Living in an Era of *Lasts*: A study on the evolution of the 'riskscape' of the Abbot Pass area

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Enroute to Abbot Pass Hut with my dad in 2012!

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Research Output

1. Introduction

Mountain environments are experiencing glacial retreat, diminished snowpacks, and permafrost thaw (Adler et al., 2022). These changes threaten the livelihood and wellbeing of mountain guides, the safety all of mountaineers (Mourey et al., 2019; Purdie & Kerr, 2018; Watson & King, 2018), and the culture and history of mountain communities. For example, this summer saw countless rockfall events across the European Alps, catastrophic glacier collapses struck Italy, Chile, and Kyrgyzstan, and permafrost thaw contributed the destabilization of countless pieces of alpine infrastructure. In Canada, the country experienced its first loss of a national historic site to climate change, the Abbot Pass Hut. In 2016 slope instabilities, connected to the loss of permanent ice and snow were first noticed on the pass to Abbot Hut and by 2018, $600,000 had been spent on remediation (Parks Canada Agency, 2022). Safety concerns in 2019 and COVID health measures in 2020 stopped stabilization efforts. The heat dome of 2021 was the final nail in the coffin, causing 114 cubic metres of material to fall from the slopes supporting the hut causing irreparable damage (Parks Canada Agency, 2022). In 2022 Abbot hut was dismantled and removed. The loss of this historic hut and the dramatic change in its surrounding environment has had a huge impact on the mountain community in Canada; changes like these have and continue to enhance objective hazards in mountain environments with consequential impacts that range from reduced accessibility of popular mountaineering objectives to increased technicality of alpine climbs to injury, and even death.

Mountaineers operate in the heart of this fast-changing environment, however, while much is known about physical change in mountain areas, deficits in understanding human dimensions of these changes persist (Gurgiser et al., 2022). Specifically, in Canada, there is limited literature examining mountain guides' experiences of, and adaptation to, climate change (n =1, Rushton & Rutty, 2023) and there is a complete absence of work that assesses the impacts of climate change on recreational mountaineering in Canada (McDowell & Hanly, 2022). The lack of understanding regarding these human dimensions limits our ability to identify key vulnerabilities mountaineers are facing, or may face in the future, and constrains our ability to devise adaptation plans capable of securing safe and prosperous futures for all mountain enthusiasts. Focusing on Banff National Park and specifically the Abbot Pass area of Lake Louise, a world-class mountain climbing destination (Pullan, 2016), my research has attempted to address this gap by using an interdisciplinary, mixed method approach to characterize mountaineers vulnerability as well as response to change in Canada's iconic yet increasingly imperiled mountain environments.

2. Methodology

To achieve my goals, I adopted a mixed methodology that incorporates statistics, photography, and textual analysis. The following provides a brief summary my methodology:

i) *A Spatio-Temporal Trend Analysis* was used to detect trends in temperature and precipitation that may be affecting glaciers, snow, and permafrost around Banff National Park. To do this, data was obtained from Environment and Climate Change Canada from the 'Banff' station located at 51°11'00.000" N, 115°34'00.000" W and at an elevation of 1383.7m. This meteorological station is approximately 55km, as the crow flies, away from Abbot Pass Hut and was chosen because it is the only meteorological monitoring station that provided a consistent data set for my entire study period (1923-2022). Using this data, a Mann-Kendall test was performed to identify statistical trends in mean, minimum, and maximum temperature as well as total precipitation between 1887 (when the data starts) to 2022 (e.g., Mullick et al., 2019). A Sen's Slope test was then used to identify the magnitude of trends in the same variables.

ii) *Repeat Photography* was used to identify if and how meteorological changes found by the trend analysis have impacted mountaineering routes in and around Abbot Pass over the last century. To do this, historic photographs from the Whyte Museum of Abbot Pass, Mt Lefroy, and Mt Victoria were identified and selected based on availability, image quality, and input from local guides. Some of the images have been taken and some are in the process of being re-taken. This process was delayed by challenges associated with access to Lake O'Hara and an unexpected injury which prevented me from climbing last season. The Image Analysis Toolkit (Sanseverino et al., 2016) has been and will continue to be used to align historic and contemporary images, facilitating a descriptive analysis of land cover change over time.

iii) *A Content Analysis* (e.g., Payne & Payne, 2004) was performed on textual archives from the Whyte Museum (e.g., Abbot Hut registers) and contemporary sources (e.g., Mountain Condition Reports) that describe climbs identified in the repeat photographs. A total of 5811 trip reports were transcribed into Excel, 5601 of which came from Abbot Hut registers and 210 from Mountain Condition Reports (MCR). The MCR reports that described climbing in the Abbot Pass area were included to make up for the missing Abbot Hut Registers between 2006-2022. Once all materials were transcribed and collated in Excel, they were deductively coded according to when and where the group climbed, conditions on the route such as the presence of snow, ice, or dry rock, and any encounters or observations of hazards such as rockfall. These codes were then quantified according to percentage of trip reports per decade to allow for comparability in the face of inconsistency regarding the number of reports per year, the number of reports that contained relevant information, and missing data. Codes were then examined and compared over time to identify change, bridging the trend analysis with the photographic analysis.

3. Findings

Part 1: Climate Change in Banff National Park

In Banff National Park there has been a statistically significant average increase in annual mean temperature of 0.11ºC warming per decade, yielding an increase of 1.46ºC in annual mean temperature since 1887 (Table 1). However, the greatest increase in temperature was found to be the average annual minimum temperature, which increased by 1.74ºC (0.13ºC/ decade) over the study period whereas the average annual maximum temperature saw the smallest change, increasing by 1.40ºC (0.10ºC/ decade). With regards to when this warming is occurring, the greatest warming was found in the late winter and early spring months (January, February, March) and summer (June, July, August) months, with minimum temperatures again seeing the greatest statistically significant increases. These trends are in alignment with the global mountain literature which states that surface air temperature is rising in mountain ranges throughout Western North America, the European Alps, and High Mountain Asia (0.3ºC ± 0.2ºC per decade) (Hock et al., 2019).

With regards to precipitation, a negative trend was found in almost every month (with the exception of April, September, and October) (Table 2). However, the only statistically significant trend was found in January. Unfortunately, the data set available did not consistently distinguish between types of precipitation (i.e., snow vs. rain) and thus, no analysis could be performed on how this critical ratio has or has not changed over time. However, the decreasing trend in precipitation in winter months could suggest a decrease in snowpack accumulation which would be in alignment with the global (e.g., Hock et al, 2019) and Canadian (e.g., Mortezapour et al., 2022) literature that suggests climate change has resulted in an overall decrease in low elevation snow cover and snow duration in recent decades.

Table 1. Summary of monthly temperature and precipitation trends between 1887 to 2022.

