudation in southeastern Canada: (1) formation of bedrock morphology by chemical weathering; (2) occurrences, characteristics, and age of saprolites; and (3) contemporary chemical denudation rates. There is a tradition, going back to McConnell (1891) and Chalmers (1898), of interpretation of the long-term evolution of Canadian landscapes. These studies appeal to the role of chemical weathering in producing the differential erosion of different lithologies. Parry (1963), Ambrose (1964), and Ritchot (1964) provide more recent illustrations of this approach in the context of Canadian landscapes. Nevertheless, the prevailing assumption among Canadian geomorphologists has been that glaciation, periglaciation, and paraglaciation have destroyed so much of the evidence of preglacial landscapes that higher priority attaches to sorting out the landform implications of these latter processes. Similar assumptions were held in Europe prior to the work of Godard (1965).

Bouchard and her colleagues have reintroduced to Canadian geomorphology a serious focus on preglacial landscapes. They have studied pockets of deeply weathered material that have survived the effects of glaciation (saprolites) (Bouchard et al., 1995) and have used a geochemical mass balance approach to provide a check on rates of breakdown of bedrock by chemical weathering processes under present conditions (Bouchard, 1983). Although this work has raised many new questions that remain unresolved, it has reminded Canadian geomorphologists of: (1) the reality of the presence of saprolites in the landscape, at least in one region of Canada; (2) the necessity of research into their characteristics; (3) the importance of assessing the environmental conditions under which they formed; and (4) how those conditions compare with those of the contemporary environment.

One of the reasons for the relative neglect of studies of the geomorphological significance of saprolites and the infrequent appeal by Canadian geomorphologists to geochemical mass balance studies relates to the comparatively small emphasis on chemistry in comparison to physics in the traditional geomorphological curriculum. The geophysical behaviour of ice, rocks, and sediments has been privileged over the biogeochemical processes. In this collection of papers, Luckman and Bryan provide some correction to this emphasis; but it is only in the work of Bouchard that we see the central importance of biogeochemistry and, incidentally, the value of biogeochemistry in linking geomorphology with other environmental sciences.

2. Subglacial volcanism

Pioneering work on subglacial volcanism was done by W.H. Mathews, a prominent Canadian geomorphologist. In the course of mapping geology in the Tuya–Teslin area of northern British Columbia, Mathews (1947) recognized eruptive features with morphologies very different from those of normal volcanoes. The features, which he termed *tuyas*, are steep-sided and have flat to gently sloping tops. Mathews proposed that tuyas formed by eruption of lavas beneath the ice sheet that covered British Columbia during late Pleistocene time. The eruptions built up piles of pillow lavas and pyroclastic debris in cavities produced by melting within the ice. The flat tops of classic tuyas define water planes of former englacial lakes, and foreset beds at the margins delineate areas where pyroclastic debris avalanched down the sides of the flat-topped mounds. Mathews (1951, 1952, 1958) later described other ice-contact volcanic landforms in the Mount Garibaldi area of southwestern British Columbia, including sinuous basalt ridges with esker-like morphologies and steep toes of lava flows that cooled against the margins of decaying late Pleistocene glaciers. The joints of these lavas have patterns consistent with cooling against ice masses that have since disappeared.

In the second paper in this collection, Catherine Hickson reviews and extends Mathews' pioneering work on subglacial volcanism. Hickson describes the full suite of landforms produced by eruptions under and at the margins of glaciers, drawing on the literature from British Columbia, Iceland, and elsewhere, as well as her own field experience (e.g., Hickson et al., 1995). She also describes the internal structure of these features and discusses the processes that produce them.

An interesting issue that is not addressed by Hickson is the temporal association of volcanism and glaciation in western Canada. Grove (1974) noted that many Pleistocene eruptions in this region occurred at times when the Cordilleran ice sheet was melting. He postulated that glacial unloading and attendant crustal deformation triggered the eruptions. This interpretation seems reasonable, but it begs the question of whether subglacial eruptions are any more common than nonglacial eruptions, of which, for example, there have been a large number during postglacial time (Souther, 1977).

