The Alpine Club of Canada's

State of the Mountains Report

Volume 6, October 2023

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The Alpine Club of Canada's State of the Mountains Report

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Cover: Indigenous guide Tim Patterson works to incorporate his academic education, love for the outdoors, and Nlaka'pamux background. Photo: Ryan Wilkes

Contents: Rope team on the glacier below King Peak at the ACC's 2023 Chess Group General Mountaineering Camp in western Canadian Rockies. Photo: Mary Sanseverino, July 24, 2023.

www.stateofthemountains.ca

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Foreword
Tipping Points

Postfire regeneration after the 2009 Upper Saskatchewan River Valley prescribed burn. Photo: Zac Robinson, 2023.

This year – 2023 – will be remembered across Canada as a year of extreme and deadly weather. Wildfires and smoke, floods, drought, extreme temperatures, tornados, and warming oceans left no region of the country unaffected. Around the world, similar extreme events led to unprecedented loss of property and life. Indeed, June through August marked the world's hottest three-month period in recorded history, with the average global temperature in July more than 1.1°C warmer than last century's average.

Tipping points provide humanity with quantifiable measures of how much change is too much.

Canada's 2023 wildfire season is the most destructive ever recorded. By September, more than 6,132 fires across the country had burned some 16.5 million hectares, an area larger than Greece. In British Columbia alone, the B.C. Wildfire Service reported a total of 2,217 fires in the province this year, burning over 25,000 square kilometres of trees, bush, and grassland, easily the worst fire season measured by land burned. The majority of this year's fires, over seventy per cent, were sparked by lightning, while twenty-three per cent were human-caused (the lowest in the past decade). The cost of fighting those fires exceeded $770 million. (For an in-depth overview of the causes, consequences, and potential for coexistence with wildfire in Canada's mountains, see Lori Daniels' feature essay "Wildfires" in the 2019 State of the Mountains Report).

Underlying conditions of extreme drought and above-average temperatures made western and northern Canada particularly susceptible to wildfires this year. These events are way outside the expectations of natural variability. These 'tipping points' in the climate system are pushing the world into a state where the impacts of climate change may accelerate even faster and become irreversible. Tipping points provide humanity with quantifiable measures of how much change is too much, and point to urgent global, local, and individual efforts required to avoid crossing these thresholds.

Indeed, recognizing tipping points does inspire positive actions. For example, the United Nations General Assembly declared 2022 the International Year of Sustainable Mountain Development, a resolution supported by ninety-four countries. The main outcome was the declaration of 2023–2027 as Five Years of Action for the Development of Mountain Regions.

Adopted by the UN General Assembly, the resolution recognized that the benefits derived from mountain regions are essential for sustainable development, and that mountain ecosystems play a crucial role in providing water and other essential resources and services to a large portion of the world's population. The resolution also recognized that mountain ecosystems are highly vulnerable to the increasing adverse impacts of climate change, extreme weather events, deforestation, forest fires and forest degradation, land-use change, land degradation and natural disasters, with increasing impacts on the environment, sustainable livelihoods and human well-being. Member states were encouraged to adopt a long-term vision to incorporate mountain-specific policies into national sustainable development strategies.

As Canada's national mountaineering organization for the past 117 years, the Alpine Club of Canada is witness to both the adverse and positive impacts of environmental and social change in Canada's mountains. In this sixth volume of the State of the Mountains Report, Tim Patterson summarizes the development of Indigenous Guiding in western Canada. Martha Warren outlines the benefits of accessible sustainability education programs in the mountains. Greg Horne and Suzanne White describe efforts to protect and celebrate unique mountain environments.

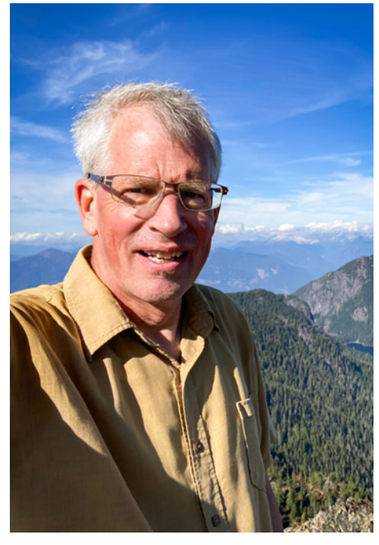
We also recognize the value of research and exploration in learning about the impacts of climate change in Canada's mountains. Sean Carey and John Pomeroy summarize thirty years of collaborative mountain watershed research in Yukon. Emily Jerome and Heather Shaw describe how Living Lakes Canada is tracking climate change impacts in alpine freshwater ecosystems. James Eastham reviews the decisions that led to Parks Canada controlling access to Moraine Lake in Banff National Park. Mary Sanseverino and Lael Parrott share photographs from a photographic survey from Observation Mountain in Banff National Park. And in our Feature Essay, James King provides a comprehensive overview of the challenges of studying dust and its impact on the environment.

We hope that you enjoy this volume of the State of the Mountains Report, and please let us know if you have suggestions for stories that could be included next year.

Lael Parrott, Zac Robinson, David Hik

The Report is co-edited by long-time Club members Lael Parrott, Zac Robinson, and David Hik. Parrott is an environmental geographer at The University of British Columbia, Robinson is an historian at the University of Alberta, and Hik is an ecologist at Simon Fraser University and Chief Scientist at Polar Knowledge Canada. All Fellows of the Royal Canadian Geographical Society, the team is dedicated to geographic literacy and the betterment of mountain peoples, places, and practices.

As Canada's national mountaineering organization for the past 117 years, the Alpine Club of Canada is witness to both the adverse and positive impacts of environmental and social change in Canada's mountains.



Co-editors Lael Parrott (left), Zac Robinson (centre), and David Hik (right) working hard in 2023.

High Latitude Dust

Daniel Bellamy, a PhD candidate, checking a meteorological station deployed next to the dried up river bed near the Kaskawulsh glacier terminus in May 2023. Photo: James King

James King

Dust consists of fine atmospheric particulates (particles in the atmosphere) that come from various sources including soil disturbed by wind, volcanic eruptions, and pollution. This airborne dust is considered an aerosol, and once in the atmosphere, it can change the scattering and absorption of incoming solar radiation and affect local meteorology by altering cloud properties.

The majority of mineral aerosol (dust) emissions are found within the subtropical high atmospheric pressure regions of the globe, in both the northern and southern hemispheres. These particulate emissions are estimated to be between 1.700 and 4.9 billion tonnes per year.[1] However, high-latitude dust emission sources (defined as north of 55°N and south of 45°S) are generally not included in these global estimates because there is still a lack of knowledge surrounding their location, variability, and propensity to emit dust, and various other factors. However, recent research has estimated their current global contribution equivalent to the total annual emissions from Australia, or two-to-five per cent.[2]

The dust emissions at these high latitudes are significant for three principal reasons: (1) the opportunities for sediment (and the nutrients that they contain) to be transported by water in these environments is greatly restricted due to frozen, or snow- and ice-covered, surfaces for the majority of the year; (2) the transport and deposition of dust can greatly alter local radiative budgets by absorbing or scattering relatively acutely angled sunlight,[3] acting as ice or cloud condensing nuclei,[4] further altering radiation budgets,[5] and augmenting insolation on snow, ice, or frozen soils[6]; and (3) anthropogenic climate change impacts are being disproportionately witnessed at high-latitude regions in the form of higher than global average temperature and severe changes in precipitation patterns and type, impacting the delicate balance that limits dust emissions historically occurring in these regions.[7]

Dust source regions hydrologically linked with glaciers are also known as paraglacial landscapes,[8] and as such they respond with various lags and intensities to glacier activity. In most cases, the glaciers are the source of sediments that are acted upon by the wind. These sediments accumulate over time and provide a reservoir of fine sediments taken from the toe of the glaciated region by pro-glacial river systems and deposited downstream as a function of river discharge, topography, and sediment yield. The glacier erosion process is extremely efficient for producing fine material (known as glacial flour) as long as the glacier is active near a region that can produce a variety of depositional environments.[9] Early research on the propensity of these depositional surfaces to produce dust through deflation were truncated by infrequent observations, which concluded that most surfaces would be armoured by coarser particles by almost fifty per cent within one year and almost completely within four years.[10] However, observations were limited to an isolated surface that is not experiencing active pro-glacial deposition every year (e.g., pro-glacial valleys), whereas more recent research demonstrates that there are repeated annual dust emissions from the same or similar emission source regions, albeit with some variability.[11]

Dust and deglaciation

Dust emissions from cold climates are not new nor understudied.[12] During previous cycles of deglaciation, including the most recent deglaciation impacting northern regions starting around 20,000 years before present, large amounts of sediment were transported by seasonal rivers away from the glacier terminus, where wind would act on the finer mode of the deposited material mostly near the margins of the river terraces.[13] Today, we see these accumulations of wind-sorted fine material, mostly preserved in regions where large geomorphic processes have yet to reoccur, but also in currently glaciated regions, known as loess deposits.[14] The loess is the leftover silt-sized material (~sixty micrometers) that has been left behind after the finer dust (<thirty micrometers) was transported by the wind hundreds of kilometres away. Loess deposits can be upwards of tens of meters, and are a reminder on the landscape of the disparate size of the previous icesheets compared to today. However, the reliance on dating techniques of loess with variable precision to recount the frequency of dust emission processes results in an incomplete understanding of the characteristics of cold climate dust emission dynamics.[15]

The glacier erosion process is extremely efficient for producing fine material (known as glacial flour) as long as the glacier is active near a region that can produce a variety of depositional environments.