	Temperature									Precipitation		
	Mean Temp. Trend	MK p-value	Sen's slope	Max Temp. Trend	MK p-value	Sen's slope	Min Temp Trend	MK p-value	Sen's slope	Total Precip. Trend	MK P-value	Sen's Slope
Jan.	↑	**0.003**	0.025	↑	**0.002**	0.023	↑	**0.004**	0.026	↓	**0.003**	-0.092
Feb.	↑	**0.001**	0.026	↑	**0.002**	0.024	↑	**0.002**	0.029	↓	0.346	-0.025
Mar.	↑	**0.0001**	0.026	↑	**0.001**	0.020	↑	**0.0001**	0.033	↓	0.556	-0.018
April	→	0.833	0	→	0.953	0	↑	0.343	0.004	↑	0.537	0.022
May	↑	0.438	0.002	→	0.856	0	↑	0.054	0.005	↓	0.859	-0.011
June	↑	**0.023**	0.006	↑	0.545	0.002	↑	**0.0001**	0.011	↓	0.241	-0.071
July	↑	**0.007**	0.008	↑	0.620	0.002	↑	**0.0001**	0.013	↓	0.395	-0.051
Aug.	↑	**0.000**	0.012	↑	0.086	0.019	↑	**0.0001**	0.016	↓	0.166	-0.087
Sept.	↑	**0.001**	0.014	↑	**0.004**	0.019	↑	**0.003**	0.008	↑	0.743	0.015
Oct.	→	0.978	0	↑	0.470	0.004	↓	0.334	-0.003	→	0.965	0
Nov.	→	0.901	0	↑	0.869	0.001	→	0.948	0	↓	0.167	-0.061
Dec.	↓	0.072	-0.013	↓	0.069	-0.012	↓	0.108	-0.014	↓	0.251	-0.045

Part 2: The Impacts of Climate Change on Climbing Conditions in Lake Louise

The rising temperatures and diminishing precipitation identified above have had a tremendous effect on the physical environment in the Abbot Pass area of Lake Louise in Banff National Park, leading to consequential impacts for climbers in this region. Inspired by the loss of Abbot Pass Hut in the summer of 2022, the following sections share the results of a first of its kind analysis that attempts to piece together how this environmentally, culturally, and historically significant area changed in response to a warming climate over its all too brief existence. To do this, I will describe change in the two primary approach routes to Abbot Pass Hut as well as the two most popular climbs in the area.

Approach Routes to Abbot Pass Hut:

There are two main approaches to Abbot Pass Hut; climbers can either approach through Lake Louise, via the historic Swiss Guides Route also known as the 'Death Trap' or through Lake O'Hara via the gully, which has been widely nicknamed the '*most famous scree slope in the Rockies'* (Figure 1).

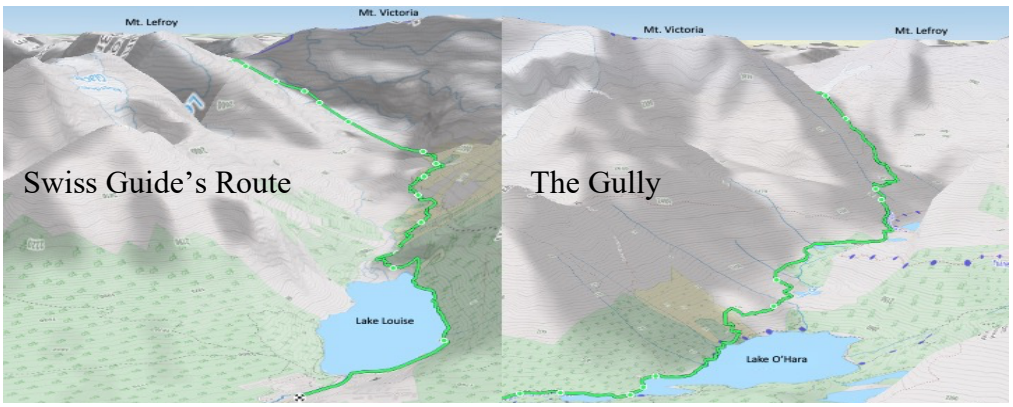


Figure 1. Topographic map of the approach routes to Abbot Pass/ Abbot Hut (Source: FATMAP).

i) The Swiss Guide's Route, Lake Louise

The Swiss Guide's Route on the Lake Louise side of Abbot Pass starts as a walk along the famous Lake Louise, past the historic Tea House and up on the Plain of the Six Glaciers trail. From the Look Out of this popular hike climbers can take various routes down Lower Victoria Glacier's lateral moraine and walk up to the toe of the glacier. The Lower Victoria can then be climbed up to Abbot Pass Hut, taking a route that weaves around crevasses and balances the threat of serac fall from Upper Victoria Glacier and rockfall from Mt Lefroy. Historically, this route was a fairly simple walk up on snow in the summer months often described as *'an easy ascent from Louise'* (Abbot Hut Entry, August 12, 1966). In fact, during the 1920's to 1950's, the biggest concern while travelling up the Swiss Guide's Route was the risk of avalanches due to too much snow on the glacier and surrounding peaks during summer months. Over time, this historic climb has changed tremendously (Figure 2). Rising temperatures and decreasing snowfall have contributed to substantial environmental change. Depicted in Figure 2, since 1929 the Lower Victoria Glacier has significantly retreated, the firn line has risen, and permanent snow patches have disappeared. The consequences of these changes on the historic Guide's Route is that climbers are increasingly encountering problematic crevasses, bare ice, and rockfall while climbing in this area.

Figure 2. Abbot Pass taken in the summer of 1929 and 2022.

Problematic Crevasses:

In this analysis, a problematic crevasse was defined as a crevasse that impedes travel, the consequence of which is a more complicated and/ or more technical climb and in some cases, represents an insurmountable challenge. The challenges presented to climbers by such problematic crevasses are highlighted by an entry in the Abbot Hut register by a team of climbers who attempted to repeat the route used for the first successful climb of Mt Lefroy:

> *"Came up the Death Trap with two others yesterday to retrace the original routes of Phillip Abbot and his trading expedition 101 years ago, and of Peter Sarbach's successful climb 100 years ago. At 6:30AM while crossing the bare ice of Lower Victoria Glacier the 3 of us had great excitement imagining we were in the same place as Sarbach's party a century ago, to the hour. Unfortunately, our excitement did not last, climbing up the Death Trap to find a massive gaping*

crevasse blocking the last 300-500 feet to the hut. We did find a small snow bridge to the right but falling rock and rotten snow, as well as a very sketchy exposed traverse over the crevasse, we made the decision to back off. Lefroy would have to wait. Came up from Lake O'Hara today in order to climb Victoria tomorrow on its centennial." (Abbot Hut Entry, August 4, 1997).

Similar descriptions of crevasse-related challenges while climbing the Swiss Guide's Route increasingly appear over time, with a steady increase from the 1970's through to the 1990's and a dramatic surge in problematic crevasses beginning in the early 2000's (Figure 4). Notably, from 2016-2021 (when the data ends due to closures), 57% of trips on the Swiss Guide's Route describe encountering such crevasses.