3. Laurentide eskers

Melting of the Laurentide ice sheet produced large volumes of meltwater that transported glacial debris from the interior of the ice sheet to its margin. Yet it is only in the past three decades that the importance of meltwater in shaping the Laurentide glacial landscape has been fully realized (Shaw, 1996). It has long been known that meltwater produced Laurentide eskers, kames, and kame terraces, but recently meltwater has been invoked to explain a much larger suite of subglacial landforms, including drumlins, rogen moraine, and tunnel valleys (Shaw, 1996; Munro and Shaw, 1997). Furthermore, it is now clear that meltwater drainage and glacier dynamics are linked, and that consideration of both is fundamental to formulating realistic ice sheet models (Arnold and Sharp, 1992; Clarke, 1996).

Three bodies of research are providing a better understanding of Laurentide meltwater drainage: (1) modern glacial hydrology (e.g., Hubbard and Nineow, 1997; Gordon et al., 1998); (2) glaciological theory (e.g., Röthlisberger and Lang, 1987); and (3) glacial geomorphology (e.g., Brennand and Shaw, 1996). A considerable dialog exists between glacier hydrologists and glacial theorists on the subject of meltwater drainage, but few geomorphologists have worked with these scientists. This is surprising given that observations on glaciofluvial landforms and sediments should provide the ultimate tests of models of Laurentide ice sheet drainage and glaciodynamics (Hughes, 1995).

The third paper in this issue, written by Tracy Brennand, bridges these three areas of research. Brennand evaluates current knowledge of Laurentide eskers in the light of recent developments in glacier hydrology and glacial sedimentology. She tackles questions about the morphology and sedimentology of eskers, the operation of subglacial channel systems, the role of supraglacial meltwater input and proglacial water bodies, controls on esker patterns, and the glaciodynamic condition of the ice sheet at the time of esker formation. Brennand proposes a morphologic classification of eskers consisting of five types that formed under different hydrological and glaciological conditions. Factors responsible for the pattern and operation of channels in which eskers formed include a combination of: (1) supraglacial meltwater drainage; (2) number and location of sink holes; (3) ice surface slope; (4) ice thickness and velocity; and (5) permeability, topography, and rigidity of the bed. These factors cause, and respond to, changes in ice dynamics and thermal regime over the course of a glacial cycle.

4. Environmental assessment from fiord sediments

The numerous fiords of Canada's Pacific, Arctic, and Atlantic coasts are part of the country's glacial heritage. The fiords encompass a range of environments, from temperate to polar, and so a range of sedimentary processes and forms (Syvitski and Shaw, 1995). Canadian scientists have long been interested in these environments and have been leaders in research that has substantially increased our understanding of the sedimentology of high-latitude fiords (e.g., Gilbert, 1983; Gilbert et al., 1993; Syvitski, 1989, 1993; Syvitski et al., 1987; Lemmen, 1990; Aitken and Bell, 1998).

Fiord sediments are used to assess sedimentary and oceanic processes, and glacial, periglacial, and geomorphic history. However, as Robert Gilbert points out in the fourth paper in this collection, fiord sediments are also important proxies for past climate and hydrology. With appropriate transfer functions, sediment proxies from fiords can reproduce the instrumental climate record with reasonable precision. Fiord sediments can also provide insights into past environments that are not available from the instrumental record. Field studies in fiords are providing point-in-time information on oceanographic and sedimentary processes, and on the erosional and depositional features that result from these processes. The investigations have contributed to conceptual models of fiord sedimentology, which combined with studies of hundreds of samples and cores, will ultimately allow detailed paleoenvironmental assessment over significant portions of Quaternary time.

This understanding provides the basis for using fiord sediments to assess future global change. Such assessments will require integration of results from fiords with those from lakes. It might seem that fiords and lakes have similar sedimentary environments: both are controlled by a similar external environment, which includes climate, hydrology, landscape, and especially the input of water and sediment. However, the sedimentary processes and deposits of fiords differ fundamentally from those of lakes due to (1) the role of salt water in inhibiting mixing and in promoting flocculation, (2) the exchange of mass and energy with the ocean beyond, and (3) the role of benthic biota. Power in applying proxy environmental records from fiords will come from comparing them with sediment records from lakes.