Examples of Recent Studies

Recent studies have been based in the Yukon, Alaska, Iceland, and Greenland, representing the better characterized high-latitude sources of dust in the northern hemisphere. These studies demonstrate that the potential for dust emissions from pro-glacial sources are at two key periods of the year, restricted by surface conditions: (1) a period of time after winter, when the surface snow begins to melt and exposes the fine valley

A panorama of the A'ą̈y Chù Valley and Lhù'àà̀n Mân during a calm day taken from the top of Thechàl Dhâl in June 2021. This over one-kilometre deep and only four-five kilometre-wide pro-glacial valley is an example of why the current dust emissions from these regions are underestimated from most global estimates. Photo: Felicity Hik

Early morning dust emissions starting up in the Kaskawulsh Valley with undergraduate student Ulrike Richter looking on. Photo: Daniel Bellamy

Attendants of the Kluane First Nation 2023 Research Summit look over the A'ą̀y Chù Valley as part of a tour given by Gùdia Johnson during a dust storm on May 26, 2023. Photo: James King

sediment before being submerged by pro-glacial rivers; and (2) a period of time just before winter begins, when the pro-glacial rivers subside (from the reduction in solar radiation and the subsequent reduced meltwater production) to expose newly deposited glacial sediments.[16] This bi-annual emission conceptual model inadvertently relies on the presence of the wind during these opportunistic surface conditions to produce dust emissions, and although the analysis of local winds has been included as part of these previous studies to determine emission potential (e.g., dust day forward trajectories), they have been mostly constrained to times when there have been observed dust emissions from either satellite or weather station observations.[17] With dramatic changes in climate recently witnessed at high latitudes (e.g., increased average temperatures, changes in precipitation patterns), and specifically within the northern hemisphere due to anthropogenic climate change, the duration of the year that the above conditions (i.e., snow-covered soil or river flow) are present are also changing quickly.[18] These changes translate to the increased duration of the two periods of the year for surface conditions amenable to wind erosion, as the amount of snowfall in many regions is decreasing, and as the air temperature rises the amount of ice that can melt every summer season is eventually decreased.[19]

An example of this climate-change induced end point is the Yukon's Kaskawulsh Glacier in Kluane National Park, which terminates at a continental divide. Due to anthropogenic climate change, rapid glacier melt has concurrently extended the pro-glacial delta at unprecedented rates and carved a new channel within the terminal moraine to result in the abandoning of its discharge from one basin to the adjacent basin in 2016.[20] Since this switch, dust emissions from this valley are unabated as the surface waters are only provided by smaller side valleys in the spring or rainfall in the summer, leading to intense dust emission periods from April to October.[21]

The wind regimes that are capable of eroding and transporting dust-sized particles in these and other high latitude regions are characterized by the presence of anomalous synoptic low-pressure ridges, diurnal katabatic flows, and topographically induced (and insolation reinforced) local heat lows under stable conditions.[22] The stability of high-pressure systems over a continent with ice-and-snow covered surfaces provides the potential for an air mass to remain in place for extensive periods of time, but that can also provide a strong pressure gradient between it and anomalous low-pressure ridges that arrive from coastal regions. This interaction between the two contrasting air masses can generate powerful winds draining from the higher elevation regions towards the coast.[23] These types of wind patterns have been responsible for dust events in Iceland and Greenland in the northern hemisphere, and are also a main driver of wind erosion events in Patagonia.[24]

Cars navigate a dust storm crossing the Alaska Highway in late June 2016. Photo: Lance Goodwin

A photo of dust researcher Professor Richard Washington returning back from servicing a dust monitoring station during a dust storm in the A'ây Chù Valley, May 2019. Photo: James King

Katabatic winds

Katabatic winds (from the Greek katabasis, meaning descend) are mainly generated by cooling air by ice-covered elevated surfaces (e.g., glaciers, icefields, ice sheets) during radiative stable periods through the upwards emission of infrared radiation by the ice and subsequently the air above it, creating a cool and dense air mass, which then flows downslope from the differential pressure gradient force of it and the regions at lower altitudes.[25] This intense down-valley air flow is generated in the afternoon to evening when the radiative processes have generated enough cold air to produce a strong gradient.[26] Depending on the strength of the radiative cooling, the low-level jet that is produced can create surface winds easily beyond the threshold for sand or snow movement (five to ten metres per second), but normally has a peak wind strength twenty to 100 metres above the surface.[27] Return or up-valley flow, if any, takes a pathway much higher in the atmosphere (above 500 metres) creating an atmospheric condition that can result in the sustained katabatic flows beyond four-to-six hours synchronous with the end of the day.[28] As these winds are characterised by descending air, they warm adiabatically and can generate a surface drying mechanism for barren soils (e.g., during low river flow conditions in pro-glacial valleys in the spring and autumn enhancing the potential for wind erosion). In strong and sudden katabatic flows, it has been theorized that a hydraulic jump can occur where the down valley flow meets the stable boundary layer in the valley, which for the case of wind eroded sediment in suspension, could create a mechanism to inject the dust higher into the atmosphere.[29] Studies on katabatic flows at mid-latitudes have generated theories around the change in insolation provided by the sun rising or setting providing the energy gradient necessary to reinforce the wind flows from high to low elevations and vice versa.[30] However, in contrast, at high latitudes, the sunrise and sunset periods are more variable, with latitudes greater than 60°N not experiencing a sunset or sunrise between the end of April and end of August, potentially altering this dynamic. Katabatic wind models have yet to be applied for this condition (no sunrise or sunset) in driving erosive winds and presents a strong avenue for future research to better merge ground-based observations with larger-scale atmospheric modeling. Furthermore, the persistence of these thermally driven flows has yet to be fully applied to estimate the relative propensity of high-latitude sources to emit dust under a changing climate.

Katabatic winds (from the Greek katabasis, meaning descend) are mainly generated by cooling air by ice-covered elevated surfaces

Including Local and Indigenous Knowledge

To conclude, I wanted to highlight that although a large amount of the science referenced above focuses on place-based research in high-latitude regions, very few of those studies acknowledge the help that was received directly or indirectly by local communities nor any explicit mention of the Indigenous Nations on whose lands the research was conducted. As a science that studies how past processes may shape the landscape of the future in high-latitudes and the impact it will have on the climate, it is of great importance to include Indigenous methodologies and voices in this research. Recent works have highlighted the importance of these approaches, including providing, for example, ten calls to action for how western science can be done differently to collectively share the responsibility of reconciling the power imbalance of who and what questions science tries to answer.[31] Although this responsibility needs to be shared by researchers, it is also the burden of the funding organizations to support research programs that geniunely strive for inclusion within research design, or even better, to change the funding structure to allow for local nations to guide the research conducted on their lands.[32] The benefits are numerous, but ultimately, they include developing more appropriate science questions to directly inform local policy and climate adaptation at the same time as addressing colonial legacies.

James King is a geomorphologist and associate professor at Université de Montréal in the Département de Géographie. He explores the processes that influence the linkages of nutrient cycles and atmospheric dynamics that govern mineral aerosol emissions and deposition. He has worked in the mountains of northwestern Canada, as well as the USA, Mongolia and southern Africa.

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Indigenous Guiding Today!

The author passing along his knowledge and skills. Photo: Ryan Wilkes

Tim Patterson

What comes to your mind when presented with Indigenous Guiding? If you are like most, early 1800 images of Indian guides with hulking loads on tumplines moving up mountain passes with David Thompson or Jimmy Simpson come to mind. While you would be correct in this assumption of Indigenous historical guiding – today – Indigenous guiding is very much alive; I am one of many professional Indigenous guides operating in the Mountain West. We are few, but we work in several important ways.

Indigenous guiding has recently become popular for those seeking authentic, story-based experiences.

First – Indigenous guiding has recently become popular for those seeking authentic, story-based experiences. Indigenous guides assist non-Indigenous people with understanding Indigenous cumulative experiences, dynamic practices, historical understandings, and transponsive narratives of our changing lands. These elements that make up our ways of knowing bridge the knowledge gap between Indigenous and non-Indigenous. This awareness of our everyday view of the mountains and mountain life provide a richer view of Indigenous perspectives and speak about our daunting environmental crisis.

Second – While small compared to our non-Indigenous guiding cadre, Indigenous guides are growing, with many hiking guides, but a few are seeking Alpine, Ski, and Mountain Guide status. There are also an expanding number of Indigenous guiding companies, like *Girth Hitch Guiding* (https://girthhitchguiding.ca) out of Nordegg, Alberta, or *Zucmin Guiding* (https://www.zucminguiding.com) out of Calgary, Alberta. In the not-for-profit realm, there's *Souls of Miistaki* (https://www.soulofmiistaki.com) in Canmore, Alberta, or *Indigenous Women Outdoors* (https://www.indigenouswomenoutdoors.ca) in Lillooet, British Columbia. These professionally certified Indigenous guides, companies, and not-for-profits are not limited to soft skills of story and culture, but offer the hard skills of climbing, skiing, and backcountry adventures.

Third – Indigenous guiding provides guests and other guides with an understanding of how to work with Indigenous content, history, and knowledge. With greater emphasis on issues related to Truth and Reconciliation, Indigenous guiding can work skilfully in the mountain environment and assist our colleagues in working better with Indigenous content, history, and knowledge. This is not about hiring Indigenous guides or developing an Indigenous program, but working collaboratively with Indigenous guiding companies. These partnerships are vital in developing both companies and guides by working daily to build both program and guiding capacity.

The challenge of Indigenous guiding today is educating both the tourists and the guiding community that we are professional and skilled – *because we are.* The more significant issue is the development of Indigenous guides. Specifically, the cost of both time and money in acquiring the necessary dirt time (time-in-the-field), equipment, and certifications is unattainable for many Indigenous people. The issue of guiding as a viable job option is not top of mind for most Indigenous people. It is still considered a short-term stop gap between "real" jobs. And so, we have a long way to go in recruiting Indigenous peoples into guiding. The most outstanding issues for guiding companies remain the capacity to work with Indigenous guides and the complexity of Indigenous content.

There are many resources, like the Indigenous Tourism Association of Canada, Indigenous Tourism Alberta, and the Association of Canadian Mountain Guides, ready to assist guides and guiding companies in navigating our collective decolonizing efforts.

Tim Patterson is a member of the Lower Nicola Indian Band that belongs to the Scwéxmx ("People of the Creeks"), a branch of the Nlaka'pamux (Thompson) Nation of the Interior Salish peoples of British Columbia. Patterson holds a Masters Degree in Environmental Education, is an accredited ACMG Hiking Guide, and is the founder and owner of Zuc'min Guiding (www.zucminguiding.com), an independent Indigenous adventure tourism company based in Calgary, Alberta.

Above: Tim Patterson at work on the shoulder of Mount Norquay in Banff National Park. Photo: Ryan Wilkes

Right: Guiding on the ice at the Columbia Icefield. Photo: Roam Creative

Moraine Lake Road: Finding a Balance

James Eastham

Parks Canada recently announced that personal vehicles will no longer be allowed to drive to Moraine Lake. Visitors to Banff National Park hoping to access the lake or one of its many hiking trails or climbing routes have one of three options:

- Make a reservation on the Parks Canada shuttle. Shuttles depart for Moraine Lake every fifteen minutes between 6:30am and 6:00pm and cost $8 for adults and $4 for seniors. The final return shuttle leaves Moraine Lake at 7:30pm. Up to ten seats can be booked under one reservation.
- Arrange for transportation on a private shuttle, taxi service, or charter bus licensed by Parks Canada.
- Bike or e-bike the twelve-kilometre-long access road.

While this system meets the needs of the vast majority of visitors, some groups, including climbers and mountaineers, may find accessing Moraine Lake more challenging than in the past.

We wanted to take the opportunity to reach out directly to the climbing community in order to outline the challenges in managing access to one of Canada's busiest destinations, to explain how this decision was made, and the alternatives we considered when planning access changes for 2023.

Why manage traffic at all?