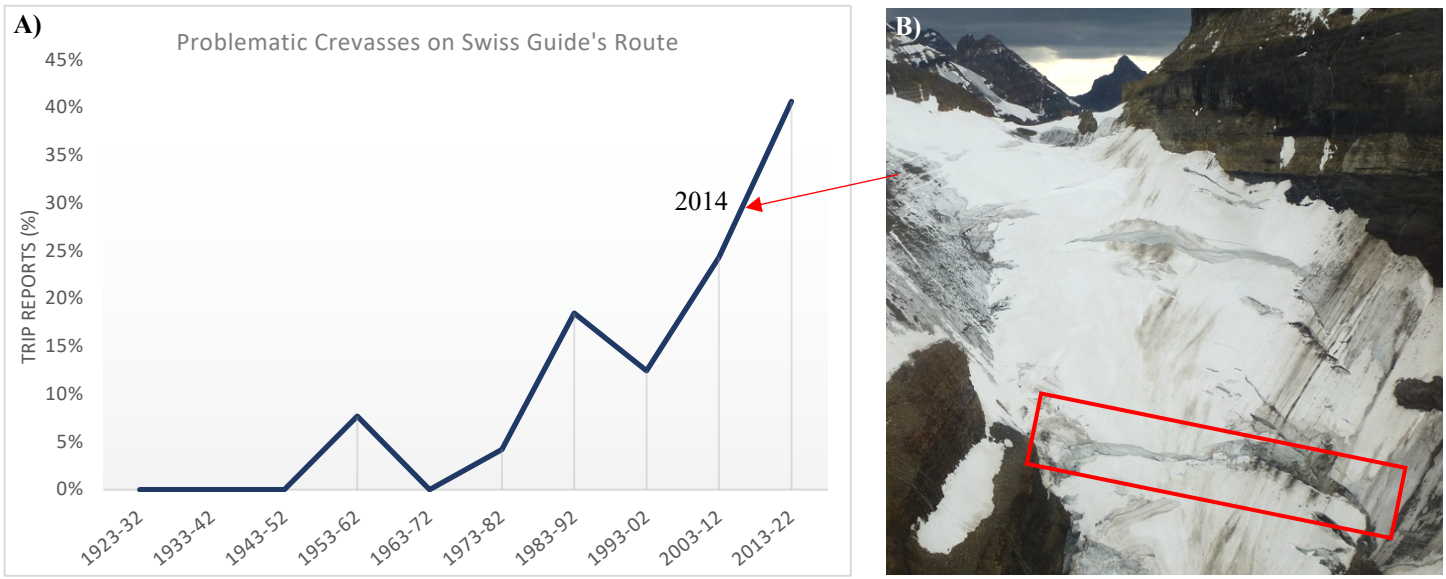


Figure 4. A) Percentage of reports that encounter problematic crevasses on the Swiss Guide's Route. B) The 'Death Trap' taken from MCR August 4, 2014. Red box highlights crevasse spanning the entire route.

In addition to the increase in number of problematic crevasses encountered on this route, the seasonality of large, impassable crevasses has lengthened (Figure 5). In the first half of the study period, climbers overwhelming encountered problematic crevasses in August (57%), with a handful in July (29%) and September (14%). Similarly, in the second half the study period climbers most frequently encountered problematic crevasses in August (39%), with a good chance in July (27%) and September (25%). However, climbers can now expect to also encounter crevasse-related challenges as early as April (2%) and as late as October (2%), expanding the season from 3 to 7 months long.

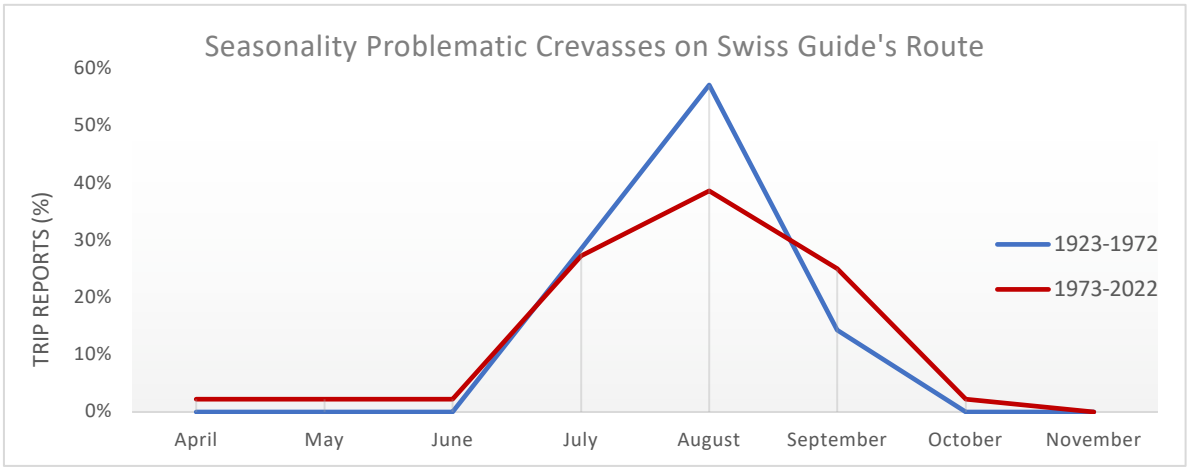


Figure 5. Percentage of reports according to month, broken into the first and second half of the study period, that describe encountering problematic crevasses while climbing the Swiss Guide's Route.

Changes in Snow Coverage

In addition to changes in crevasse patterns, a distinct trend emerged in the amount of snow covering the Lower Victoria Glacier on the Swiss Guide's Route (Figure 6 A). Throughout all summer climbing months (i.e., June, July, August) from the 1920's through to the late 1950's, there are reports describing deep snow on the glacier:

> *"Big ice falls and avalanches. 3 feet of snow. Weather good. From Lake Louise to O'Hara* Abbot Hut Entry, June 28, 1943)
>
> *"Three feet of snow on the glacier"* (Abbot Hut Entry, July 21, 1948)
>
> *"Climbed from teahouse. Good snow until icefall. No crust at all – sunk into knee- even to hips for a while."* (Abbot Hut Entry, June 17, 1955)
>
> *Left Lake Louise 5:50AM, here at 10:50AM. 50-pound packs; otherwise, nice hike over snow not too hard or too soft."* (Abbot Hut Entry, August 23, 1957)

Some reports begin to emerge in the late 1960's of thin snow on the Lower Victoria and some bare ice poking through, however these reports are very limited and only appear in August and early September after a summer of melt. In contrast, the second half of the study period saw both an increase in the number of climbers encountering bare ice on the route and an expansion of the season where one may expect to find bare ice (Figure 6 B). In the second half of the study period (1973-2022), a climber may encounter bare ice on the glacier of this route anytime from May through to November. This is a dramatic increase from 2 months of the year to 7 months of the year.

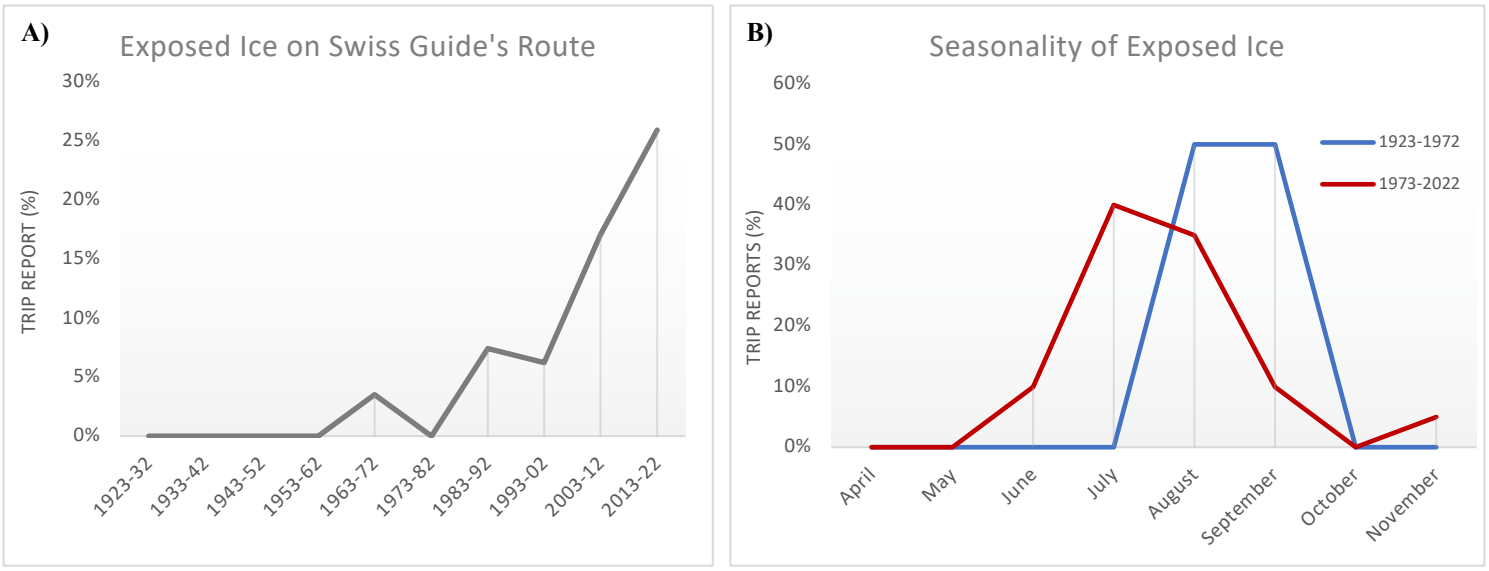


Figure 6. A) Percentage of trips that encounter bare ice over time while climbing the Swiss Guide's Route. B) Percentage of trip reports according to month, broken into the first and second half of the study period, that encounter bare ice.