5. Glacio-isostatic effects of decay of the Laurentide ice sheet

The Laurentide and Innuitian ice sheets constituted the largest, late Pleistocene glacier complex on Earth, covering at their maximum much of Canada and the northern United States. They have been the focus of an extraordinary amount of geomorphic research and are better understood than other late Pleistocene ice sheets.

One aspect of Laurentide glaciation that has received considerable attention is the isostatic response of the lithosphere to glacial unloading. The recovery of the lithosphere from decay of the Laurentide and Innuitian ice sheets has been established by studies of relict elevated shorelines, deltas, and other littoral landforms in Atlantic and Arctic Canada (e.g., Andrews, 1970; Dyke, 1998; Dyke and Prest, 1987; Dyke et al., 1991; England, 1992; Gray et al., 1993). Relative sea-level curves have been constructed by radiocarbon dating fossil shells, bone, and wood associated with these landforms. Comparison of relative sea-level curves from different areas in Atlantic and Arctic Canada has allowed inferences to be made of, not only the pattern and timing of deglaciation, but also the thickness and rheology of the lithosphere.

Clark (1980) and Andrews and Peltier (1989) have shown that patterns of postglacial relative sea-level change in and near glaciated regions are of three general types. Sites that were heavily loaded by ice during the last glaciation exhibit continuous postglacial emergence; sites near the glacial limit show initial emergence followed by submergence; and more distal sites exhibit continuous submergence.

In the fifth paper in this issue, Arthur Dyke and William Peltier take this analysis a step further by examining spatial variability in the speed of emergence (response time) and by commenting on the probable causes and significance of these variations. They show that relative sea-level curves from glaciated North America display coherent spatial patterns of response times. Response-time ‘‘half-lives’’ in the Laurentide Ice Sheet area range from 1.2 to 1.4 ka at the uplift centre to 1.7 to 2.0 ka along a ridge inboard of the glacial limit. Half-lives decline from this ridge to less than 1.0 ka along the margin of the ice sheet. In the Innuitian Ice Sheet area, half-lives are about 2.0 ka at the uplift centre and decline to less than 1.0 ka at the margin. The central Laurentide response times are about half those of central Fennoscandia, which was covered by a much smaller ice sheet. This result is consistent with the theoretical expectation that central response times are inversely proportional to ice sheet radius for large ice loads which are insensitive to lithospheric thickness. The central Innuitian response time indicates that rebound at the centre of this ice sheet, which is much smaller than the Fennoscandian Ice Sheet, is sensitive to lithospheric thickness. Radial gradients in response times reflect the increasing influence of the lithosphere at sites increasingly closer to the margin. Near the glacial limit, isostatic adjustment is complicated by forebulge migration and collapse.

6. Effects of environmental change on postglacial scree slope development

Interpretation of environmental change from the evidence of slope deposits alone is difficult; most of the literature that attempts to analyse environmental change during the Holocene is concerned with dated sedimentary sequences of marine, lacustrine, or fluvial origin. Bernard Hétu and James Gray, however, have shown that slope deposits can provide valuable paleoenvironmental information. In a series of well documented papers, they have transformed our understanding of the postglacial evolution of Gaspésie (Hétu, 1995; Hétu and Gray, 1980; Hétu et al., 1995). The sixth paper in this collection is the culmination of this research effort.

Hétu and Gray have used three organising frameworks in their research: (1) the paraglacial model of Church and Ryder (1972); (2) contemporary slope process studies (e.g., Gray, 1971), and (3) paleoenvironmental reconstruction (e.g., Labelle and Richard, 1984). A seminal paper by Church and Ryder (1972) introduced the term *paraglacial sedimentation* to describe sedimentation conditioned by glaciation. They invoked the concept to explain landforms and deposits in the interior of British Columbia that spoke of unusually high rates of fluvial sedimentation in the early postglacial period. The paraglacial concept has been widely, though not universally, adopted by students of rapid valley sedimentation (e.g., Slaymaker and McPherson, 1977; Jackson et al., 1982; Clague, 1986; Jordan and Slaymaker, 1991).

