Reconnaissance sub-bottom profiling studies of Peyto Lake, Banff National Park

Barbara E. Medioli & Michael N. Demuth
Geological Survey of Canada, 601 Booth Street, Ottawa ON K1A 0E8

Introduction

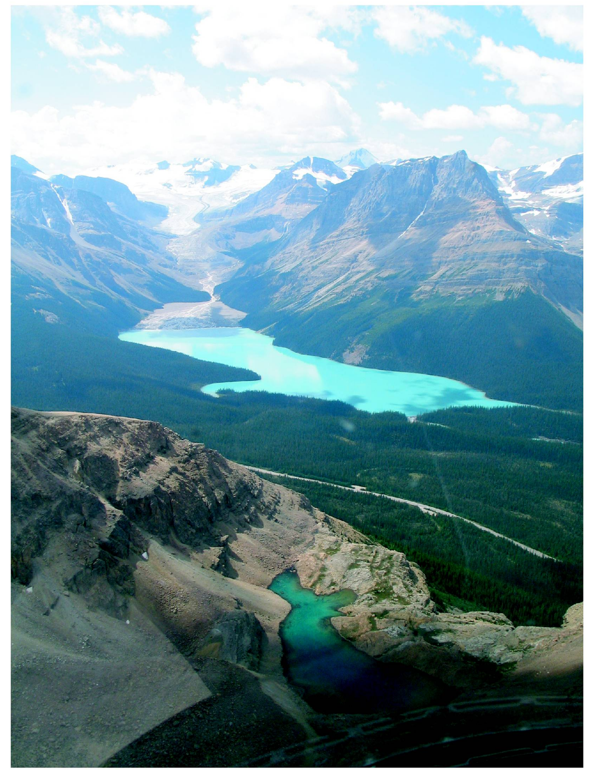

Fig. 1. Aerial photograph taken from a helicopter facing south. The view is upvalley and shows Peyto Lake in the middle of the photograph, the outwash plain and Peyto Glacier in the background. Photograph taken July 24, 2006.

Recent studies have pointed to significant negative flow trends in the glacierized catchments of Canada's Southern Cordillera. These trends and a reduction in the flow regulation effect of glacier cover are due to marked reductions in the aerial extent of glaciers over the last half of the 20th Century (Hopkinson and Young 1998; Moore and Demuth 2001; Demuth and Pietroniro 2002; and Stahl and Moore 2006). These conclusions are the result of analyses conducted using the available instrumental records describing summer month river flows.

In the context of water resources, and to better define the warm-dry climate episode adaptation limits provided by the presence of glaciers, it is desirable to place these observations within the perspective of glacier fluctuations that have taken place over the last several millennia. In several instances recent and paleo-glacier fluctuations from direct or proxy evidence have been well documented. For example, Demuth (1997), Demuth and Keller (2006), Hopkinson and Demuth (2006), Luckman (2006), and Watson and Luckman (2004) provide such evidence for Peyto Glacier. Peyto Glacier is situated in the eastern slopes of the Canadian Rocky Mountains and provides flow to the North Saskatchewan River Basin. This glacierized mountainous headwater region plays a critical role in providing orographically derived precipitation, seasonal snowmelt and glacier melt to natural and human systems downstream.

Study Area Location & Description

The study is located in Banff National Park, approximately 40 km NW of the town of Lake Louise. Peyto Glacier has an area of ~12 km^2 and has an elevation ranging from 3180 to 2140 m a.s.l. The glacier sits on carbonate bedrock ranging from PreCambrian to Upper Cambrian in age, and in its lower reaches it is bounded by ice-cored moraines (Fig. 1). Meltwater from the glacier are carried down valley by Peyto Creek which passes over Middle Cambrian limestone and shale bedrock and enters Peyto Lake (Fig. 2). The lake is confined within its basin by steep valley sides to the east and west. The lake itself lies primarily on the lower Cambrian Gog Formation which is composed of quartzites and quartzose sandstones.

Peyto Lake is fed by Peyto Creek, a stream that flows from the glacier snout, through an opening in the Little Ice Age (LIA) terminal moraine, and then fans out across the outwash plain before emptying into Peyto Lake (Fig. 1). The lake is oriented north-south and its outlet stream flows north. This paraglacial lake sits in the bottom of the glacial valley and extends from valley side to valley side (Fig. 2).