Rock and Serac Fall

Rockfall and serac fall on the Swiss Guide's Route was not reported in the Abbot Hut Registers until August 10, 1974, when a climber wrote *"Close call in the death trap (falling seracs).".* In the 1970's about 5% of trips up the Swiss Guide's Route reported rock or icefall, this number doubled to about 10% in the 1990's, to 25% in the mid to late 2000's, and up to 35% by 2022 (Figure 7 A). However, the percentage of reports of rock or serac fall on an annual basis shows a substantial increase in rock and icefall events starting in 2017, with an average of 80% of trips up the Swiss Guides Route

reporting rock or ice fall events between 2017-2021 (when the area was closed). 2017 and 2018 standout, as each year saw 100% of trips report rock or icefall.

Like crevasse and exposed ice encounters, the season of rock and icefall is lengthening. In the first decade where rock and serac fall were reported, these event exclusively occurred in June, July, and August, with the majority of events occurring in August (Figure 7 B). In contrast, the most recent decade (2013-2022) saw an expansion of this season to April through to September effectively doubling the length of season (3 to 6 months) that climbers may experience heightened rockfall risk.

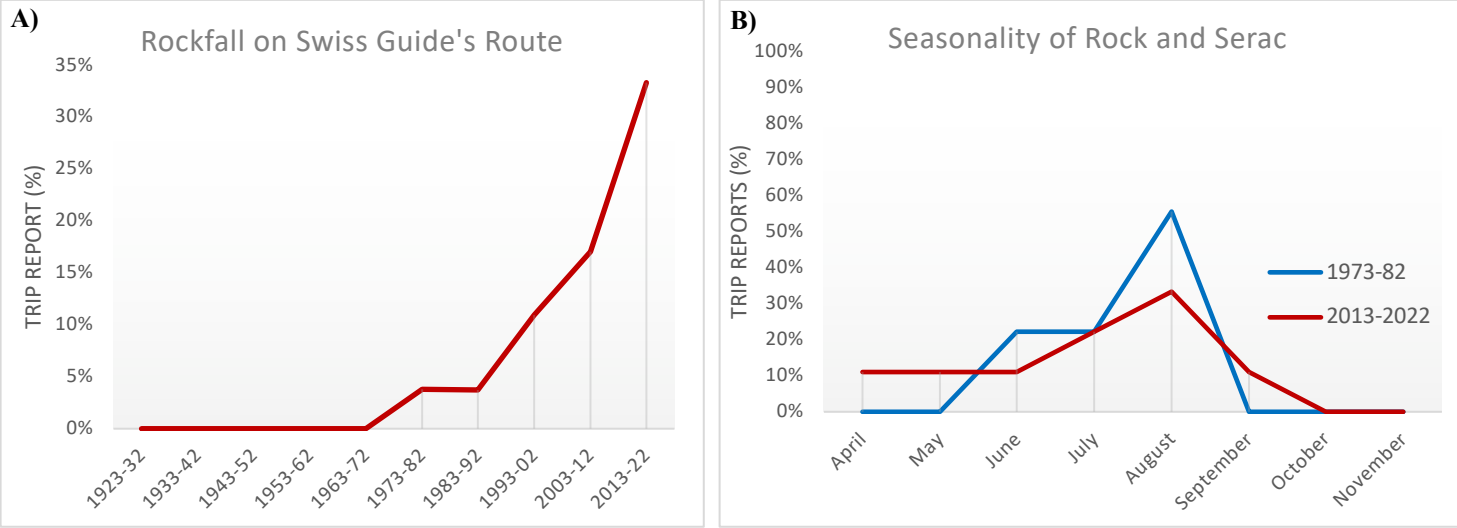


Figure 7. A) Percentage of reports where rock/serac fall was reported while climbing the Swiss Guide's Route. B) Percentage of reports according to month, broken into the first and last decade where rock/serac fall was reported.

ii) <u>The Lake O'Hara Gully:</u>

The gully route up to Abbot Pass Hut starts at Lake O'Hara and gradually climbs up to Lake Oesa via Lawrence Grassi's famous rock steps. Climbers heading up to the hut leave this beautiful trail at Oesa, turning to what has been dubbed '*the most famous scree slope in the Rockies'*. From here it is a 700m vertical climb on steep snow and/or loose rock up to the hut. The most significant climate-related changes identified in this approach are a decrease in the presence of snow in the gully, an increase in rockfall, and of course the slope instabilities that contributed to the closure of Abbot Hut. The hut was closed in 2020 due to Covid-19 health measures and beginning in 2021 the closure expanded to include Abbot Pass and it's two approaches (Parks Canada Agency, 2022). Consequently, no data exists for this time and so the focus of my research was on precursors that may have contributed to this such as observations of the loss of permanent snow and changes in rockfall patterns.

Snow in the Gully

The gully up to Abbot Pass Hut from Lake O'Hara has earned the reputation of being the *"most famous scree slope in the Canadian Rockies"* due to the loose nature of the rock, the steepness of climb, and the sheer amount of vertical elevation that must be gained. Common descriptors in the registers include *'monstrous', 'hazardous', 'terrible', 'terrifying', 'never ending'* and a few other colour words. However, while it has always been a tough climb, the presence of snow historically made the grunt more manageable. In fact, the first mention of scree in the Abbot Hut Registers doesn't appear in the registers until August 13, 1954, and then again on August 10, 1957, when a climber wrote:

> *"Arrived 4pm Saturday Aug. 10 after a later start from second meadows above Lake O'Hara. A long haul over miserable scree. Some snow patches helped considerably."*

While the report acknowledges the miserable experience of climbing the scree, indicating some scree was present, they also mention the importance of snow patches that made the climb easier. Unfortunately, these critical snow patches are increasingly less present in the gully (Figure 9A, C, D). A substantial decrease in snow patches is evident as of the early 1990's and this phenomenon accelerated throughout the 2000s (Figure 9A). In fact, in the 5 years (2017-2021) leading up to the closure of the hut and surrounding area, the average percentage of reports that describe an absence of snow is 67%.