Hétu and Gray have concluded from their geomorphic studies in Québec that paraglacial sedimentation is one part of the story, but by no means all of it. Based on an elaborate programme of field measurements and analysis of the paleoenvironmental record, they conclude that slope change in Gaspésie has continued unabated throughout the 10,000–13,000 years of the postglacial period. Rock glacier formation and movement were important slope processes in this part of Gaspésie in the early postglacial period; after 7250 years BP, however, scree development was the dominant slope process. Scree formation has diminished during the Holocene only in areas where summit rock walls have disappeared. The main question that arises out of this study is whether we are looking at a punctuated, catastrophic history or a continuously changing process of slope evolution. The authors do not explicitly address this question on the grounds that the data do not allow a clear-cut conclusion.

7. Little Ice Age

The term *Little Ice Age* was coined by Matthes (1939) to describe a period of more extensive glacier cover that followed a warmer part of the Holocene. Interest in the Little Ice Age has grown in recent years, partly because of its significance to the debate over natural versus human-induced climate change. The Little Ice Age precedes the period of the instrumental climate record. Detailed information on Little Ice Age climate variability obtained from proxy, paleoenvironmental records is providing a better understanding of what drives climate change on timescales as short as decades.

Early paleoenvironmental studies of the Little Ice Age were founded on relatively simple assumptions about climate change, namely that periods of relatively uniform climate are separated by sharp boundaries. The Little Ice Age was viewed as a relatively uniform cold period, with perhaps two or three peaks, preceded by a similarly uniform warm period (the *Medieval Warm Period*) and abruptly followed by the warmer twentieth century. The development of continuous, high-resolution, proxy climate records for the last millennium challenges this simple viewpoint and is the subject of the seventh paper in this issue, written by Brian Luckman.

Luckman provides an overview of the Little Ice Age in the Canadian Rocky Mountains. He has contributed more to our understanding of the Little

Ice Age in western Canada than any other researcher, although his work is part of a much larger effort (e.g., Ryder and Thomson, 1986; Osborn and Luckman, 1988; Clague and Mathews, 1992; Desloges and Gilbert, 1995; Smith et al., 1995; Leonard, 1997). Luckman summarizes the two main types of proxy climate records: the glacial record and the lacustrine record.

The glacier record includes moraines and the sediments that form them. Little Ice Age moraines fronting many glaciers in western Canada have been mapped, and they have been dated using lichenometric and dendrochronological techniques. The dating commonly provides only moraine abandonment ages and only rarely provides information on the advance of the glacier. However, dendrochronological dating of snags and logs which are covered by till and occur in the cores of some Little Ice Age moraines have yielded fairly precise glacier advance dates. The glacier record, of course, is selectively preserved and thus is necessarily incomplete. Nevertheless, Luckman has established a chronology of glacial events for the last 700 years from studies of moraines in the Canadian Rockies. Detailed information on climate during this period has been provided by analysis of the width and density characteristics of long tree-ring series at some of the study sites.

Varve sequences in proglacial lakes provide continuous, annually resolved records of sediment yield in glacierised catchments. Variations in thickness and texture of long sequences of varves have been linked to glacier fluctuations in the basins.

The glacial and lacustrine records from the Canadian Rockies collectively indicate glacier advances in the 12–13th, early 18th, and throughout the 19th centuries. Regional ice cover was probably greatest in the middle 19th century, although in places the early 18th century advance was more extensive. Tree-ring data show that most glacier advances resulted from both increased precipitation and reduced summer temperatures. Negative mass balances in the last 25 years, however, have been caused primarily by decreased winter snowfall.

Luckman concludes that the glacial record does not contain a simple climate signal. Rather, the record is a complex response to several factors that interact with one another and operate on different time scales. He argues that simplistic concepts of Little Ice Age climate should be abandoned and replaced with more realistic records based on continuous proxy data.

8. The influence of dynamic soil properties on hillslope erosional response

Rorke Bryan and his co-workers at the University of Toronto (Scarborough Campus) have carried out the definitive Canadian experimental work on hillslope erosional processes, such as rainsplash, surface wash (Bryan, 1991), piping, rill erosion, and gullying. Much of the field work has been done in the Dinosaur Provincial Park badlands in Alberta (Bryan et al., 1978). Bryan has been principally responsible for new understandings of the mode of evolution of badland landscapes in particular and the role of soil characteristics in influencing hillstope evolution in general.