Demand for vehicle access to Moraine Lake has grown steadily and Parks Canada has had to actively manage traffic to ensure emergency access to Moraine Lake and Lake Louise, and to prevent congestion along Lake Louise Drive from backing up onto the Trans-Canada Highway.

In previous years, active traffic management on Moraine Lake Road was only required during the early morning to early evening. In 2022, traffic management was required twenty-four-hours-a-day. No matter how early visitors arrived, they were likely to be turned away. At peak times, one vehicle was turned away every two seconds due to a lack of available parking. Approximately 5,000 vehicles per day – ninety per cent of all vehicles attempting to access Moraine Lake – were turned away.

This number likely includes many climbers who arrived in the twilight hours only to find the access road closed due to a lack of parking.

Moraine Lake in the Valley of the Ten Peaks, Banff National Park. Photo: J.F. Bergeron

Moraine Lake parking lot. Photo: Zoya Lynch

Why not just run an earlier shuttle?

Many online commentators have suggested the easiest solution is for Parks Canada to simply extend the shuttle operational hours. Unfortunately, this is not currently possible.

To understand why, we have to take a step back to examine how Parks Canada balances human use and access to the park with ecological preservation. These mutually supportive goals are the foundation of Canada's national parks system and the Parks Canada mandate.

There are two main wildlife corridors in the Lake Louise area. Both are bisected by roads. The Fairview Corridor, on the west (lake) side of the Trans-Canada Highway, is bisected by Lake Louise Drive. The Whitehorn Corridor, on the east (Park & Ride) side of the highway, is bisected by Whitehorn Drive. Busy traffic periods on these roads act as barriers to wildlife travelling through these corridors. To maintain habitat connectivity, Parks Canada works hard to minimize disturbances in both corridors during the early-morning and late-evening hours to give wildlife opportunity to move for food, mates, and safety. We do this by managing vehicle traffic to maintain predictable periods of low-traffic volumes, including an overnight vehicle restriction on Whitehorn Drive leading to the shuttle Park and Ride. Between 6:00am and 8:00pm, no vehicles are allowed past the junction at the Bow Valley Parkway (Highway 1A) on Whitehorn Drive. Running an early morning shuttle could jeopardise wildlife movement.

Public engagement on the Banff Park Management Plan (2022) revealed strong support for protecting wildlife and wildlife movement corridors. Parks Canada continues to look for ways to maintain or improve connectivity through these wildlife corridors while striving to provide opportunities for a full range of visitors to experience these iconic places.

Ok, but in the meantime, why don't you run an early shuttle from the old Park and Ride location?

The old Park and Ride location is five kilometres east of Lake Louise on the Trans-Canada Highway. It does pose fewer disturbances to wildlife corridors, and coordinating a small number of early morning departures would be a simple enough task. However, returning visitors to this location throughout the day would require running a second shuttle system. Two Park and Ride locations would create confusion for visitors and add complexity and untenable cost to the system that could not be recovered through user fees.

Demand for vehicle access to Moraine Lake has grown steadily and Parks Canada has had to actively manage traffic to ensure emergency access to Moraine Lake and Lake Louise.

The Parks Canada shuttle service for Lake Louise

Parks Canada considered both twenty-four-hour reservable parking and reservable parking outside of shuttle access hours.

Additionally, the Trans-Canada Highway location was decommissioned as a Park and Ride site in response to feedback received during public engagement for Banff Park Management Plan. This was in part due to safety concerns with traffic turning left across the Trans-Canada Highway. Operating from the former location would negate the safety benefits realized from moving the Park and Ride to the Lake Louise Ski Area. During summer season, the decommissioned Park and Ride site now serves as overflow camping for the Lake Louise campground and an inspection station for aquatic invasive species.

If you can't run an early shuttle, why not allow people to reserve parking?

Parks Canada considered both twenty-four-hour reservable parking and reservable parking outside of shuttle access hours. However, these options were deemed infeasible for two reasons.

First, reservable parking requires space to stop and check vehicles against the reservation list. The Moraine Lake Road junction on Lake Louise Drive does not have the space to conduct these checks without causing significant congestion. Even one car stopped for thirty seconds can be enough to cause a traffic jam. The junction's proximity to the Trans-Canada Highway means that congestion can, and in the past did, back up onto the highway in a matter of minutes.

Second, in order to maximize the use of available parking, reservable parking systems also feature timed entry and limits. For example, parking at the Grotto in Bruce Peninsula National Park is reservable for four-hour blocks. The wide variety of visitor needs at Moraine Lake, ranging from those staying thirty minutes to those staying for twelve hours or more, make timed parking difficult to implement efficiently.

Why not create a climber's only parking pass?

There is no practical way for Parks Canada to ensure that only "real climbers" would receive these permits. In practice, anyone could apply, demand would still outstrip supply, and such a system would effectively become a lottery for parking at Moraine Lake.

It's worth noting that prioritizing certain users over others invites questions about who is most deserving of access to national parks. Other groups, such as sunrise photographers or once-in-a-lifetime visitors, would be quick to argue that they too deserved the privilege.

Safeguarding access at the expense of convenience

Reserving transportation through a licensed Parks Canada commercial operator will take more effort for climbers whose needs are not met by the Parks Canada shuttle system. But reserved transportation will also guarantee access to the lake. No longer will you arrive at 2:00am, stoked to begin your climb up the East Ridge of Mt. Temple, only to be turned away. When you have your weather window and make your plans, you will make it to the start of the climb.

Parks Canada aims to protect these extraordinary places while meeting the needs of visitors equitably and fairly. Yet no solution is perfect. We remain committed to improving access to busy places and will continue to make changes to safeguard access for future generations of climbers.

For more information on access to Moraine Lake and Lake Louise, please visit: https://parks.canada.ca/pn-np/ab/banff/visit/parkbus/louise

James Eastham is a Public Relations and Communications Officer for the Lake Louise, Yoho, Kootenay Field Unit, Parks Canada.

Sea to Sky Gondola Sustainability Education Program

Martha Warren

In times of competing and often confusing messaging about sustainability, it can be difficult to be heard. So how best to develop an education program on the subject of Mountain Sustainability?

Dr. James Thornton, GEO Mountains Scientific Project Officer at the Mountain Research Initiative, connected Michael Allchin, Martha Warren, and Scott Williamson, in a collaboration between the Sea to Sky Gondola, GEO Mountains and the Mountain Research Initiative, the University of Calgary, and the Arctic Institute.

The result is a comprehensive program for learners of all ages covering how mountains are created, what changes them, and the shared responsibilities of mountain stewardship. The main pieces of the program are: mountain building; climate and weathering; glaciers, snow, and water; natural hazards; biodiversity; and mountains and people. Careful consideration was given to student engagement, incorporating the natural and social sciences, arts and humanities, and also to accommodating different learning styles.

Built around the question "What do mountains mean to you?", the course structure is circular, asking students to share how they feel on the mountain when they meet at the beginning, and then again during a reflection exercise at the end. In between are a hike, hands-on activities, and demonstrations. We explore questions like: How is a chewy candy bar like a glacier? What is watermelon snow? Why should we count the tadpoles in this vernal wetland? What art has been inspired by mountains?

All age groups do a weather measurement activity to stress the importance of being proactive in the face of climate change, and the power of mass participation in citizen science initiatives. Students consider how weather impacts mountains, and how mountains impact weather, using sling-psychrometers, anemometers, compasses, and soil thermometers.

Teaching the course at the Gondola is an easy fit due to the location. The mountain is more than an outdoor classroom. First of all, it is situated on the traditional, ancestral and unceded territory of the *Skwxwú7mesh* (Squamish Nation.) The summit is at 885 metres, just high enough for visitors to travel from coastal rainforest at base, to the subalpine at the summit. And it is located in *Átl'ka7tsem* Howe Sound, a Biosphere Reserve recognized by UNESCO as being of global ecological

Sea to Sky Gondola, along the Sea to Sky Highway/Hwy 99, just south of Squamish, British Columbia. Photo: Tara O'Grady

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Don't underestimate the school science curriculum. Most visiting students have an excellent grasp already of subduction and tectonic plate movement in general

significance and rich in biodiversity. With a profusion of examples of how mountains are made and change, students can see the rock cycle at work. There is a local volcano (Mount Garibaldi, or *Nch'ka̱y̓*) and folded mountains. Students study how glaciers move and sculpt mountains and carve out a fjord. There are flagging trees and *krummholz*. Roots grow out of rock, and there is an abundance of regolith and duff, felsic dykes, and erratics.

The program is primarily about shared experience and stewardship of mountains around the world, focusing on the extreme at-risk areas of the Hindu Kush Himalaya, South Caucasus, Andes, and East Africa, and on transboundary cooperative efforts. In keeping with the theme of sharing mountains in a sustainable way, all the teaching materials are also shared online. These are open source, available to anyone, at Mountain Sustainability teaching materials and the GEO Mountains site at Mountain Sustainability course. The next step in the program's evolution is to develop further case studies and actively connect teachers with teachers, and students with students, citizen science groups, and environment clubs, so they can connect with each other while doing similar activities.

What have we learned from running the course so far?

Don't hand out the candy bars for the glacier demonstration until you have explained they are in fact for demonstration first, and for eating afterwards.

Don't presume a student's body language tells you whether they are really listening and engaged. It could well be the student who appears asleep during the weather experiments will be the one who later explains to you precisely how an anemometer works.

Don't underestimate the school science curriculum. Most visiting students have an excellent grasp already of subduction and tectonic plate movement in general. They want hands-on experiments and activities that allow for creative expression and problem-solving.

Don't expect reluctance. In response to our attempt to embed emotions with substantive learning, students have shared their personal experiences generously and enthusiastically as demonstrated by their personal reflections in their field guides at the end of the program. Some of the reflections are sketches of wildlife, or doodles, or concrete poetry in the shape of mountains. One had the following words scattered across the page: "In awe, Beauty, Creative, Freedom, Joy, Loved, Open." Student comments have ranged from "Being here makes me want to ski" to deep metaphors about the mountains we climb every day in our minds.

We feel the message is being heard. We hope the students feel heard, too.

Martha Warren is the Education Coordinator at Sea to Sky Gondola in Squamish, BC, and the architect of their new Mountain Sustainability Program.