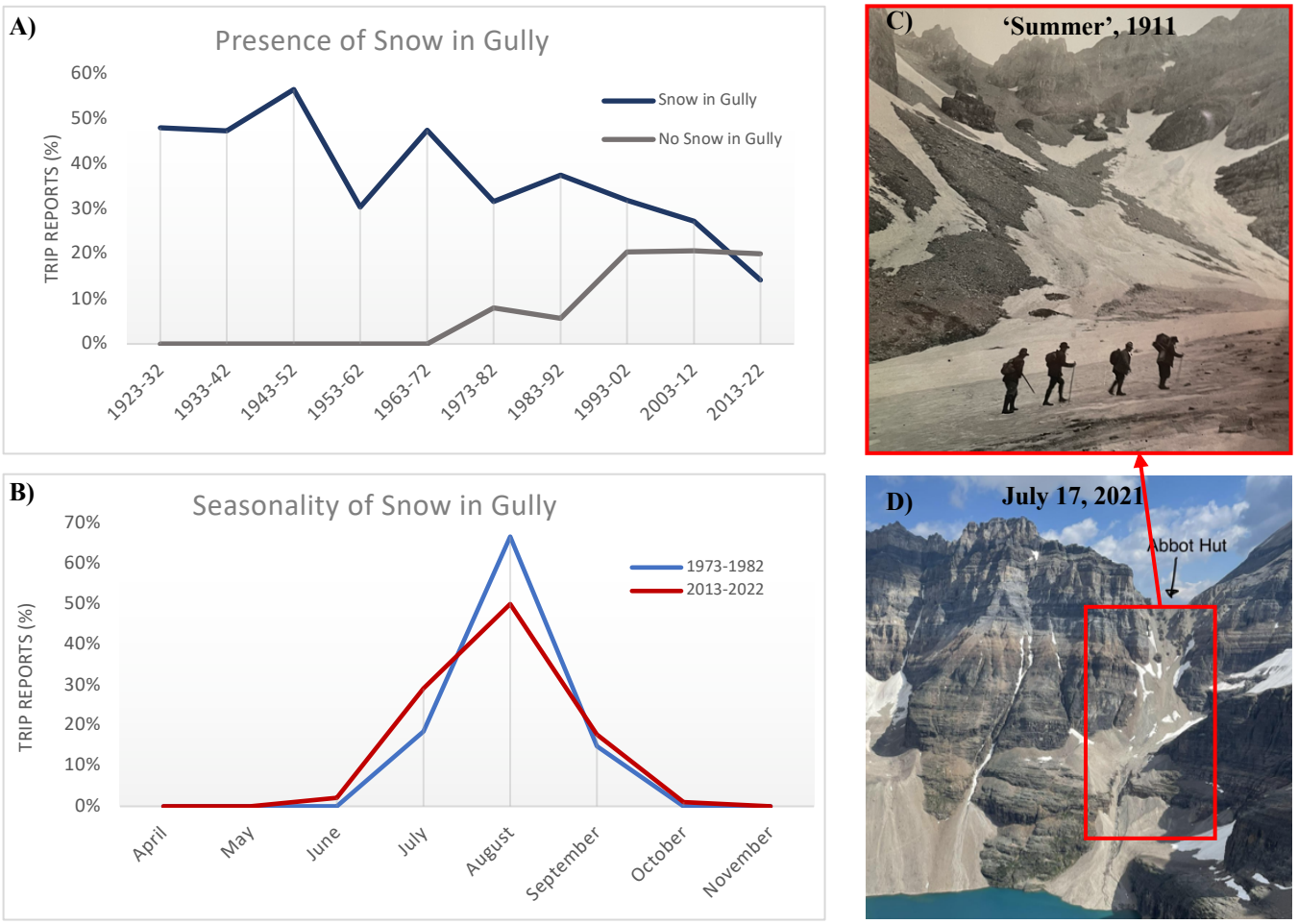


Figure 9. A) Percentage of reports that describe the presence and absence of snow in the Lake O'Hara gully. B) Percentage of reports according to month, broken into the first and last decade where no snow was reported. C) Abbot Pass gully in the summer of 1911 taken from the Edward Feuz fonds at the Whyte Museum. D) Abbot Pass gully on July 16, 2021, taken from the Mountain Conditions Report database.

Further, the length of season where the gully is snow free is increasing (Figure 9 B). The first report that explicitly states the gully was snow free appeared in July of 1975: *"An unforgettable day - a long climb all on scree but luckily with a glorious summer day."* (Abbot Hut Entry, July 25, 1975). In this first decade (1973-82) there were only a handful of reports stating that the gully was snow free and of these reports, the majority came from August (67%) with some in July (19%) and September (15%). In the most recent decade, 2013-2022, there has been an expansion of the snow free season to include June (2%) through to the beginning of October (1%) (Figure 9B), an increase from 3 to 5 months.

Rockfall

Rockfall in the Abbot Pass gully has always been a hazard but appears to have become an increasing concern over the last 50 years. The first report of rockfall was written on August 6, 1976:

"*Got to be back at Lake O'Hara by four, dodged a few boulders on the way up, hope my luck holds up.*" Since this time there has been a steady increase in the number and perhaps severity of rockfall reports, inspiring climbers to write stories, poems, songs, come up with analogies (Figure 10A), and draw pictures (Figure 10B) of their experiences with rockfall in this area

A)

"As a future army officer, in the US Army, I tend to think a lot about what leading troops in combat is like I often wonder what it is like to do patrols in enemy territory and try to imagine the sensation of getting shot at. For some reason I feel like it won't be too different, then scrambling up the loose Rock and dodging the boulders on the way up to the cabin." (Abbot Hut Entry, August 11, 2015)

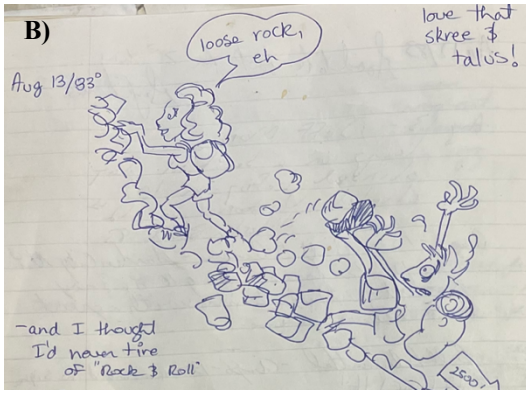


Figure 10. A) Quote and B) drawing of loose and falling rock from the Abbot Hut registers (August 13, 1983).

The early 1990's is an important point of inflection where rockfall reports dramatically increase (Figure 11A). Further, this hazard has become particularly problematic over last 5 years of hut data (2017-2021), where 70% of trip reports from the gully report rockfall events (Figure 11A). This in part could be due the expansion of the rockfall season. In the 1970's climbers could expect rockfall for 3 months of the year, through July to September, but over the last decade the season has lengthened 6 months long, including June through to October (Figure 11B).

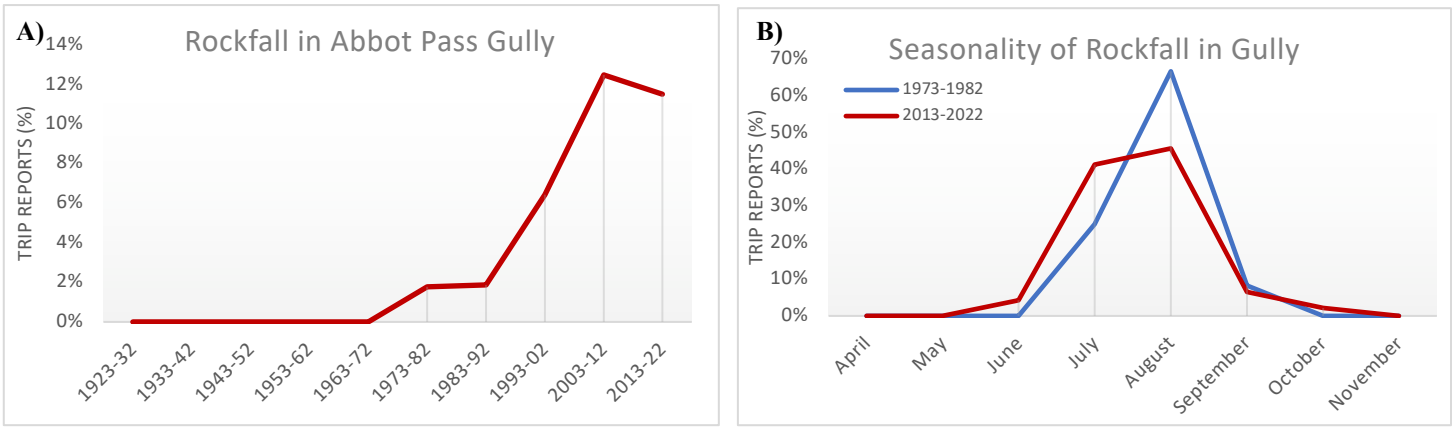


Figure 11. A) Percentage of trip reports that describe rockfall in the Abbot Pass Gully over time. B) Percentage of reports, according to month, that describe rockfall in the gully.