It is worth noting that the pioneering work in this field was carried out by American soil conservation specialists, notably Bennett (1926) and Middleton (1930). While acknowledging his debt to these workers, Bryan summarises the difficulty of relating their experimental results to the full-scale field problem of geomorphology. Indeed, it seems fair to say that only two laboratories world-wide have consistently related their laboratory and field experiments to significant geomorphological problems. One of these laboratories is at Scarborough; the other is the Belgian laboratory at Louvain, founded by DePloey and Savat (1968) and maintained today by Poesen and Govers (Govers et al., 1990).

Bryan has dedicated much of his career to investigations of soil erodibility variations, the heterogeneous nature of natural soil profiles and their influence on water partitioning, and the temporal variability of the soil properties that control soil erodibility. In the eighth paper in this volume, he focusses on (1) inter-rill processes, (2) rill erosion, and (3) piping, and shows how soil erodibility is dominated by a few soil properties, specifically soil aggregation, consistency, and shear strength. The spatial and temporal variations in soil erodibility are then explained by the ways in which frost action, moisture conditions, and soil organic matter and microorganisms influence dynamic soil properties. He sees stochastic modelling as the most promising direction for future research.

9. Large-scale flow structures in a gravel-bed river

Canadian fluvial geomorphology has its origins in the 1960s with Tom Blench at the University of Alberta and his passionate defence of mobile bed fluviology, a regime theory-based interpretation of river channels (Blench, 1969). At that time, fluvial geomorphologists internationally were preoccupied with sand-bed rivers. During the 1970s, Kellerhals and Church commenced a series of studies of the hydraulics and formative flow and sediment transport regimes of gravel-bed rivers in the Canadian Cordillera (Kellerhals et al., 1979). By the 1980s, a Canadian gravel-bed rivers group emerged under the creative leadership of Mike Church (Church, 1983; Church and Jones, 1982) and included a new generation of fluvial geomorphologists (Ashmore and Parker, 1983; Lapointe, 1992; Robert et al., 1993; Roy et al., 1999). One of the major challenges for this group has been unravelling the causal links between the hydraulics of the flow and the response of the container, namely the form of the river channel.

In the last paper in this issue, Thomas Buffin-Belanger, André Roy, and Alistair Kirkbride focus on the identification of large-scale flow structures in an attempt to relate similar scales of hydraulic phenomena to morphological changes in gravel-bed rivers. The paper confirms that large-scale flow structures do indeed exist in gravel-bed rivers and display a complex organisation. Wedges of intermittent high speed are separated by regions of lower velocity. Because of their duration and size, these wedges are likely to play a major role in bedload sediment transport.

It is interesting to note that Roy's laboratory, out of which this study comes, maintains a strong field experiment programme in addition to its laboratory experiments. One of the signal achievements of this contribution is that of developing flow visualisation techniques and highly sophisticated measurement programmes on a real gravel-bed river, the Eaton North River in Québec. Future research is indicated on the origin, development and interactions of wedges with the adjacent river bed and banks.

References

Aitken, A.E., Bell, T.J., 1998. Holocene glacimarine sedimentation and macrofossil palaecology in the Canadian High Arctic: environmental controls. Mar. Geol. 145, 151–171.

Ambrose, J.W., 1964. Exhumed paleoplains of the Precambrian Shield of North America. Am. J. Sci. 262, 817–857.

Andrews, J.T., 1970. A Geomorphological Study of Postglacial Uplift with Particular Reference to Arctic Canada. Inst. Brit. Geogr. Spec. Publ. No. 2.

Andrews, J.T., Peltier, W.R., 1989. Quaternary geodynamics in Canada. In: Fulton, R.J. (Ed.), Quaternary geology of Canada and Greenland. Geol. Surv. Can., Geol. Can. Vol. 1pp. 543–572.

Arnold, N.S., Sharp, M., 1992. Influence of glacier hydrology on the dynamics of a large Quaternary ice sheet. J. Quat. Sci. 7, 109–124.