Peyto meltwaters flow north and then east, into the Mistaya and North Saskatchewan river systems. The glacier has lost 70% of its mass since the end of the Little Ice Age and the rate of melt has increased since the 1980s.

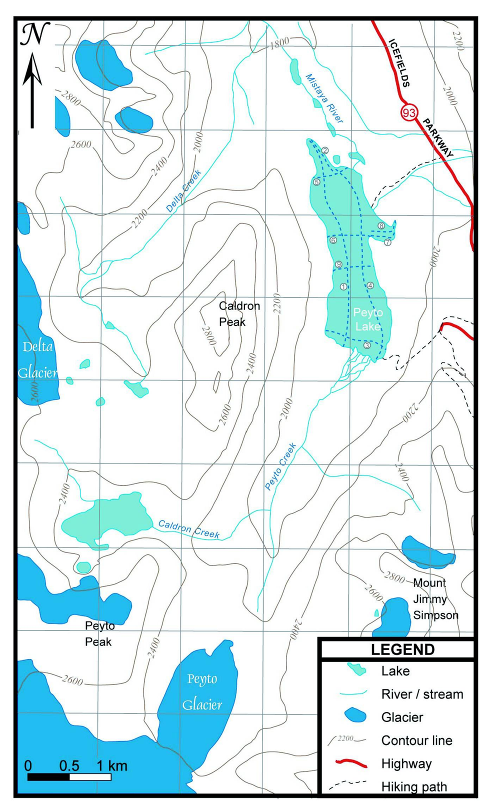

Fig. 2 Map showing the location of Peyto Glacier and Peyto Lake. The sub-bottom profiles routes are overlain on the lake.

Methods–*Sub-bottom profiling*

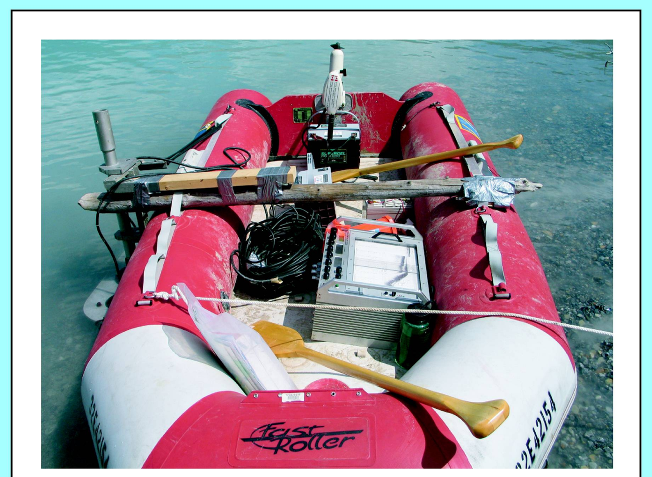

Fig. 3 The Zodiac Fastroller 310, with the Knudsen 320M™ sub-bottom profiler and 12V batteries, loaded and ready to go.

Sub-bottom profiling was undertaken on July 25 and 26, 2006, using a Knudsen 320M™ high-resolution echo sounder with low (3.5-7.0 kHz) and high (200 kHz) frequency transducers (Fig. 3). Power supply was provided by two 12V DC gel pack batteries connected in series. Profiles were printed on a thermally sensitive plastic medium in 32-tone grey-scale. Water column depths ranged from 0 to ~50 m, based on a sound velocity of 1500 m•s^{-1}.

The surveys were conducted using an inflatable 10 ft. (2 man) Zodiac Fastroller 310 powered by an electric 12V trolling motor. Traversing speeds ranged from 1.5 to 5 km•hr^{-1}, with the variation influenced by wind speed and current. Profiling routes were dead reckoned using a 1:50 000 topographic map and shoreline features for reference. The profiling routes are depicted in Fig. 2.

The lake surveys consist of two longitudinal profiles that approximately followed the eastern and western shorelines of the lake (Fig. 2) and a series of cross-sectional profiles.

Canada

The role of glaciers in stream flow regulation

The presence of perennial ice within a mountain watershed impacts the season variability in runoff. In addition, the duration of snowmelt is extended in glacial catchments. A regulatory effect on streamflow is observed downvalley of temperate mountain glaciers. This is the result of a delayed and extended period of maximum seasonal discharge due to the storage effects of glaciers. During the late summer/early fall months, when snowpack has melted and moved downstream, glacial meltwater becomes the most significant contributor to streamflow, providing water during what would otherwise be a low flow season.