Mt Lefroy, West Face

The West Face of Mt Lefroy is described as a moderately angled snow and ice climb with a short traverse to the summit ridge, located to the west of Abbot Pass Hut. Historically this climb predominantly involved travel over a snow-covered slope that overlay alpine ice. Throughout the spring and summer, seasonal snow would melt off and by late summer climbers would mostly be climbing névé with some patches of exposed ice. Névé is snow left behind from previous seasons and helps to maintain climbing conditions later in the season when the seasonal snow has melted. Over time, more and more melt has occurred, melting away the névé and eventually alpine ice which has exposed bare rock (Figure 12). The loss of névé, which historically provided a form of interannual stability for the climbing season,

has made conditions on this route increasingly fickle because it is now reliant on seasonal snow depth and quality for good climbing conditions.

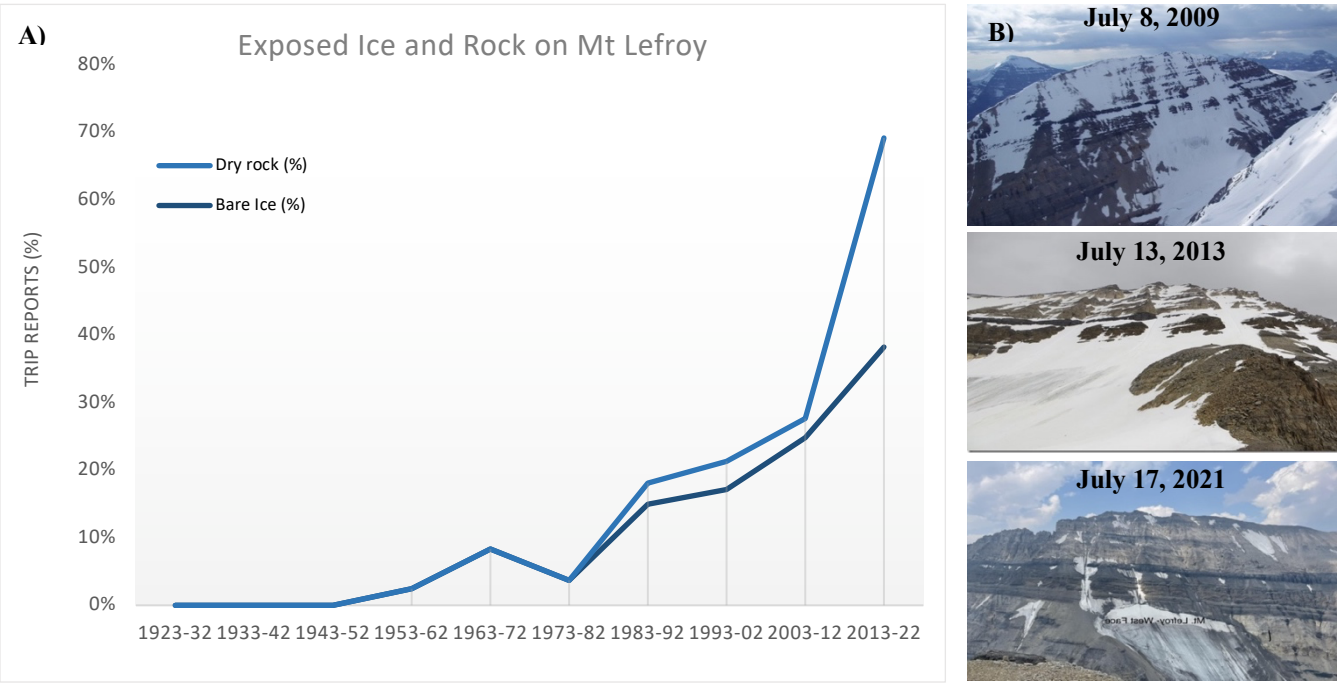


Figure 12. A) Encounters with exposed ice and dry rock while climbing Mt Lefroy over time. B) Mt Lefroy West Face, taken from the Mountain Conditions Report Database showing increases in ice and rock over

The loss of snow on Mt Lefroy's West Face emerged in the 1960's with sporadic reports of icy conditions and dry rock (Figure 12A). However, in the 1990's and 2000's the number of these reports dramatically increased and in the last 5 years of available data (2017-2021), 100% of climbs on Mt Lefroy report bare ice and 58% exposed rock. With this increase in occurrence of rock on the route, it is perhaps unsurprising that rockfall is also increasing on Mt Lefroy (Figure 13A). A consistent increase in rockfall began in the 1980's and surged in the early 2000's with 58% of trip reports encountering rockfall in the last 5 years. As with rockfall elsewhere, the season for rockfall has expanded from June and July to include May all the way through to October, representing 4-month extension to the rockfall season.

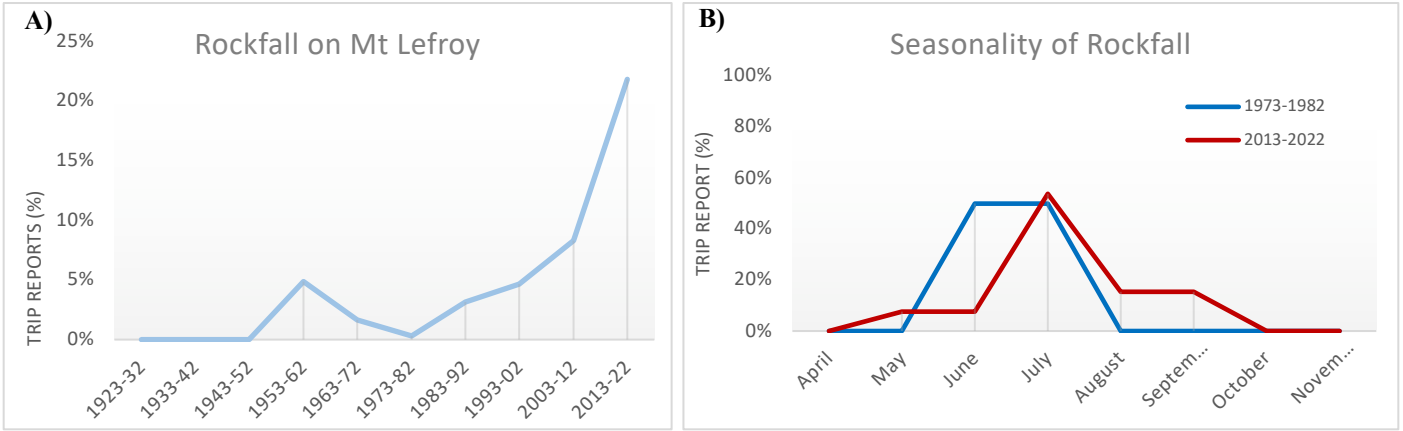


Figure 13. A) Percentage of trip reports that describe rockfall on Mt Lefroy over time. B) Percentage of reports, according to month, that describe rockfall on Mt Lefroy.

Mt Victoria

There are a few commonly climbed routes on Mt Victoria. The focus of this research is predominantly on the South Peak climbed via the classic South-East (SE) Ridge which is most frequently accessed via Abbot Pass. The route to the South Peak via the SE ridge is a long, exposed ridge that involves travel on snow, sometimes ice, and loose rock. According to the Abbot Hut registers, the SE Ridge of Victoria was typically climbed later in the season because of the sheer amount of snow that lingered on its ridge well into summer months. However, over the past 100 years Mt Victoria has experienced glacial retreat and a loss of permanent snow patches clearly depicted in Figure 14.