Ashmore, P., Parker, G., 1983. Confluence scour in coarse, braided streams. Water Resour. Res. 19, 392–402.

Bennett, H.H., 1926. Some comparisons of the properties of humid tropical and humid temperate American soils. Soil Sci. 21, 349–375.

Blench, T., 1969. Mobile Bed Fluviology. University of Alberta Press, Edmonton.

Bouchard, M., 1983. Influences stationelles sur l'altération chemique des sols dérivés de till. Catena 10, 363–382.

Bouchard, M., Jolicoeur, S., Pierre, G., 1995. Characteristics and significance of two pre-late Wisconsinan weathering profiles. Geomorphology 12, 75–89.

Brennand, T.A., Shaw, J., 1996. The Harricana glaciofluvial complex, Abitibi region, Quebec: its genesis and implications for meltwater regime and ice-sheet dynamics. Sediment. Geol. 102, 221–262.

Bryan, R.B., 1991. Surface wash processes. In: Slaymaker, O. (Ed.), Field experiments and measurement programs in geomorphology. Balkema, Rotterdam, pp. 107–169.

Bryan, R.B., Yair, A., Hodges, W.K., 1978. Factors controlling the initiation of runoff and piping in Dinosaur Provincial Park badlands. Z. Geomorphologie 34, 48–62.

Chalmers, R., 1898. The pre-glacial decay of rocks in eastern Canada. Am. J. Sci. 4–5, 273–282.

Church, M., 1983. Pattern of instability in a wandering gravel bed channel. In: Modern and ancient fluvial systems. Collinson, J.D., Lewin, J. (Eds.), Int. Ass. Sediment. Spec. Publ. 6, pp. 169–180.

Church, M., Jones, D., 1982. Channel bars in gravel bed rivers. In: Hey, D., Bathurst, J.C., Thorne, C.B. (Eds.), Gravel-bed rivers. Wiley, Chichester, pp. 291–338.

Church, M., Ryder, J.M., 1972. Paraglacial sedimentation: a consideration of fluvial processes conditioned by glaciation. Geol. Soc. Am. Bull. 83, 3059–3072.

Clague, J.J., 1986. The Quaternary stratigraphic record in British Columbia. Can. J. Earth Sci. 23, 885–894.

Clague, J.J., Mathews, W.H., 1992. The sedimentary record and Neoglacial history of Tide Lake, northwestern British Columbia. Can. J. Earth Sci. 29, 2283–2396.

Clark, J.A., 1980. A numerical model of worldwide sea level changes on a viscoelastic earth. In: Mörner, N.A. (Ed.), Earth rheology, isostasy and eustasy. Wiley, London, pp. 525–534.

Clarke, G.K.C., 1996. Lumped-element analysis of subglacial hydraulic circuits. J. Geophys. Res. 101, 17547–17559.

DePloey, J., Savat, J., 1968. Contribution à l'étude de l'érosion par le splash. Z. Geomorphologie 12, 147–193.

Desloges, J.R., Gilbert, R., 1995. The sedimentary record of Moose Lake: implications for late-glacial and Little Ice Age glacier activity in the Mount Robson area, British Columbia. Can. J. Earth Sci. 32, 65–78.

Dyke, A.S., 1998. Holocene delevelling of Devon Island, Arctic Canada: implications for ice sheet geometry and crustal response. Can. J. Earth Sci. 35, 885–904.

Dyke, A.S., Prest, V.K., 1987. Late Wisconsinan and Holocene history of the Laurentide ice sheet. Géogr. physique Quaternaire 41, 237–263.

Dyke, A.S., Morris, T.F., Green, D.E.C., 1991. Postglacial tectonic and Sea Level History of the Central Canadian Arctic. Geol. Surv. Can. Bull., 397.

England, J., 1992. Postglacial emergence in the Canadian High Arctic: integrating glacioisostasy, eustasy, and late deglaciation. Can. J. Earth Sci. 29, 984–999.

Gilbert, R., 1983. Sedimentary processes of Canadian arctic fiords. Sediment. Geol. 36, 147–175.