Since 1950 a decrease in base flow has been observed in Central Cordilleran mountain watersheds despite increases in montane precipitation during the same period. Ultimately, this suggests that the ability of glaciers to regulate stream flow has declined since the mid-1900s. This is an alarming change because mountain watersheds have steep climatic gradients that result in highly climate-sensitive hydrological regimes.

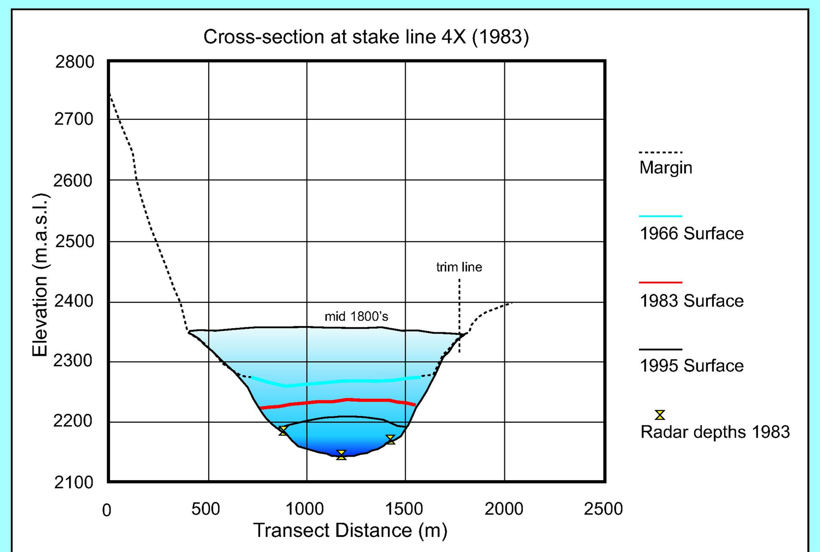

Fig. 4. Typical ice surface and bedrock cross-section profiles across Peyto glacier snout referenced to the Little Ice Age maximum lateral moraines and trimlines (after Demuth, 1997).

Post-LIA maximum glacier variations

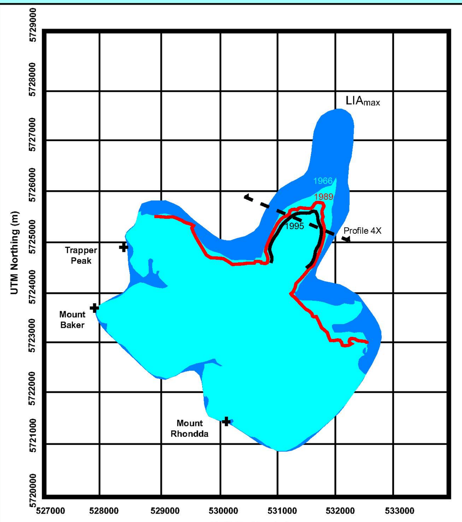

Fig. 5 Aerial view of Peyto Glacier showing the extent of glacial retreat since the LIA maximum. The cross-sectional profile corresponds to Fig. 4 (after Demuth, 1997).

Peyto was first observed and photographed in 1896 but instrumental monitoring did not begin until 1966. Mass balance records are short and only measure ~30 years of change. We know from proxy records (tree rings, moraine positions and photographs) that Peyto Glacier has lost upwards of 70% of its volume since the Little Ice Age Maximum (Figs. 4 and 5). These proxies indicate that the rate of melt has increased between 1920-1950, then slowed and then accelerated again after 1976, within a further increase in the 1990s. This phenomenon has been observed for other glaciers in the Eastern Canadian Cordillera and suggests glacier cover is approaching the limit for Holocene variability at an unprecedented rate (Fig. 6).

The observed changes in glacier mass balance are primarily regulated by climate controls in the form of winter precipitation (accumulation rates) and summer temperature regimes (ablation rates) which are in turn controlled by large scale circulation patterns.