Sea to Sky Gondola's Summit Lodge. Photo: Paul Bride

It's Dark Dark: Castleguard Cave Designated a Key Biodiversity Area

Greg Horne

New signage in Castleguard Cave's Subway Passage. Photo: Colin Magee

The Wildlife Conservation Society Canada (WCS) is implementing a plan to research, nominate, and assist with the designation of Key Biodiversity Areas (KBAs) across Canada. Their mission reads as follows:

> *Key Biodiversity Areas … are the most important places in the world for species and their habitats. Faced with a global environmental crisis we need to focus our collective efforts on conserving the places that matter most. The KBA Programme supports the identification, mapping, monitoring and conservation of KBAs to help safeguard the most critical sites for nature on our planet – from rainforests to reefs, mountains to marshes, deserts to grasslands and to the deepest parts of the oceans. KBA designation provides a means of highlighting the importance of an area, but does not provide any protections in and of itself. But highlighting these areas should spur federal and provincial and Indigenous governments and companies to take steps to protect the values that have led to their designation as KBAs. The KBA process is also an important tool for identifying areas with high ecological value that are vital for sustaining biodiversity. This can, for example, help us shift the focus of our protected areas planning in Canada away from areas with low or limited biodiversity to more productive and ecologically important areas that will contribute more to protecting biodiversity across larger landscapes.*[1]

On January 30, 2023, a joint media release was made by Parks Canada and WCS after months of evaluation and discussion: "A tiny natural treasure had been found," read the release, "buried deep beneath a mountain."[2] The story was picked up by CBC afternoon radio in Edmonton and Calgary, and a reporter asked me something like how dark the cave is. I explained the cave is about twenty-one kilometres long, light penetrates maybe 200 metres maximum, so most of the cave – like ninety-nine per cent of it – *is dark dark*.

The story was covered by the Royal Canadian Geographic Society.[3] Other online content was posted by BBC Canada, Gripped Magazine, and CTV Calgary. Earlier in December, the WCS showed a short video at the 2022 UN Biodiversity Conference, COP15, in Montréal.

The only Canadian cave nomination for KBA status so far has been Castleguard, the longest in Canada. At least one other cave in British Columbia was considered but rejected because of the risk that the nomination/designation of that cave, without any management protection, might

The only Canadian cave nomination for KBA status so far has been Castleguard, the longest in Canada.

Above: Searching for invertebrates.
Photo: Colin Magee

Left: The Subway Passage of Castleguard Cave.
Photo: Kathleen Graham

Below: Amphipod Stygobromus canadensis inside Castleguard Cave.
Photo: Greg Horne

lead to new or increased impacts to its resources. In the case of Castleguard Cave, it is situated in Banff National Park, and secured by a locked gate. The designation is not believed to change visitation impacts.

WCS states that "[S]ites can be designated under one of five criteria: threatened biodiversity; geographically restricted biodiversity; ecological integrity; biological processes; and irreplaceability." The primary trigger species for the KBA is Stygobromus canadensis, a cave obligate aquatic amphipod only found so far in three locales in the cave. Discovered in 1977 during a major McMaster University expedition lead by Derek Ford, this species of invertebrate, and a much more widely distributed (in Castleguard Cave) aquatic isopod Salmasellus steganothrix, were collected for taxonomic identification. International amphipod expert John Holsinger (Virginia, USA) determined the amphipod was a unique new species, and to this day it has only been found in Castleguard Cave.

Initially, Stygobromus canadensis was found only in shallow pools near the end of the iconic Subway passage, about two kilometres from the entrance. More recently, in this twenty-first century, two additional sites in Castleguard for the species have been found, in a stream near Camp 1 and a still pool enroute to Boon's Sump. The other secondary trigger species for the KBA, Salmasellus steganothrix, is found at a minimum of six sites in the cave: Ice Crawls (side wall inlet), The Pools, Boon's Sump, Subway, near Camp 1, Second Fissure near F7 junction. Undoubtedly, with more dedicated searching, additional sites will be discovered.

Besides the two previous described species, two additional aquatic invertebrates have been found in the cave: a worm (*Rhynchelmis saxosa*), identified by S.V. Fend, collected by the author in Castleguard and Wood Buffalo caves), and a planarian flatworm species. As well, a tiny terrestrial mite (*Robustocheles occulta*) in the back of the cave.

Based on radioactive isotope dating of speleothems (formations like stalagmites), the current human traversable passages in the cave are a minimum of 700,000 years old. This is a very old landscape for Canada, most of Canada's present landscape is ten or twenty thousand years old after being revealed from under melting continental glacial ice. Some of Castleguard's invertebrate species were likely carrying on with their daily business of survival during the past continental-wide glaciation periods, the cave serving as a subglacial refugium for some species of preglacial fauna.

Very little is known about the life cycle of Stygobromus canadensis and Salmasellus steganothrix in the context of Castleguard. What exactly is their food source, how long do they live, what is their reproductive cycle? These and more questions are reasons to continue studying and monitoring them. The fact that a blind unpigmented critter, barely the size of a grain of rice, can capture our attention, even briefly, shows efforts to better understand caves and all the things they contain are worth it.

Isopod Salmasellus soteganothrix inside Castleguard Cave.
Photo: Greg Horne

Greg Horne is a member of the Alberta Speleological Society. He has visited Castleguard Cave more than 20 times over the last 27 years. He is conducting research about the present flood hydrology and ice formation of the cave and its possible connection to climate change.

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1 For more information about the Wildlife Conservation Society, see https://www.wcscanada.org/KBA.aspx

2 See https://www.wcscanada.org/Latest-News/ID/18625/A-tiny-natural-treasure-buried-deep-beneath-a-mountain.aspx. Note: The labelled invertebrate photo is incorrect, it shows another Castleguard species, *Salmasellus steganothrix*.

3 https://canadiangeographic.ca/articles/castleguard-cave-recognized-as-a-globally-significant-key-biodiversity-area/

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Living Lakes Canada: Tracking Climate Impacts on Alpine Freshwater Systems

Sapphire Lake in Kokanee Glacier Provincial Park. Photo: Living Lakes Canada

Emily Jerome and Heather Shaw

Mountains give rise to both torrents and trickles of freshwater. From melting glaciers and snowpacks, rivers and streams cascade down from the alpine, through the mountains, and disperse throughout watersheds. High-elevation headwaters are the lifeblood for people and ecosystems alike. They provide the freshwater that pours through taps, supports the growth of food, and nurtures a diversity of freshwater species, including the iconic Kokanee Salmon. Mountainous rivers and streams also hold cultural, recreational, and intrinsic value. However, these sensitive freshwater systems are changing, and the climate crisis is the catalyst.

A comprehensive and science-based understanding of these sensitive ecosystems is needed.

High elevation ecosystems are more vulnerable to climate change than lower elevation ecosystems. Consequently, they're expected to experience climate impacts more rapidly.[1] Research suggests that small changes in climate can drive large shifts in alpine freshwater systems.[2] Shorter winters, an earlier freshet, and increased rainfall will continue to impact the health and function of alpine ecosystems. This will have a ripple effect on the human and biological communities that share these watersheds.

A comprehensive and science-based understanding of these sensitive ecosystems is needed. There is an urgency to start collecting data to help fill important data gaps, inform water management and decision-making, and support climate change adaptation. Many high elevation areas in Canada have not been actively monitored. It is with this lens that Living Lakes Canada developed its High Elevation (HE) Monitoring Program.

In 2022, the program began surveying two areas nestled among the Selkirk Mountains in the West Kootenays. Located northeast of Nelson B.C., Kokanee Glacier Provincial Park — historically and culturally significant for regional Indigenous communities — is an epicentre for mountaineering, skiing, hiking, and fishing. Sapphire Lake, Lemon Creek, Tanal Lake, and Upper Joker Lake were selected for monitoring here. Farther west to the opposite side of Slocan Lake, the second monitoring area is located north of the majestic Valhalla Provincial Park, and includes Shannon Lake and Huss Creek. Together, the two monitoring areas and their selected sites represent a mosaic of diverse alpine lakes and streams.

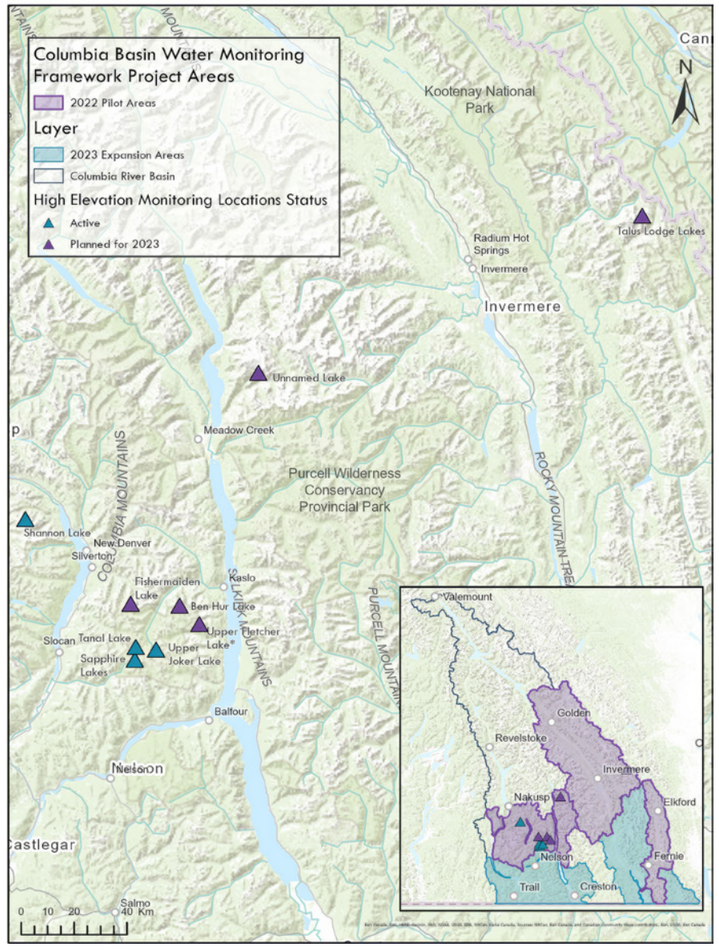
The HE Monitoring Program aims to generate baseline data on alpine ecosystems and establish long-term monitoring to understand how these ecosystems, and the watersheds they are a part of, are responding to climate change. Monitoring field trips to date have included measuring the water's biological, physical, and chemical characteristics, and capturing photographs to track changes on a landscape level. A day of monitoring might include hauling in and pumping up an Alpacka raft to travel the lake's surface in order to map the underwater terrain of an alpine lake — a technique known as bathymetric map surveying. The contours of the lake bottom inform where light and temperature sensors will be installed (two parameters closely linked to aquatic ecosystem function and health). The day might also include collecting samples of benthic macroinvertebrates (small water-dwelling bugs) using a standardized biomonitoring protocol to determine stream health.

Climate, streamflow, snowpack, and glacier mass balance are important alpine features that contribute to the quality and quantity of freshwater systems. The HE Monitoring Program also tracks data related to these features. Climate variability and streamflow parameters are collected through climate and hydrometric stations installed as part of Living Lakes Canada's larger Columbia Basin Water Monitoring Framework project, and in combination with existing climate stations. Snowpack measurements are shared with the program by partnering backcountry lodge owners, and glacier mass balance is collected and published by the World Glacier Monitoring Service.