Gilbert, R., Aitken, A.E., Lemmen, D.S., 1993. The glacimarine sedimentary environment of Expedition Fiord, Canadian High Arctic. Mar. Geol. 110, 257–273.

Godard, A., 1965. Recherches géomorphologiques en écosse du nord-quest. Publications de la Faculté des Lettres, Strasbourg.

Gordon, S., Sharp, M., Hubbard, B., Smart, C., Ketterling, B., Willis, I., 1998. Seasonal reorganization of subglacial drainage inferred from measurements in boreholes. Hydrol. Processes 12, 105–133.

Govers, G., Everaert, W., Poesen, J., Rauws, G., De Ploey, J., Lautridou, J.P., 1990. A long flume study of the dynamic factors affecting the resistance of a loamy soil to concentrated flow erosion. Earth Surface Processes Landforms 15, 313–328.

Gray, J.T., 1971. Processes and Rates of Development of Talus Slopes and Pro-talus Rock Glaciers in the Ogilvie and Wernecke Mountains. Ph.D. thesis, McGill University, Montreal.

Gray, J.T., Lauriol, B., Bruneau, D., Ricard, J., 1993. Postglacial emergence of Ungava Peninsula, and its relationship to glacial history. Can. J. Earth Sci. 30, 1676–1696.

Grove, E.W., 1974. Deglaciation — a possible triggering mechanism for recent volcanism. Proc. Int. Ass. Volcanol. Chemistry Earth's Interior, Symp. Andean Antarctic Volcanol. Problems, Santiago, Chile, pp. 88–97.

Hétu, B., 1980. Évolution postglaciaire des versants de la région de Mont-Louis, Gaspésie. Géogr. physique Quaternaire 39, 77–84.

Hétu, B., 1995. Le litage des éboulis stratifiés cryonivaux en Gaspésie. Permafrost Periglacial Processes 6, 147–171.

Hétu, B., Van Steijn, H., Bertran, P., 1995. Le rôle des coulées de pierres sèches dans la genèse d'un certain type d'éboulis stratifié. Permafrost Periglacial Processes 6, 173–194.

Hickson, C.J., Moore, J.G., Calk, L., Metcalfe, P., 1995. Intraglacial volcanism in the Wells Gray–Clearwater volcanic field, east-central British Columbia, Canada. Can. J. Earth Sci. 32, 838–851.

Hubbard, B., Nienow, P., 1997. Alpine subglacial hydrology. Quat. Sci. Rev. 16, 939–955.

Hughes, T.J., 1995. Ice sheet modelling and the reconstruction of former ice sheets from glacial geo(morpho)logical field data. In: Menzies, J. (Ed.), Modern glacial environments: processes, dynamics and sediments. Butterworth-Heinemann, Oxford.

Jackson, L.E., MacDonald, G.M., Wilson, M.C., 1982. Paraglacial origin for terraced river sediments in Bow Valley. Can. J. Earth Sci. 19, 2219–2231.

Jordan, P., Slaymaker, O., 1991. Holocene sediment production in Lillooet River basin. Géogr. physique Quaternaire 45, 45–57.

Kellerhals, R., Church, M., Davies, L.B., 1979. Morphological effects of interbasin river diversions. Can. J. Civil Eng. 6, 18–31.

Labelle, C., Richard, P.J.H., 1984. Histoire postglaciaire de la végétation dans la région du Mont Saint-Pierre, gaspésie. Géogr. physique Quaternaire 38, 257–274.

Lapointe, M., 1992. Burst-like sediment supsension events in a sand-bed river. Earth Surface Processes Landforms 17, 253–270.

Lemmen, D.S., 1990. Glaciomarine sedimentation in Disraeli Fiord, high arctic Canada. Mar. Geol. 94, 9–22.

Leonard, E.M., 1997. The relationship between glacial activity and sediment production: evidence from a 4450-year varve record of Neoglacial sedimentation in Hector Lake, Alberta. J. Paleolimnol. 17, 319–330.

Mathews, W.H., 1947. ''Tuyas,'' flat-topped volcanoes in northern British Columbia. Am. J. Sci. 245, 560–570.