Figure 14. Mt Victoria from Fairview in 1903 taken from the Mountain Legacy Project – Aug 20, 2022.

My analysis supports the visual findings in Figure 14 by revealing that climbers are increasingly encountering snow free conditions on the SE ridge of Mt Victoria, exposing both rock and ice (Figure 15A,B). Approximately 50% of all trip reports describing ascents of Mt Victoria describe snowy conditions on the route and 50% dry conditions. However, 60% of the first half of the century (1923-1972) and 49% of the second half (1973-2022) report encountering snow enroute and thus, there appears to be a subtle negative trend in snowy conditions. This finding is in alignment with the increasing incidence of climbers encountering exposed rock and ice on the SE ridge (Figure 15B). The number of climbers reporting exposed rock and ice has jumped from 3% and 5% respectively in the first decade it was reported (1953-62) to 31% and 30% in the last (2013-22).

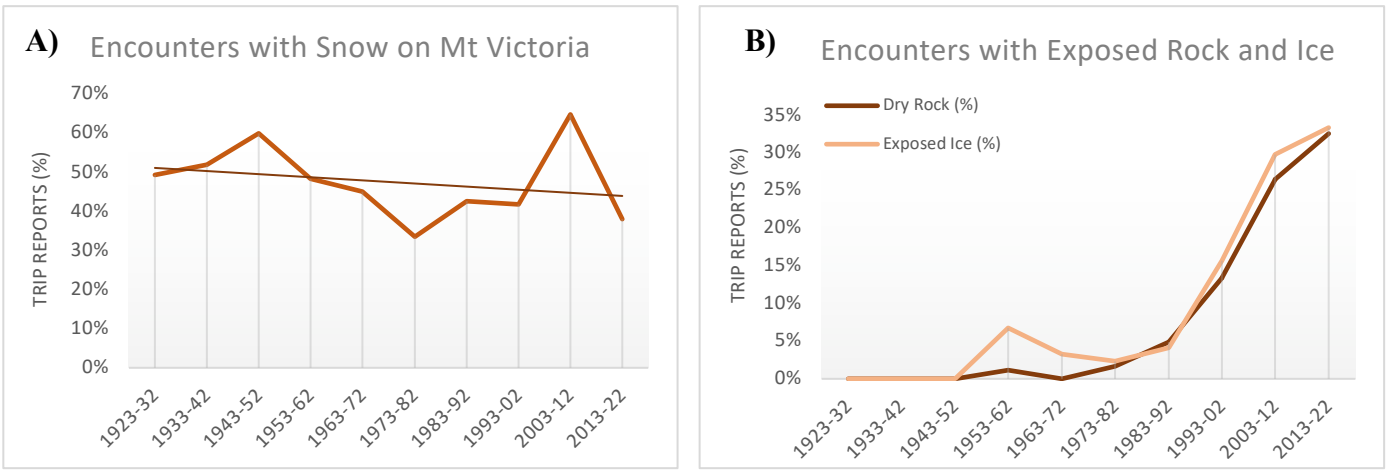


Figure 15. A) Trip reports describing encounters with snow on the SE ridge of Mt Victoria. B) Encounters with exposed rock and ice on SE ridge of Mt Victoria.

Further, climbers are increasingly reporting rockfall while climbing the SE ridge. The first report of rockfall was on August 4, 1955, when a climber wrote *"Left for Victoria at 9.45. Snow conditions were fair, the snow [was] melting uncovering sections. Very slow up the notch, many rocks falling from above having come free from the snow"*. However, reports of rockfall did not begin to consistently increase until the mid to late 1990's and into the 2000's when it dramatically surged (Figure 15A). And once again, the rockfall season has lengthened from exclusively August in the 1970's when it began to be consistently reported to June through till September in the last decade of the study period.

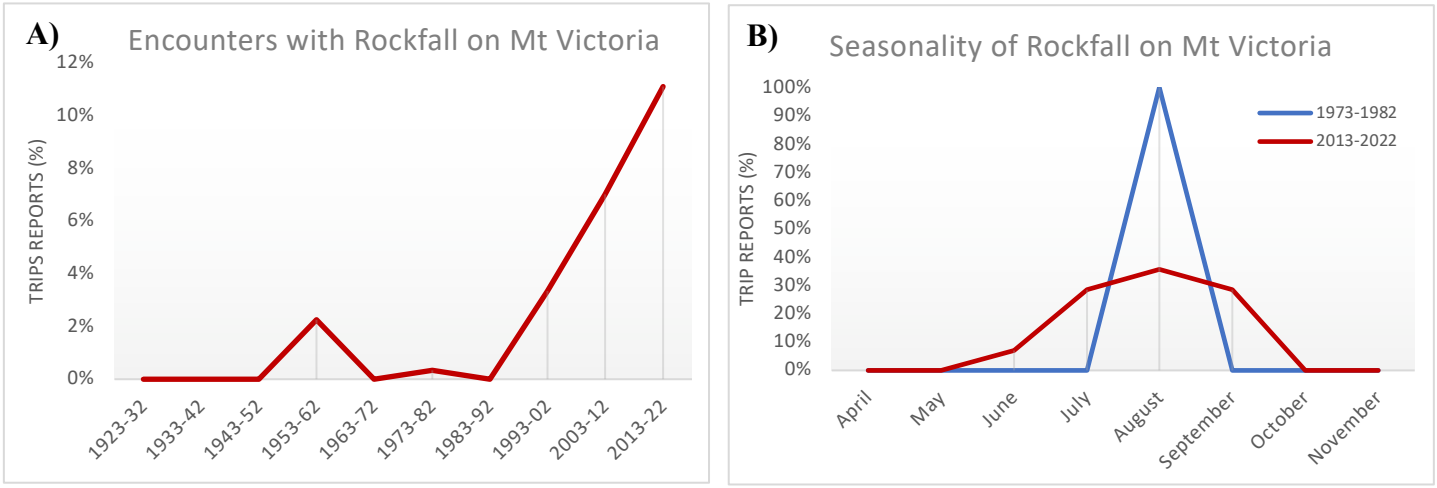


Figure 15. A) Percentage of trip reports that describe rockfall on Mt Victoria, SE Ridge over time. B) Percentage of reports, according to month, that describe rockfall on Mt Victoria SE Ridge.

Part 3: The Impacts of Climate Change the Mountaineer Behavior

The Abbot Pass Hut registers have provided empirical evidence suggesting that the pass and surrounding area has experienced an increase in objective hazards over the last 100 years. Climbers are increasingly encountering problematic crevasses, rock and serac fall, and are more frequently experiencing snow-free, icy climbing conditions. These findings are in alignment with an emerging body of literature documenting increased objective hazards in mountainous landscapes. But how do mountaineers respond to these changes? For example, does the increased risk of rockfall or poor climbing conditions necessitate behavioral change? And can mountaineers adapt to these increased risks? To better understand this relationship, the last section of my analysis is a review of how climbers have adapted to climate change and the evolving 'riskscape' at Abbot Pass to date.

i) Where are Mountaineers Climbing?