Monitoring high elevation spaces is only one piece of the puzzle for understanding freshwater systems. The HE Monitoring Program supplies data to the larger, scaled-up monitoring framework developed by Living Lakes Canada. The Columbia Basin Water Monitoring Framework aims to support decision makers in climate change adaptation efforts across the region's watersheds. All the water data collected is housed on a publicly accessible database, known as the Columbia Basin Water Hub. It's here that decision makers, researchers, students, professionals, and the public can access a wide variety of data and information about water. The Water Hub also stores biodiversity observations collected by citizen scientists.

In partnership with the Alpine Club of Canada, the "High Elevation Monitoring Program - Living Lakes Canada" project

2022 High Elevation Monitoring Locations and Proposed 2023 Monitoring Locations



Map of High Elevation Monitoring Locations. Courtesy of Living Lakes Canada

Tarn below Kokanee Glacier in Kokanee Glacier Provincial Park. Photo: Living Lakes Canada

Kokanee Glacier in Kokanee Glacier Provincial Park. Photo: Living Lakes Canada

Glacier Monitoring in Kokanee Glacier Provincial Park. Photo: Nick Waggoner

launched on the popular citizen science platform, *iNaturalist*. It invites anyone recreating in the program's monitoring locations to help gather information on flora and fauna. Volunteer observations collected in 2022 included Hoary Marmots, American Alpine Lady Fern, and Tiger Swallowtails. By participating in the project, ACC members can learn about mountain biodiversity, while contributing important data to the HE Monitoring Program. The *iNaturalist* project has expanded and new volunteers are always welcome. Information on the locations and how to join can be found on the HE Monitoring Program page, where you'll also find an eye-catching report highlighting the program's pilot year.[3]

In 2023, the HE Monitoring Program moved into five new areas, which includes the addition of six lake monitoring sites and six stream monitoring sites. Short-term data from the program is contributing to our understanding of the current state of these lakes and streams. Long-term data established through continuous multi-year monitoring will help us more accurately model climate trends and impacts, which in turn can inform climate adaptation planning for these fragile mountain ecosystems and the watersheds they support.

Emily Jerome is the Communications Coordinator for Living Lakes Canada. She received her BSc in Biological Sciences from the University of Calgary and holds a Master of Arts in Environmental Education and Communication from Royal Roads University.

Heather Shaw is the High Elevation Monitoring Program Manager with Living Lakes Canada. She is a graduate of the Selkirk College Recreation, Fish & Wildlife program and holds a degree in Natural Resource Science from Thompson Rivers University.

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Fire and Ice: The Mount Meager Volcano Project

Christian Stenner & Glyn Williams-Jones

Kathleen Graham and Christian Stenner ascending from Mount Meager's cave system after taking measurements and samples from inside. Photo Adam Walker

In Canada, volcanoes are not widely known elements of the mountain landscape. However, the knowledge surrounding them is of increasing importance as we attempt to understand and mitigate their associated hazards. Application of the US Geological Survey threat warning classification system to Canadian volcanoes results in "very high" threat ratings for two British Columbia volcanoes: Mount Meager (*Qwelqwelústen*) and Mount Garibaldi (*Nch'ka'y'*). Familiar US volcanoes recognized with the same hazard level include Mount Baker and Mount St. Helens in Washington state.[1]

Mount Meager has been described as Canada's most dangerous mountain, due to past volcanic activity, instability resulting in part from geochemical alteration of the rock, and numerous landslides that have occurred in recent times.[2] A fifty-three million cubic metre landslide in August 2010 was the largest recorded in Canada, with numerous additional unstable slopes identified.[3] Mount Meager was also the site of the last large explosive volcanic eruption approximately 2,400 years ago. Its volcanic history beyond Western science and records is known: the name *Qwelqwelústen* can translate as the "burned face place" in *Ucwalmícwts*, the language of the *Lil'wat* people.

Active volcanism and natural hazards at this massif have significant potential impact to the area residents and infrastructure. During a flight over the Job Glacier on Mount Meager in 2016, large openings billowing steam and gas were seen in the glacier. These rare and poorly understood landforms – glaciovolcanic caves[4] – are a unique phenomenon in our cryosphere that form in glacier ice or firn by geothermal heat from below, rather than glacial melt from above which erodes moulins and similar features. The development of new glaciovolcanic cave systems provides a unique indicator of volcanic activity on glacier-mantled volcanoes and can help studies of subglacial environments.[5]

Initial investigations were hindered by volcanic gasses and the difficulties of exploring a glaciovolcanic cave. Due to safety challenges, no direct measurements of fumarole temperatures or undiluted gas compositions were feasible. However, exploration to assess the source of the

Mount Meager has been described as Canada's most dangerous mountain.

Top: Team members traverse across the ice towards the cave entrance. Photo: Glyn Williams-Jones

Middle: The mouth of the glaciovolcanic cave, billowing a vapor cloud of steam and toxic volcanic gases. Photo: Adam Walker

Bottom: Christian Stenner and Kathleen Graham approaching the mouth of the cave while wearing SHIELD life support systems. Photo: Adam Walker

increases our knowledge of similar environments on Earth; their unique microclimates are analogs for conditions that might exist on other planets and moons, and a place to potentially discover unique extremophile microbial life.[7] As subglacial environments remain poorly understood, this work will help expand our understanding of the ecology of the global cryosphere. Exploration of this unique environment also provides an opportunity to study the habitability of subglacial, volcanic associated microbial communities and their survivability during outgassing from beneath the glacier and following their deposition on an icy surface. The plume of volcanic gas and steam from within the cave to an extent mimics Ocean Worlds, such as Saturn's moon *Enceladus*, which exhibits water ejecting from underneath an icy crust. Microbiological studies of the glaciovolcanic cave system likewise support the development and field testing of extraterrestrial missions, such as the Extant Exobiology Life Surveyor (EELS).[8] A NASA/Jet Propulsion Laboratory project, EELS focuses on the development of a robotic snake-like platform capable of exploring and delivering scientific payloads to both englacial conduits on Earth and subsurface features on Enceladus.

Supported by the Trebek Initiative, a partnership between the Royal Canadian Geographical Society and National Geographic, an interdisciplinary team of citizen scientist explorers, students, volcanologists, planetary scientists, and robotics engineers came together in September 2022 for the Mount Meager Volcano Project.

To confront the dangerous gas concentrations, and to validate the capability of specialized life support equipment, new protocols were developed and implemented. Explorers entered the cave system wearing a specialized hybrid self-contained breathing apparatus called SHIELD (Self-Contained Hybrid Integrated Evolution Life-support Device). It was the first use of the equipment in this environment. Inside the fifty-nine-metre-deep cave (equivalent to a thirteen-story building), multiple drops were encountered and then a tunnel containing a subglacial stream leading to a large room and the second entrance. Locating the subglacial fumaroles, measurements were taken of the gas compositions and temperature, along with samples of rock, ice, sediment, and water. The temperature (90.5°C) and gas compositions (CO_2, H_2S, SO_2 and CO) were indicative of an active but dormant volcanic system. The exploration team succeeded in safely navigating the hazardous atmosphere of the glaciovolcanic cave and capturing the first fumarole measurements from a Canadian volcano.

Samples of ice, snow, and sediment were also taken from the subglacial environment and near the caves. Portable VNIR/SWIR (visible to near infrared and short-wavelength infrared) reflectance spectrometry revealed microalgae in H_2S elevated areas of the glacier and minerals associated with hydrothermal alteration and oxidation on the surface near the fumarole and within the cave. Preliminary microbiological analyses showed biomarkers such as ATP and chlorophyl, and, recently, microbial life that favors sulphurous environments was confirmed from samples taken from inside the cave and on the ice surface. Such observations, when tied to phylogenetic analyses of the microbial communities in these areas, provide insights into which metabolic (chemo-autotrophic, photosynthetic) pathways may be dominant in these environments. Long term, these analyses may reveal interesting pathways for unique microbial life.

The EELS sensor head was also successfully tested by being lowered into the glaciovolcanic caves, crevasses, and on glacier surfaces while collecting data from its 3D LiDAR, four stereo camera pairs, Inertial Measurement Unit, and pressure sensor. This field testing has provided large amounts of data to support development of the prototype's autonomous mobility capability. Subsequent phases of the project will involve week-long campaigns at Alberta's Athabasca Glacier in the Fall of 2023, 2024, and 2025, with the primary objective of testing the entire EELS robot in the field. At the end of the project, the EELS team will have demonstrated a state-of-the art robotics platform capable of exploration into glacial environments. This could enable planetary missions to ocean worlds and support future exploration of subglacial channels here on Earth.

Following the 2022 Mount Meager Volcano Project expedition, outreach efforts have included presentations to over 2,000 young people, discussions with the *Lil'wat* community, and ongoing development of media products for STEM education and natural hazards outreach. Thanks to this interplay of volcanism and ice at Mount Meager, the Earth science and astrobiology communities have a new and exciting suite of research directions to pursue.

A view from just inside the glaciovolcanic cave towards the upper entrance. Photo: Adam Walker

Christian Stenner looks up from the floor of the volcano within an incredibly large subglacial room, the light coming from one of the cave entrances. Photo: Kathleen Graham

Christian Stenner has been a caver for nearly twenty years, completing expeditions in North America as a member of the Alberta Speleological Society. He is a Fellow of the Royal Canadian Geographical Society and a Fellow International of the Explorers Club. He also serves as the Alberta provincial coordinator for Alberta/British Columbia Cave Rescue Service.

Glyn Williams-Jones is a Professor and Chair in the Department of Earth Sciences at Simon Fraser University, where he leads the Physical Volcanology Group and is Co-Director of the Centre for Natural Hazards Research. Both Stenner and Williams-Jones are former contributors to the ACC's State of the Mountains Report.