Mathews, W.H., 1951. The Table, a flat-topped volcano in southern British Columbia. Am. J. Sci. 249, 830–841.

Mathews, W.H., 1952. Mount Garibaldi, a supraglacial Pleistocene volcano in southwestern British Columbia. Am. J. Sci. 250, 81–103.

Mathews, W.H., 1958. Geology of the Mount Garibaldi map-area, southwestern British Columbia, Canada: Part II. Geomorphology and Quaternary volcanic rocks. Geol. Soc. Am. Bull. 69, 179–198.

Matthes, F.E., 1939. Report of the Committee on Glaciers. Trans. Am. Geophys. Union 20, 518–523.

McConnell, R.G., 1891. Report on an Exploration in the Yukon and Mackenzie Basins. Geol. Surv. Can. Annual Rep., New Ser., 4 (1888–1889), Rep. D.

Middleton, H.E., 1930. Properties of Soils which Influence Soil Erosion. U.S. Dept. Agric. Tech. Bull., 178.

Munro, M., Shaw, J., 1997. Erosional origin of hummocky terrain in south-central Alberta, Canada. Geology 25, 1027–1030.

Osborn, G.D., Luckman, B.H., 1988. Holocene glacier fluctuations in the Canadian Cordillera (Alberta and British Columbia). Quat. Sci. Rev. 7, 115–128.

Parry, J.T., 1963. The Laurentians: A Study in Geomorphological Development. Ph.D. thesis, McGill University, Montreal.

Ritchot, G., 1964. Problèmes géomorphologiques de la vallée du St. Laurent. Revue Géogr. Montréal 18, 5–64.

Robert, A., Roy, A.G., De Serres, B., 1993. Space–time correlation of velocity measurements at a roughness transition in a gravel-bed river. In: Clifford, N.J., French, J.R., Hardisty, J. (Eds.), Turbulence. Wiley, Chichester, pp. 165–184.

Röthlisberger, H., Lang, H., 1987. Glacier hydrology. In: Gurnell, A.M., Clark, M.J. (Eds.), Glacio-fluvial sediment transfer. Wiley, Chichester, pp. 207–287.

Roy, A.G., Biron, P., Buffin–Belanger, T., Levasseur, M., 1999. Combined visual and quantitative techniques in the study of natural turbulent flows. Water Resour. Res. 35, 871–877.

Ryder, J.M., Thomson, B., 1986. Neoglaciation in the southern Coast Mountains of British Columbia: chronology prior to the late-Neoglacial maximum. Can. J. Earth Sci. 23, 273–287.

Shaw, J., 1996. A meltwater model for Laurentide subglacial landscapes. In: McCann, S.G., Ford, D.C. (Eds.), Geomorphology sans Frontières. Wiley, Chichester, pp. 181–236.

Slaymaker, O., McPherson, H.J., 1977. An overview of geomorphic processes in the Canadian Cordillera. Z. Geomorphologie 21, 169–186.

Smith, D.J., McCarthy, D.P., Colenutt, M.E., 1995. Little Ice Age glacial activity in Peter Lougheed and Elk Lakes Provincial Parks, Canadian Rocky Mountains. Can. J. Earth Sci. 32, 570–589.

Souther, J.G., 1977. Volcanism and tectonic environments in the Canadian Cordillera — a second look. In: Baragar, W.R.A., Coleman, L.C., Hall, J.M. (Eds.), Volcanic regimes in Canada. Geol. Ass. Can. Spec. Pap. 16, pp. 3–24.

Syvitski, J.P.M., 1989. On the deposition of sediment within glacier-influenced fiords: oceanographic controls. Mar. Geol. 85, 301–329.

Syvitski, J.P.M., 1993. Glaciomarine environments in Canada: an overview. Can. J. Earth Sci. 30, 345–371.

Syvitski, J.P.M., Shaw, J., 1995. Sedimentology and geomorphology of fjords. In: Geomorphology and sedimentology of estuaries. Perillo, G.M.E. (Ed.), Develop. Sedimentol. 53, Elsevier Sci. pp. 113–178.

Syvitski, J.P.M., Burrell, D.C., Skei, J.M., 1987. Fiord Processes and Products. Springer-Verlag, New York.