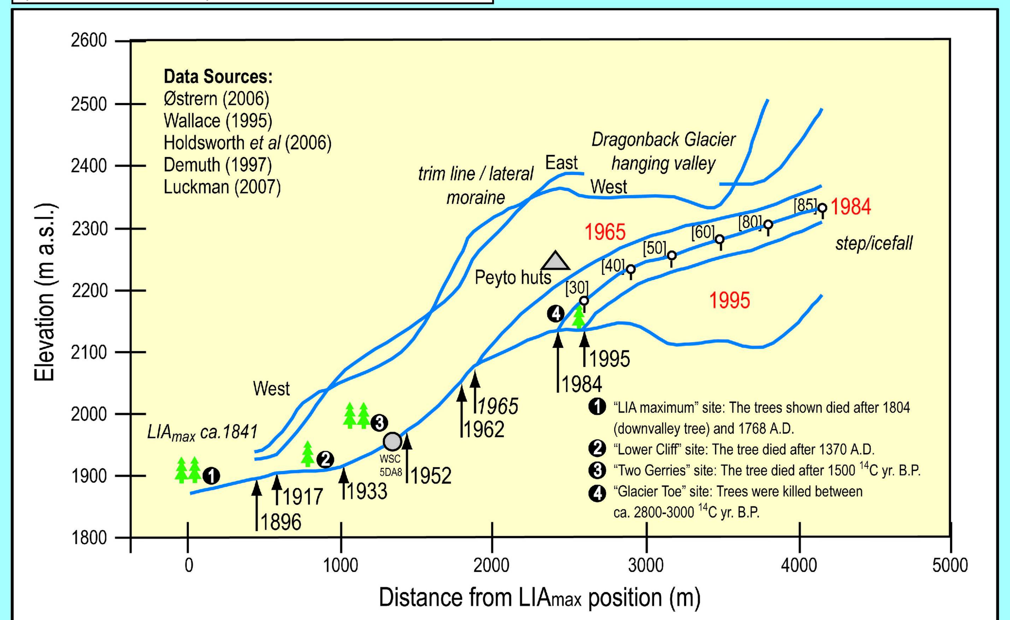

Fig. 6. Peyto Glacier terminal positions since the Little Ice Age maximum and the locations of morphostratigraphic and botanical evidence suggesting that the glacier has overridden mature forested surfaces at least 4 times during the last 3000 years (after Luckman, 2006).

Much of the data on past glacial retreat has been obtained from tree ring chronologies and sheared wood records (Fig. 4, 5 and 6). These records, however, do not always constrain the timing of the onset of ice advance or of maximum ice stand. In contrast, the use of sediment cores can provide information on seasonal ablation rates which provide information on ice extent over a longer time scale since proglacial sedimentation reflects both sediment availability and meltwater stream capacity.

Climate variability

In the Pacific, tropical sea surface temperatures have been recorded from 1870 to present and show shifts in the Pacific Decadal Oscillation (PDO), which moderates climate over similar spatial scales as ENSO (El Niño-Southern Oscillation) but over much longer time scales (20-30 years). In 1976 a sea surface temperature shift was observed and the PDO switched from a cold phase to a warm phase. This caused a decreased winter mass balance and decreased regional snow accumulation that has been linked with decreased mean mass balance for several western Canadian glaciers. During warm PDO phases dryer air circulates over the Cordillera in winter thus producing less snowpack. In the summer months temperatures are warmer, causing more melt. This results in an overall decrease in mass balance. Conversely, during a cold PDO phase, strong advection of moisture occurs over the Cordillera producing more snow and cooler summers result in less melt (Demuth and Keller, 2006).

The glaciers of western Canada and the Pacific Northwest of the USA have experienced a rapid retreat during the 20th century. It has been suggested that this relates to the unusually warm and dry conditions brought on by large scale circulation patterns, as has been observed between 1924-1944 and 1976-1998, mainly during the winter and spring months. In addition to the influence of PDO regimes, winter precipitation is also influenced by ENSO. El Niño years are typically associated with lower precipitation and greater glacial melting whereas La Niña years produce higher precipitation and less melting.

Overall, summer temperatures are believed to influence mass balance of continental glaciers more than winter conditions and exhibit greater variability. While large interannual variability is observed in net, summer and winter mass balances, the overall trend in mass balance in the Canadian Cordillera has been consistently negative starting in the mid-1970s, coinciding with the PDO shift.

Sub-bottom facies

Five acoustic facies are identified in the lake from nine lines run to cover the entire area of the lake. The facies are named A-E and represent depositional setting rather than a chronological sequence (Fig. 7). Four of the facies (A-D) are believed to be composed of unconsolidated sediment whereas the fifth facies (E) represents bedrock.