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Kathleen Graham and Christian Stenner after their successful first descent into the most hazardous atmosphere of the cave system. Photo: Adam Walker

Mountain Hydrology Research in Yukon

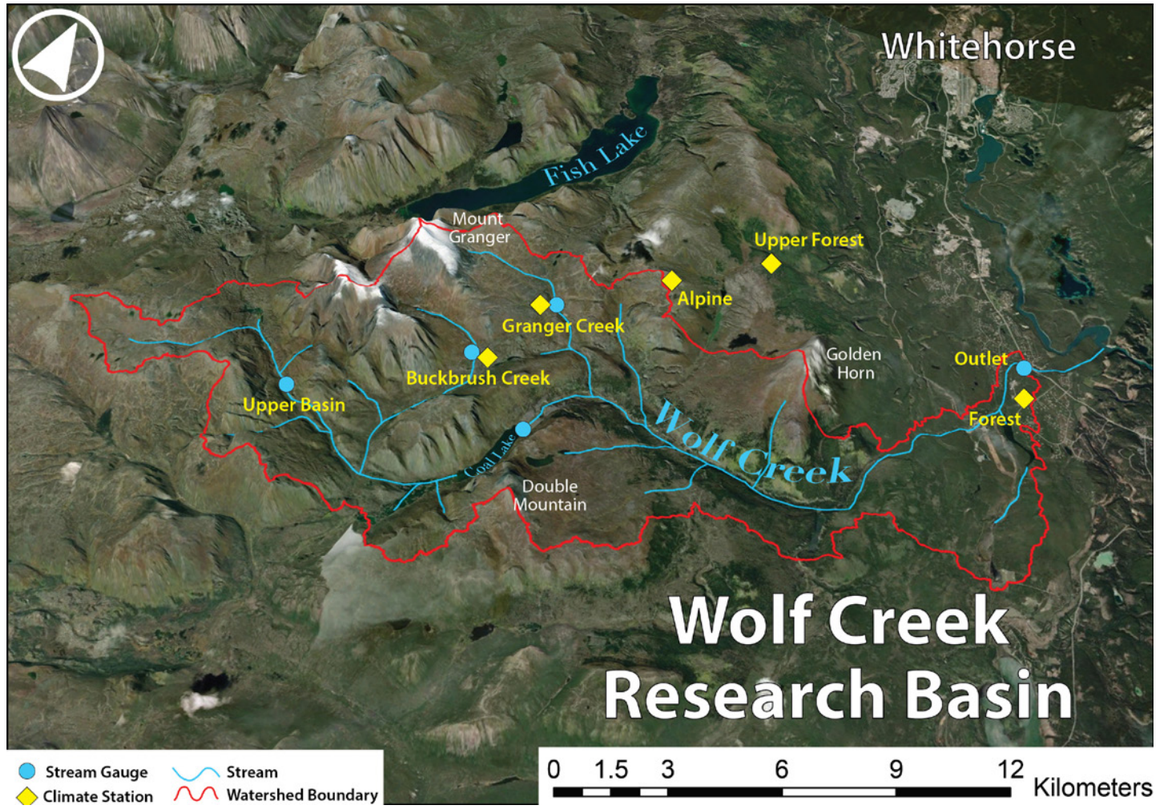
Sean Carey and John Pomeroy

The Wolf Creek Research Basin and Coal Lake in the fall. Photo: Sean Carey

Rapid climate and hydrological changes are detrimentally impacting Canada's western mountains, and communities are struggling to understand and adapt to this new reality. Sparse observations and limited scientific capacity hamper our ability to forecast changes across Canada's northwest. As part of the Global Water Futures program, the largest university-led water-focussed initiative in the world, the Mountain Water Futures (MWF) project worked to provide Canadians with tools and techniques to manage water futures in Canada's western mountains. This region is undergoing rapid change as glaciers recede, snowpacks diminish, permafrost thaws, and vegetation shifts. By working with a host of partners, MWF maintains several observatories where mountain hydrometeorological processes are studied and long-term data is collected. Work at these observatories helps guide the development of numerical models that can be used to predict future scenarios, which supports stakeholders in decision-making and policy development. Here, we selectively highlight the ongoing partnership MWF has forged with the Government of Yukon, and the development of a next-generation flow forecast system.

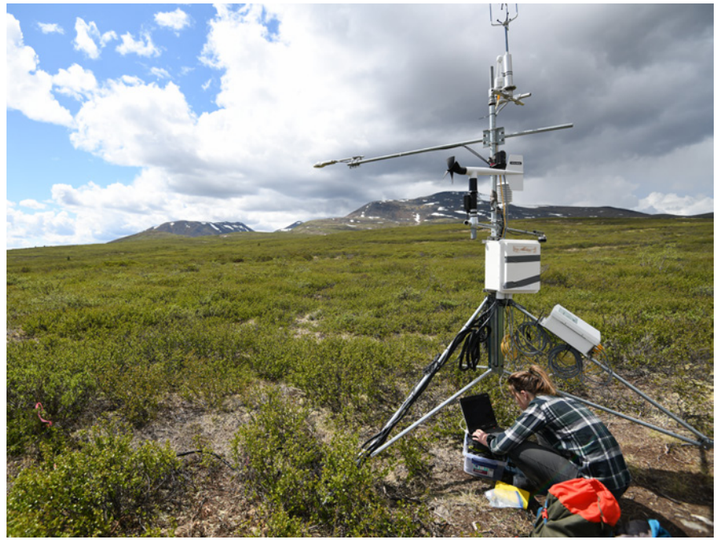
The Wolf Creek site was selected to represent many headwater basins along the far northern reaches of the North American Cordillera.

In 1992, the Wolf Creek Research Basin (WCRB) was established in the sub-arctic mountainous headwaters of the Yukon River, near Whitehorse, Yukon.[1] The site was selected to represent many headwater basins along the far northern reaches of the North American



Map of Wolf Creek and its infrastructure, Yukon Territory

Dr. Erin Nicholls checking on one of several climate stations within the basin. Photo: Sean Carey



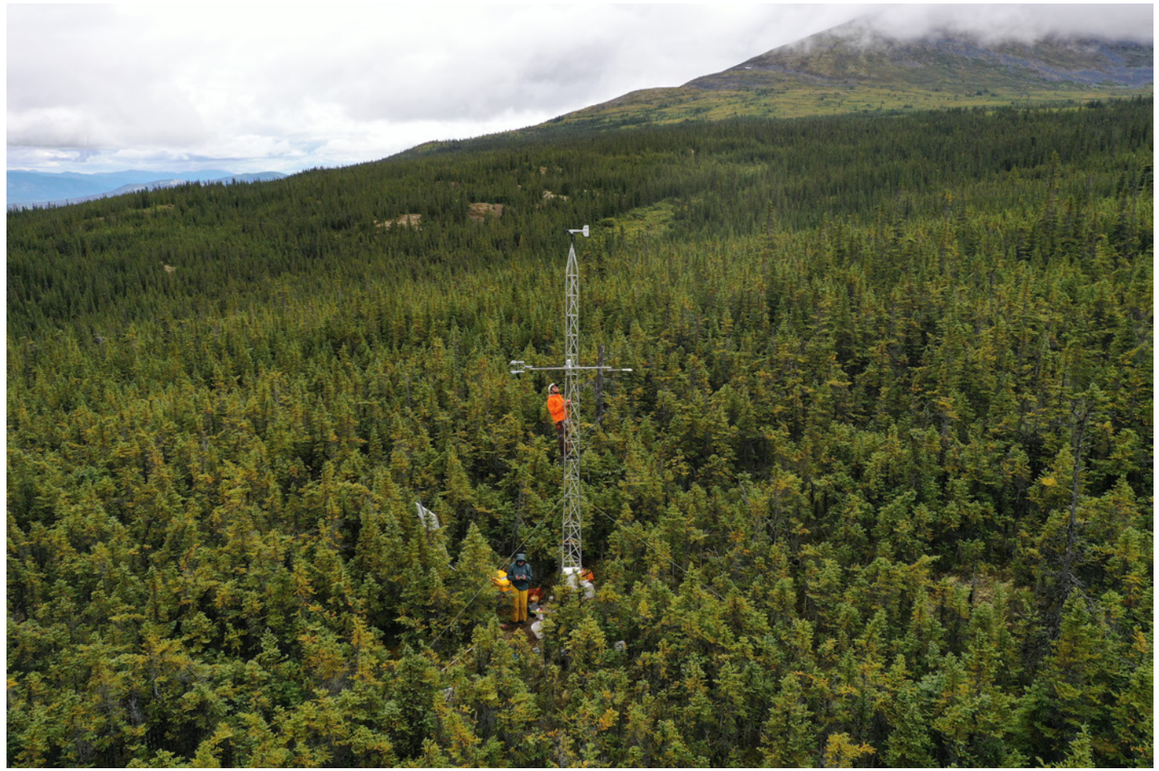
Cordillera. At the time, the role of WCRB was to provide science-based evidence for decision-making about water, climate, and the biosphere, and to provide a testbed to help resolve deficiencies in hydrological models that performed very poorly in cold climates. Careful measurements of climate, the water cycle, and ecological change across its different elevation-based biomes provided the foundation to support large-scale scientific programs and have attracted scientists and students from across Canada and the world. In the face of steep declines in federal government monitoring capacity, these programs have positioned WCRB as a sentinel observatory that is part of several global environmental monitoring programs. In 2022, WCRB celebrated its thirtieth anniversary and deepened its partnership with the Government of Yukon through a formal agreement to share physical space and resources, and to continue to collaborate in tackling emerging scientific issues. While the past thirty years have produced a considerable scientific legacy, maintaining and diversifying WCRB becomes increasingly important to help understand environmental change and provide guidance for adaptation initiatives.

The Yukon River Basin (YRB) is one of the main mountain rivers of North America and is shared between Canada and the US. The Canadian part covers almost half of the Yukon and a small portion of the province of British Columbia, while the US part falls entirely within the state of Alaska. Prior to 2018, there was no predictive hydrological model for the Canadian portion of the YRB, despite the severe flood damages to the many Yukon communities that lie on its main river and tributaries from high streamflow and river ice breakup events. Global Water Futures, working with Yukon's Department of Environment and Environment and Climate Change Canada, set up a streamflow forecasting system for the YRB. This project developed, calibrated, validated, and operationalized a physically based streamflow discharge forecasting system for the Yukon River and several of its tributary rivers within the territory. There were several challenges in doing so due to the cold regions hydrology of the basin. The southern part of the YRB is characterized by large glaciers at high elevations (up to 4,700 metres above sea level) with steep slopes, thus generating considerable runoff. There are also mountain ranges on the eastern and northern boundaries of the basin, while the western areas are milder in slope and partially forested. Snow redistribution, snowmelt, glacier melt, and frozen soil processes in winter and spring, along with summertime rainfall-runoff and evapotranspiration processes, are key to the simulation of streamflow in the basin.

The Yukon River Basin streamflow forecasting system uses the MESH (Modélisation Environmentale Communautaire - Surface and Hydrology) hydrological land surface model. MESH is a state-of-the-art semi-distributed cold regions hydrological land surface model, which models both the vertical exchanges of heat and moisture between the land surface and the atmosphere, as well as the horizontal transfer of water to streams that is routed hydrologically to the outlet of the basin. MESH relies on meteorological forecasts from Environment and Climate Change Canada (ECCC) to run the model across Yukon, with the system running on Amazon cloud services for reliability, and sends automated daily reports to the Government of Yukon.

As the surging waters of the Klondike River near Dawson City subsided late in the spring of 2023, Yukon government officials reflected on how these hydrological modelling efforts helped them better forecast flood events and issue flood advisories. This is the third year in a row that Yukon communities have seen record flooding in at least one area. Anthony Bier, acting senior hydrologist at the Yukon government, stated: "In my experience, over the past two years especially, we use the reports on a daily basis." Bier added that the model outputs help forecasters gauge the warning level for the advisories they release to the public, and in

Forest meteorological tower. Photo: Sean Carey



View of upper forest climate station. Photo: David Barrett

The Wolf Creek Research Basin in winter. Photo: Sean Carey

turn help emergency response officials understand the level of risk an event presents to communities. "We rely on this relationship triad between the [Government of] Yukon, the University of Saskatchewan, and McMaster University," he said. "One day we hope to run the forecasts ourselves, but we are not quite there yet."

Further resources:

Global Water Futures: http://gwf.usask.ca

Mountain Water Futures: http://www.mountainwaterfutures.ca

Wolf creek Research Basin: http://wolfcreekresearchbasin.ca

Dr. Sean Carey is a Professor in the School of Earth, Environment & Society and heads the Watershed Hydrology Group at McMaster University. His research interests include hydrological, biogeochemical, and land surface processes in cold environments and has been working in Wolf Creek since 1995.

Dr. John Pomeroy is the Canada Research Chair in Water Resources and Climate Change at the University of Saskatchewan. His research interests are on the impact of land use and climate change on cold regions hydrology and water quality, and improved prediction of climate change impacts, especially floods and droughts. Dr. Pomeroy has been working in Wolf Creek since 1992.

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Iconic Geology: Two Parks Canada Sites Named to Exclusive Global List

Suzanne White

The Tablelands, Gros Morne National Park. Photo: Guillaume Paquette- Jetten

The Burgess Shale, Yoho National Park. Photo: Shannon Martin

The iconic Canadian Rockies are home to stunning vistas of mountain tops, rivers, and glaciers that feed our senses, and populations of unique plants and animals, from the whitebark pine to the grizzly bear. High in the mountains of Yoho National Park, the rocks tell a story of the Earth before tree roots and elk hooves, where a vast sea hosted the beginning of life as we know it, in a place we know as the Burgess Shale.

A short time later (geologically speaking), the continents were crashing together on Canada's east coast, pushing rock from the earth's mantle and ocean crust towards the surface. Today we see these mantle rocks at the Tablelands – a barren, flat-topped mountain in Gros Morne National Park – in dramatic contrast to the surrounding forested hills. The great diversity of rocks reminds us of these violent beginnings and that these landforms display more than recent glacial handiwork.

In early 2023, Gros Morne National Park and the Burgess Shale site in Yoho and Kootenay national parks were named to a prestigious international list of the first 100 geological heritage sites, an initiative of the International Union of Geological Sciences (IUGS) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). This new international designation acknowledges iconic locations

Anomalocaris canadensis, one of the iconic fossils from the Burgess Shale. Photo: J.B. Caron, Royal Ontario Museum

A panel of earth scientists evaluated 181 proposals from across the world and selected outstanding geological sites from fifty-six countries.

around the world, recognized for their contribution to the development of geological science and their relevance and impact in understanding the Earth and its history.

There was a lot of competition to be included in this inaugural list. A panel of earth scientists evaluated 181 proposals from across the world and selected outstanding geological sites from fifty-six countries, including a total of six sites from Canada, with the Burgess Shale and Gros Morne as the two Parks Canada-administered locations.

The first 100 IUGS geological heritage sites were announced during the IUGS 60th anniversary celebration in October 2022 in Zumaia, Basque Coast UNESCO Global Geopark in Spain. Parks Canada's own Todd Keith from Yoho National Park attended the IUGS conference and gave a presentation to the international community on the significance of the Burgess Shale.

The Burgess Shale is one of the most significant fossil sites in the world, first identified in 1909, but with new discoveries still being made today. The sites preserve evidence of some of the earliest complex animals that existed in the oceans of our planet over 508-million-years ago. Most of these fossils are of soft-bodied animals that are only very rarely preserved. The research and discoveries at these mountain sites shed new light on how life began and developed in the world's oceans giving us new insights into the evolution of complex life.

The Burgess Shale is critical to our understanding of how animals evolved shortly after the Cambrian Explosion, when life began to flourish and diversify. It is a reference for paleontologists globally, such that similar Cambrian deposits around the world are often referred to as "Burgess Shale-type" fossil sites. The Burgess Shale fossils were first documented in 1909 and the vast majority of research has focused on a few sites in Yoho National Park but since 2008, scientists have explored related sites in Kootenay National Park, leading to the discovery of several new species, and to new understandings.

There are lots of ways to learn more about the Burgess Shale:

- Book a guided hike to see the fossils in person in Yoho or Kootenay national parks
- Visit the joint Parks Canada / Royal Ontario Museum website https://burgess-shale.rom.on.ca/
- Visit Parks Canada's Google Arts and Culture story about the Burgess Shale at https://artsandculture.google.com/story/_AXBopUHLSXaEQ
- Visit the Royal Ontario Museum in Toronto and tour the Willner Madge Gallery, Dawn of Life

Gros Morne National Park is acknowledged as having one of the world's best exposures of the Moho – or Mohorovičić discontinuity – the boundary between crust and mantle rocks. In the Tablelands, you can walk across a "fossil" Moho, rocks normally found up to seventy kilometres beneath the Earth's surface that were pushed up as continents collided more than 450 million years ago. These rocks illustrate the birth and death of an ancient ocean, and the creation of both supercontinents and mountain chains. This geology has played a key role in our understanding of plate tectonics and the formation of mountain systems.

Gros Morne National Park is proud to be recognized as a UNESCO World Heritage Site for its scenic beauty and unique geology. Walking through Gros Morne is like taking a trip back in time to when an ocean was dying over half a billion years ago. The "Moho" can be found in the Tablelands in the southern section of the park, where its rusty orange rock – peridotite – is so rich in metals that it is toxic to most plants. Walk the Tablelands Trail and explore this bizarre and beautiful landscape with a Parks Canada guide, or hike it on your own with a virtual tour available on your phone through the Parks Canada app.

You can see this amazing geology at Gros Morne's Discovery Centre and throughout the park's many trails:

- Hike the Green Gardens trail down to a shoreline of volcanic rock to coastal cliffs, beaches, fertile meadows, and towering sea stacks.
- Summit Gros Morne Mountain and enjoy views of the glacier-carved cliffs while standing on the rocks formed from the shallow water sands of a long-destroyed ocean.
- Explore the layered rocks of Green Point's seaside cliffs where tiny fossils mark the point for the boundary between the Cambrian and Ordovician periods.

Both Gros Morne National Park and the Burgess Shale and the surrounding mountain parks are known as places of inspiration, reflection, connection, renewal, and transformation. By continuing to build connections to these places, we can foster tomorrow's stewards of these extraordinary places.

For more information on the conference and geoheritage, visit iugs-geoheritage.org.

Suzanne White is a Public Relations and Communications Officer for the Lake Louise, Yoho, Kootenay Field Unit, Parks Canada.

An example of Moho in Gros Morne National Park. Photo: R. Hingston

Bow to Peyto and Beyond: A 1903 / 2022 Photo Comparison

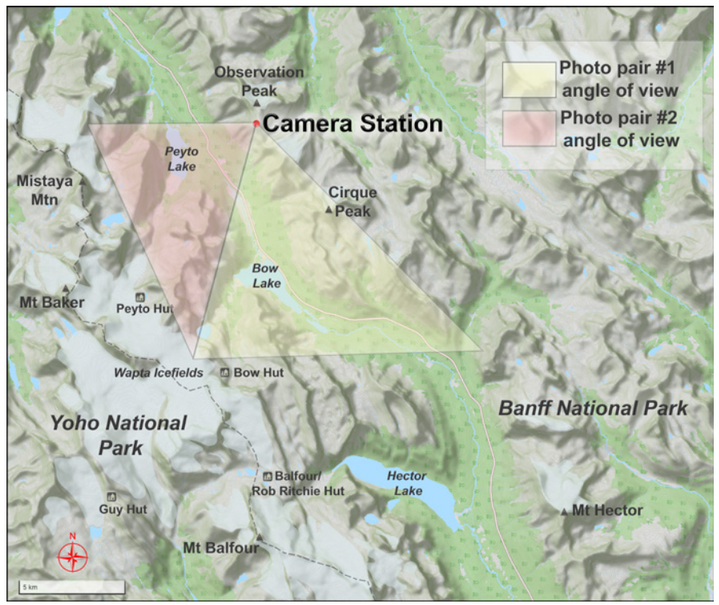
A panoramic view over the Wapta Icefield from below Observation Peak. Inset photo: A.O. Wheeler, 1903. Framing image: M.E. Sanseverino & L. Parrott, Aug 22, 2022.

Mary Sanseverino and Lael Parrott

In the summer of 1903, Dominion Land Surveyor Arthur Wheeler, along with his brother Hector and assistant Morrison Bridgland, were working on Observation Peak in what today is Banff National Park.

They established a camera survey station on the false summit south of the main peak. This vantage point afforded them outstanding views of the area, from Mount Hector to beyond Peyto Lake. They set up their transit and camera and proceeded to take readings and photographs – all part of the process allowing them to make topographic maps of the region for the Dominion government.

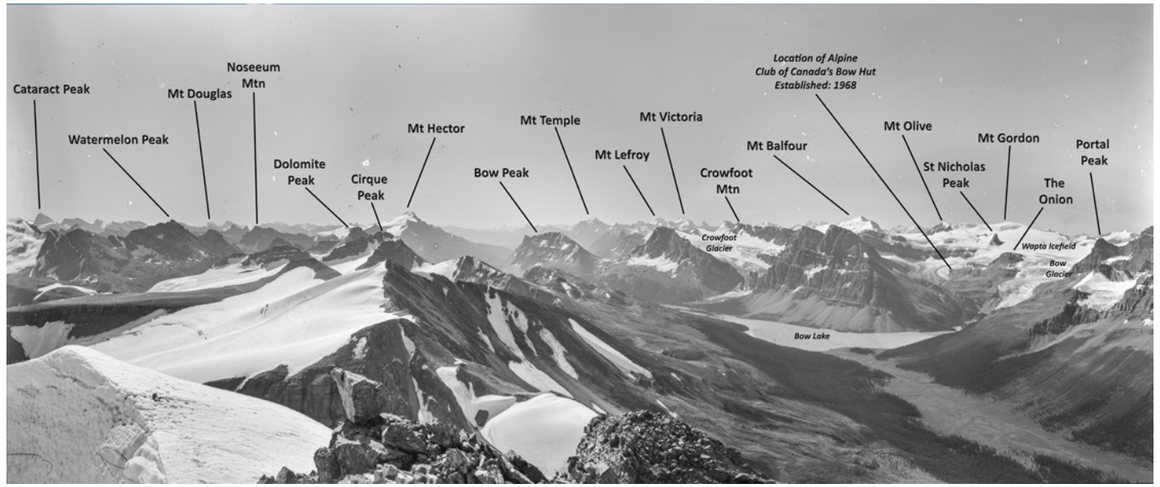
Observation Peak camera station, Banff NP, Alberta, Canada.