Facies A:
Facies A consists of a well defined sediment package with decimeter-scale internal reflectors. This facies is 7-10 m thick but can be as much as 12 m thick. It generally occurs at depths of 35 m or more and thins from the south end of the lake to the north end (Fig. 7a, b, c). The reflectors follow the lake bottom topography and remain parallel on the lake bottom until they begin to pinch out at the north end of the lake. Facies A overlies Facies C in parts of the lake whereas in other parts of the lake it is overlain by Facies C. Facies A is interpreted as Holocene glaciolacustrine sediments deposited into the lake by meltwaters derived upvalley, primarily during the late spring and summer. This is consistent with the description of glaciolacustrine sediments from other paraglacial lakes.

Facies B:
Facies B consists of thick (5+ m), massive, chaotic deposits and is limited to the area adjacent to the outwash plain. It is interpreted as an offshore (0-35 m water depth) continuation of the coarse (pebble/cobble/boulders) deposits carried downstream from the glacier to the lake (Fig. 7a). Onshore equivalent sediments indicate fines are typically washed from these deposits, leaving behind the load the stream can no longer carry.

Facies C:
Facies C consists of massive deposits that are acoustically similar to Facies B, but this facies is confined to the steep sides of the lake. These deposits are interpreted as equivalent to the mass movement (i.e. rockslide) deposits observed along the steep banks of the lake (Fig. 7c).

Facies D:
Facies D consists of massive, gas-rich deposits that were only observed in the eastern bay, in the shallow (typically less than 5 m water depth), wetlands at the head of the bay. These deposits probably consist of organic-rich, methane-rich gyttja (Fig. 7b).

Facies E:
Facies E represents a strong, opaque reflector and is observed in various parts of the lake. It can be relatively flat lying or irregular (Fig. 7b) and can have multiples associated with it (Fig. 7a). It occurs near the lake bottom in the north end of the lake and beneath Facies C on some of the steep sides of the lake. Facies E is interpreted to represent bedrock.

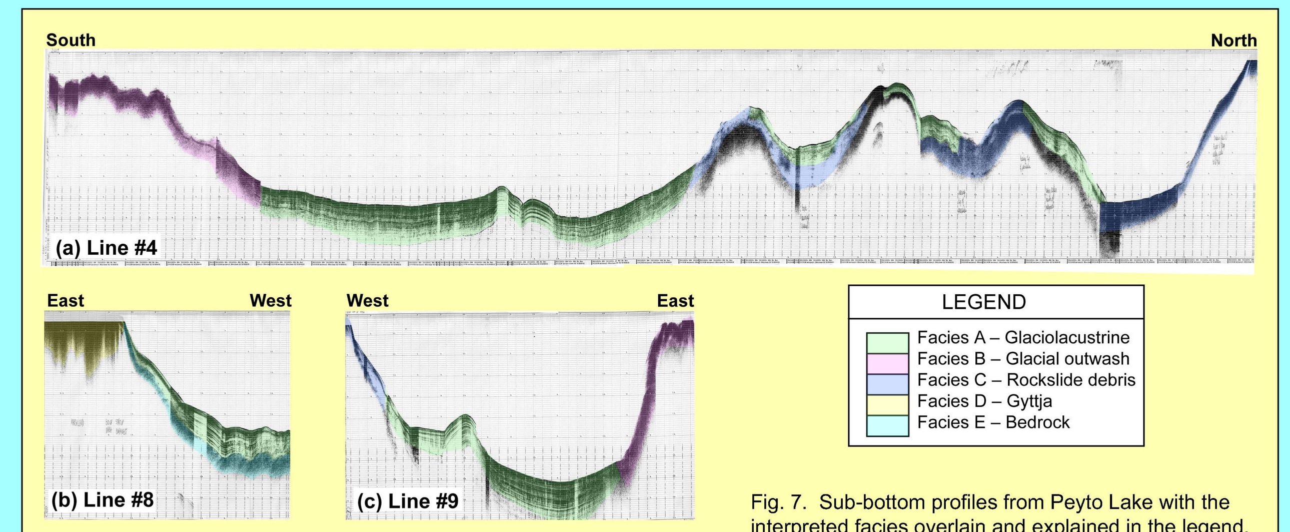

Fig. 7. Sub-bottom profiles from Peyto Lake with the interpreted facies overlain and explained in the legend.

Table 1. Comparison of the glacier history at Peyto Glacier with other sites in the Canadian Rockies (*after Luckman, 2006*).