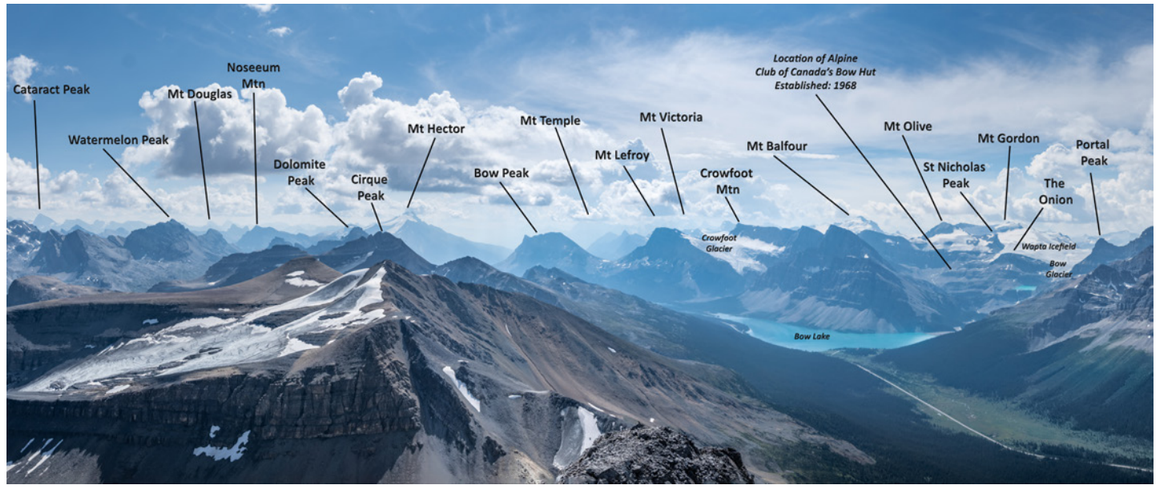


On August 22, 2022, Mary Sanseverino and Lael Parrott – both from the Alpine Club of Canada – retraced Wheeler's footsteps. Working on behalf of the Mountain Legacy Project (University of Victoria, mountainlegacy.ca), Parrott and Sanseverino located the exact position of Wheeler's camera station and repeated the images taken 119 years earlier. The historic/modern photo sets tell a tale perhaps more compelling than any written word could capture.

Mary Sanseverino is a Teaching Professor Emerita, Department of Computer Science, Faculty of Engineering, University of Victoria. She is also an alumna of UVic's Mountain Legacy Project. She currently serves on the Nomination Committee for the Alpine Club of Canada and is the ACC's Corresponding Delegate to the International Climbing and Mountaineering Federation's Mountain Protection Commission.

Lael Parrott is the past Alpine Club of Canada Vice-President for Access & Environment. She is Professor of Sustainability and Associate Dean for Faculty & Research in the Irving K. Barber Faculty of Science at the University of British Columbia, Okanagan.

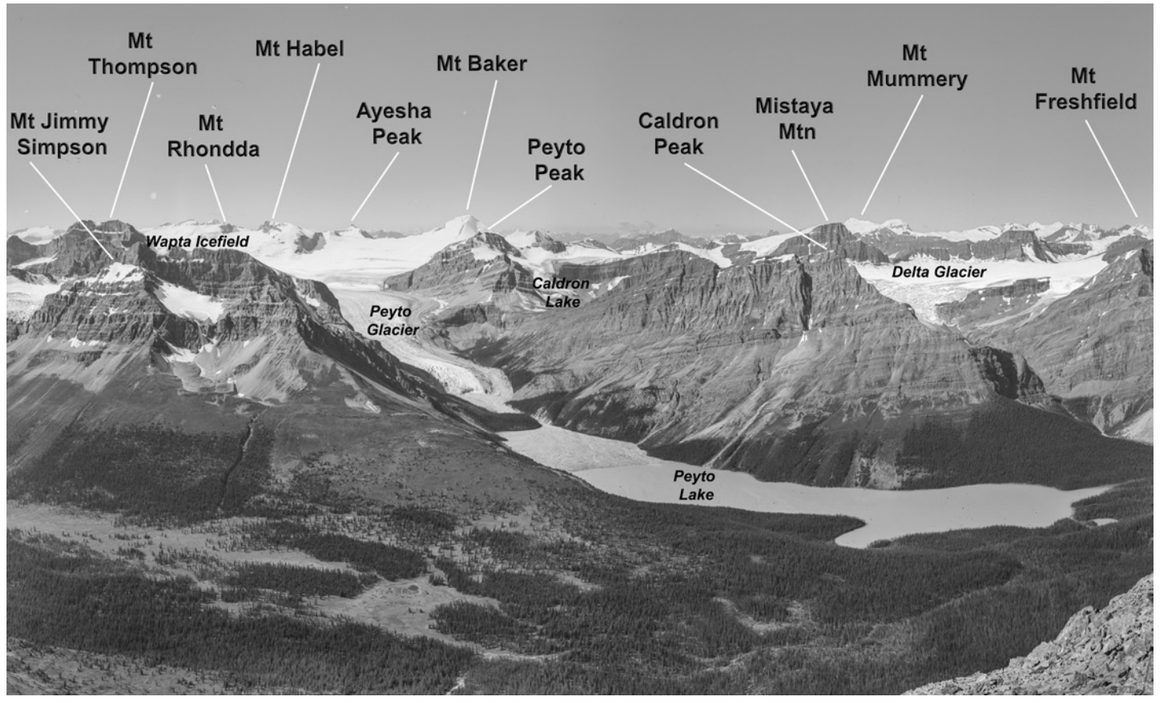




Top: Photo 1. Below Observation Peak looking southward over Bow Lake, Banff National Park, Alberta, Canada. Photography: A.O. Wheeler and team, 1903. Image courtesy of Library and Archives Canada / Bibliothèque et Archives Canada. Ecopy #e011083102 – 103.

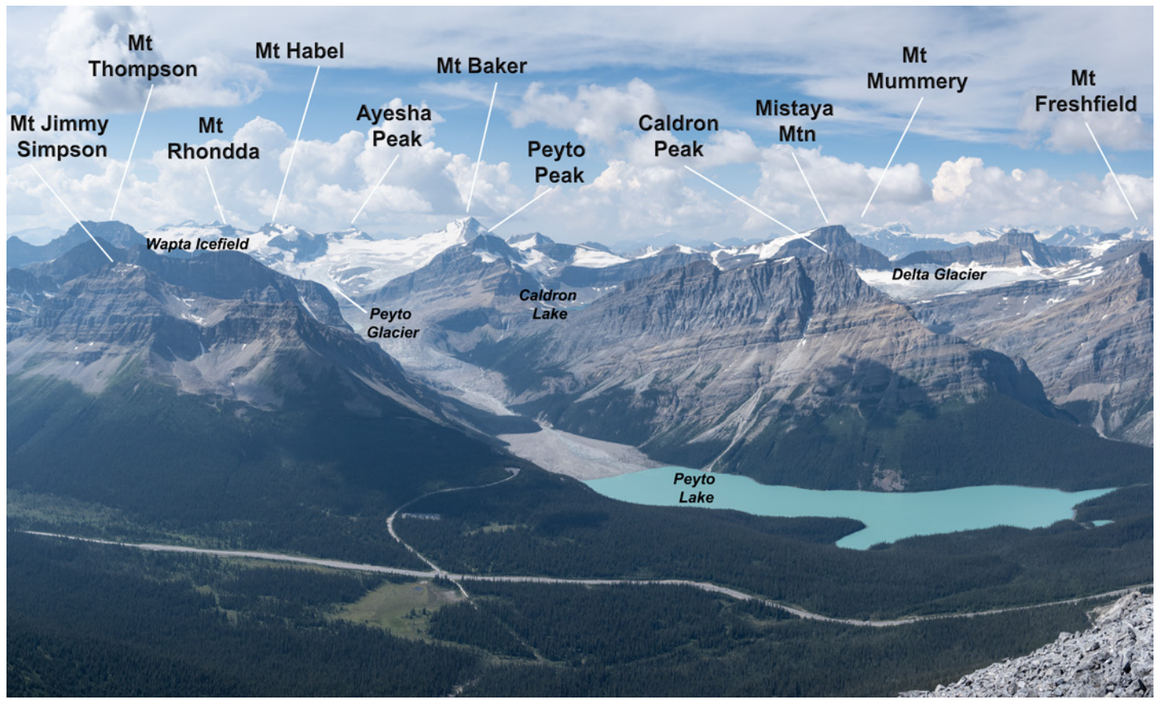
Middle: Repeat of Photo 1. Looking southward over Bow Lake in Banff National Park. Photography: M.E. Sanseverino & L. Parrott, for the Mountain Legacy Project, Aug 22, 2022.

Bottom: Lael Parrott setting up to help determine the actual 1903 camera station location. Repeat photos are taken after the historic camera station is pinpointed. Photo: Mary Sanseverino.



Above: Photo 2. Below Observation Peak looking south west over Peyto Lake, Banff National Park, Alberta,Canada. Photography: A.O. Wheeler and team, 1903. Image courtesy of Library and Archives Canada / Bibliothèque et Archives Canada. Ecopy #e011083104 – 105.

Below: Repeat of Photo 2. Looking south west over Peyto Lake in Banff National Park. Photography: M.E. Sanseverino & L. Parrott, for the Mountain Legacy Project, Aug 22, 2022.



Participants and staff at the ACC's 2022 International Basin General Mountaineering Camp, in the Purcell Mountains, British Columbia. Photo: Aloke Surin, July 8, 2022.

Established in 1906, The Alpine Club of Canada is a not-for-profit organization that promotes alpine experiences, knowledge and culture, responsible access, and excellence in mountain skills and leadership.

http://alpineclubofcanada.ca

Western anemone (Anemone occidentalis) below Soprano Peak in the Cayoosh Range south west of Lillooet, British Columbia. Photo: Mary Sanseverino, August 10, 2022

The State of the Mountains Report

Canada's diverse mountains define much of the country. Mountains provide critical natural and economic resources like water, biodiversity, forests and recreational opportunities. They're also home for many people living in small and remote communities. But both local and global changes influence these places in ways that are still not well understood. The ACC's State of the Mountains Report is a contribution to compiling and sharing the best available knowledge about Canada's mountains, from coast to coast to coast.

www.stateofthemountains.ca

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