PERIOD	DIST[1]	PEYTO	ELSEWHERE IN THE ROCKIES
LIA maximum	0	1836-1846 A.D.	1840s (regional) 1700-25 limited earlier advances
Early LIA	0.6	1246-1375 A.D.	1142-1350 A.D. Robson post 1272 A.D. Stutfield
"Two Gerries"	1.0	Post 1500 BP	post 1660 BP Cavell
Peyto	2.5	<2800-3000 BP	post 2830 BP Yoho post 2880 BP
Saskatchewan			post 3100 BP Robson
Older events		No evidence	post 3500 BP Robson post 3840 BP Boundary

[1]Dist = approximate distance upvalley of the LIA maximum position at Peyto (km)

Future Work

- Sediment coring to determine if Peyto Lake sediments are varved.
- If varved sediments are present, paleo-hydrological, paleoclimatological and paleo-environmental reconstructions will be undertaken.
- Ongoing mass balance studies of Peyto Glacier.
- Comparison with work done on other Cordilleran glaciers.

OPEN FILE
DOSSIER PUBLIC
5727
GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
2009

Open files are products that have not gone through the GSC formal publication process.

Les dossiers publics sont des produits qui n'ont pas été soumis au processus officiel de publication de la CGC.

Recommended citation:

Medioli, B.E. and Demuth, M.N.
2009: Reconnaissance sub-bottom profiling studies from Peyto Lake, Banff National Park; Geological Survey of Canada Open File 5727, 1 sheet.

Available from
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

References:

Demuth, M.N. 1997. Effects of short term and historical glacier variations on cold stream hydro ecology: A synthesis and case study. Environment Canada National Hydrology Research Institute Contribution Series CS 96003, 15 pp.
Demuth, M.N. and Keller, R. 2006. An assessment of the mass balance of Peyto Glacier 1965-1995 in relation to recent and past-century climate variability. *In* Peyto Glacier: One Century of Science. (Demuth, M.N., D.S. Munro and G.J. Young Editors). National Hydrology Research Institute Report 8, p. 83-133.
Demuth, M.N. and Pietroniro, A. 2002. The impact of climate change on the glaciers of the Canadian Rocky Mountain eastern slopes and implications for water resource adaptation in the Canadian prairies. CCAF - Prairie Adaptation Research Collaborative, Final Report Project P55, plus Technical Appendices, 162pp.
Holdsworth, G., Demuth, M. N. and Beck, T. M. H. 2006. Radar measurements of ice thickness at Peyto Glacier, Alberta--Geophysical and climatic implications. *In* Peyto Glacier: One Century of Science. (Demuth, M.N., D.S. Munro and G.J. Young Editors). National Hydrology Research Institute Report 8, p. 59-79.
Hopkinson, C. and Demuth, M. N.. 2006. Using airborne lidar to assess the influence of glacier downwasting on water resources in the Canadian Rocky Mountains. Canadian Journal of Remote Sensing v. 32, p. 212-222
Hopkinson, C. and Young, G. J.. 1998. The effect of glacier wastage on the flow of the Bow River. Hydrological Processes, v. 12, p. 1745–1763.
Luckman, B.H. 2006. Neoglacial History of Peyto Glacier. *In* Peyto Glacier: One Century of Science. (Demuth, M.N., D.S. Munro and G.J. Young Editors). National Hydrology Research Institute Report 8, p. 25-57.
Moore, R.D. and Demuth, M. N.. 2001. Mass balance and streamflow variability at Place Glacier, Canada, in relation to recent climate fluctuations. Hydrological Processes, v. 15, p. 3473-3486.
Østrem, G. 2006. History of Scientific studies at Peyto Glacier. *In* Peyto Glacier: One Century of Science. (Demuth, M.N., D.S. Munro and G.J. Young Editors). National Hydrology Research Institute Report 8, p. 1-23.
Stahl, K. and Moore, R.D. 2006. Influence of watershed glacier coverage on summer streamflow in British Columbia, Canada. Water Resources Research 42, W06201, doi:10.1029/2006WR005022.
Wallace, A. L. 1995. The volumetric change of the Peyto Glacier, Alberta, Canada 1896-1966. Unpublished Masters Thesis, Wilfrid Laurier University, Canada.
Watson, E. and Luckman, B. H. 2004. Tree-ring-based mass-balance estimates for the past 300 years at Peyto Glacier, Alberta, Canada. Quaternary Research, v. 62, p. 9-18.

Natural Resources Canada
Ressources naturelles Canada