The first trend that emerged from the analysis was a change in how mountaineers were choosing to approach Abbot Pass Hut and where they were choosing to climb (Figure 16A,B). Historically, the Swiss Guides route from Lake Louise was the most popular approach to the hut (Figure 16A). This is because the hut was built by Swiss Guides who worked for Canadian Pacific Railway out of the Château Lake Louise and thus, it made the most sense to approach this way. However, not long after the hut opened climbers began to approach the hut from the Lake O'Hara side via the gully, resulting in a surge of O'Hara-based trip reports in the 1930's and 40's. Throughout the 1950's and 60's it became very popular to complete the 'Trip over the Passes', which involved hiking up either the Louise or O'Hara side and coming down the opposite side of the pass. By the 1970's and into the early 1980's, climbers used the Guide's Route and the gully equally. However, this equalization was followed by a very sharp decrease in access via the Guide's Route and a surge in access via the gully. By the 1990's access via the

Swiss Guide's Route had plummeted and a quote from the hut registers written by famous guide Peter Fuhrman provides some insight into the level of hazard and condition of the route at the time:

> *"Rain at hut, leaving for O'Hara. Ps. Anyone travelling the Deathtrap should buy additional insurance and have his head checked.* " (Abbot Hut Entry, August 21, 1997).

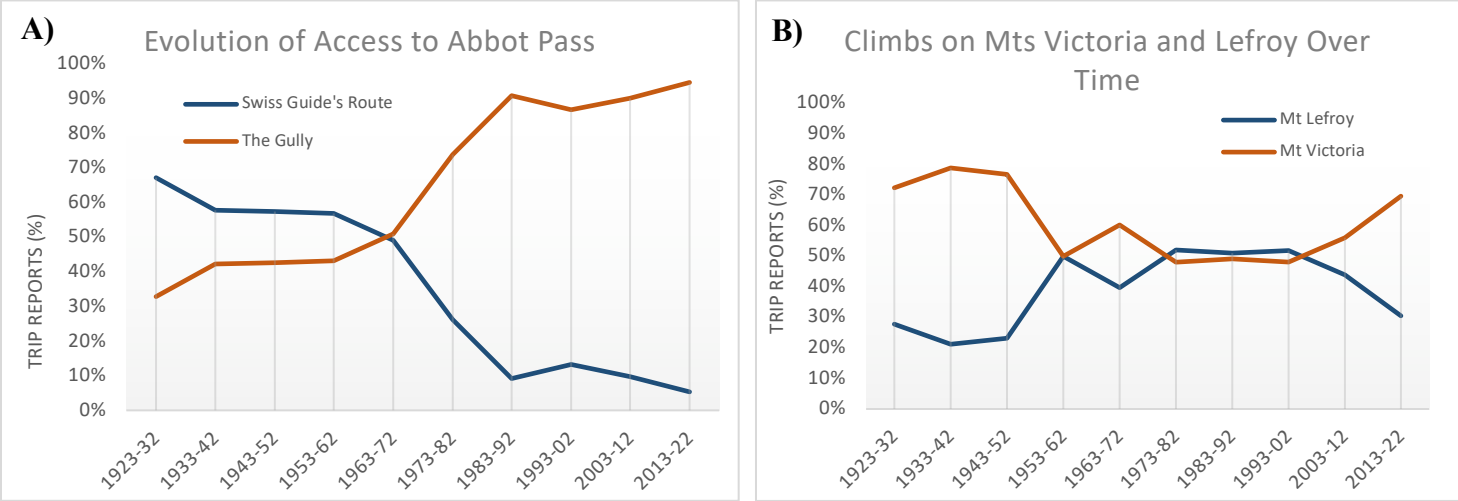


Figure 16. A) Percentage of reports that use the Swiss Guide's route vs the Gully over time. B) Percentage of reports that describe climbing Mts Victoria and Lefroy over time.

Peter's recommendation for additional insurance, and perhaps a mental wellness check, implies the route was in very poor condition and extremely hazardous at the time of his entry. This quote is representative of the observed change in mountaineer's pattern of access and correlates with the observed sharp increase in rock and serac fall, problematic crevasses, and encounters with bare ice discussed earlier. Thus, it appears as though mountaineers are spatially adapting to climate-related change by preferentially taking approach routes that are comparatively less hazardous which in this case is the Lake O'Hara gully. Interestingly, around the same time the usership of the Guide's Route decreases in late 1980's and early 1990's, there is an increase in the use of a new Lake Louise based approach called the Fuhrmann Ledges which bypasses the infamous Deathtrap all together by climbing up the ledges on Mt Lefroy – perhaps another example of spatial adaptation?

In addition to changes in approach routes, it appears that mountaineers are also changing the mountains they are climbing. Historically, Mt Victoria was the most desirable mountain to climb (Figure 16B) as the picturesque ridge appears perfectly framed by the windows of Château Lake Louise, possessing the imagination of countless visitors. In fact, it was so popular that "after growing weary from so many requests to climb the mountain Ernest (Feuz), declared, with some creative license, that the route in the pass was not negotiable. This, he explained to his fellow guides, was due to a crevasse which had opened and become an impossible barrier to ascent of the mountain" (Stephen, 2021, p. 131). Overtime Mt Lefroy became increasingly popular, reaching an equivalent number of climbs to Mt Victoria by the 1950's and staying this way through to the early 2000's. At this time however, the popularity of Mt Lefroy waned. Again, this was found to correspond with increases in rockfall and encounters with ice and exposed rock, both of which can give rise to poor climbing conditions such as:

> *"Lefroy turned us back maybe halfway. There is always next time (with less ice!). Who drove the Zamboni up and down Lefroy over night?"* (Abbot Hut Entry, August 13, 2000)

> *"Attempted Lefroy today, fog and snow lifted for a couple of minutes and made it most of the way up the middle chute. It was very icy with little snow."* (Abbot Hut Entry, September 10, 2010)

"On the bad news side-Lefroy and Glacier are almost snow free with lots of melting ice so rockfall is becoming a regular occurrence on the standard routes with any warming or rain." (MCR, August 2, 2018)

"Lefroy is another matter. The snow is melting off the face so there is some bare ice and exposed rock steps on the normal route and LOTS of rock exposed on the face around the gully. Rock barrages started on Monday afternoon in a thunder and intense rainstorm. Saw a couple of BIG blocks rattle down during the storm and that was not pretty or survivable." (MCR, July 14, 2019)

In what could be inferred as a response to the poor conditions on Mt Lefroy, mountaineers appear to be preferentially climbing Mt Victoria as conditions on the SE ridge remain comparatively better in the face of climate change. For example, while conditions on this route are changing, they seem to not be quite as impactful as they are on Mt Lefroy. For example, where increased encounters with exposed rock on Mt Lefroy often correlated with increases in rockfall, on Mt Victoria a dry ridge appeared to at times make climbing easier and faster. For example: *"the rock terrain on the route was completely dry and made for good travel."* (MCR, August 6, 2012) and *"Victoria was in just about perfect conditions, dry on the ridge."* (Abbot Hut Entry, July 27, 2013). Thus, the identification of a persistent change in the spatial behavior of mountaineers seems to imply that they are adapting to climate change by altering where they climb and preferentially choosing routes that are relatively less hazardous in the face of climate change.

ii) When are Mountaineers Climbing?

Lastly mountaineers appear to be changing when they are climbing (Figures 17, 18). Historically, Mt Lefroy was climbed in July and August when most of the seasonal snow had melted off and significantly reduced the risk of avalanche hazard. However, climbers are increasingly climbing Lefroy earlier in the year (Figure 17A). In the first decade Abbot Pass Hut was open (1923-32), the average season in which Mt Lefroy was climbed was July 17 to August 14 and in the last decade the hut was open (2013-2022) the average season was June 26 to July 26. Compared to the 1920's, the climbing season on Mt Lefroy has shifted forward, starting on average 21 days earlier and ending 19 days earlier. This finding is supported by Figure 17B which depicts the number of climbs on Mt Lefroy per month over time, clearly demonstrating an advancement of the climbing season. Interestingly, over the last 2 decades Mt Lefroy has, on occasion, had a second climbing season in the fall when early snowfall substantially improves climbing conditions. (A second season here is defined by an absence of climbing reports of climbs on a route for 3 or more weeks.)

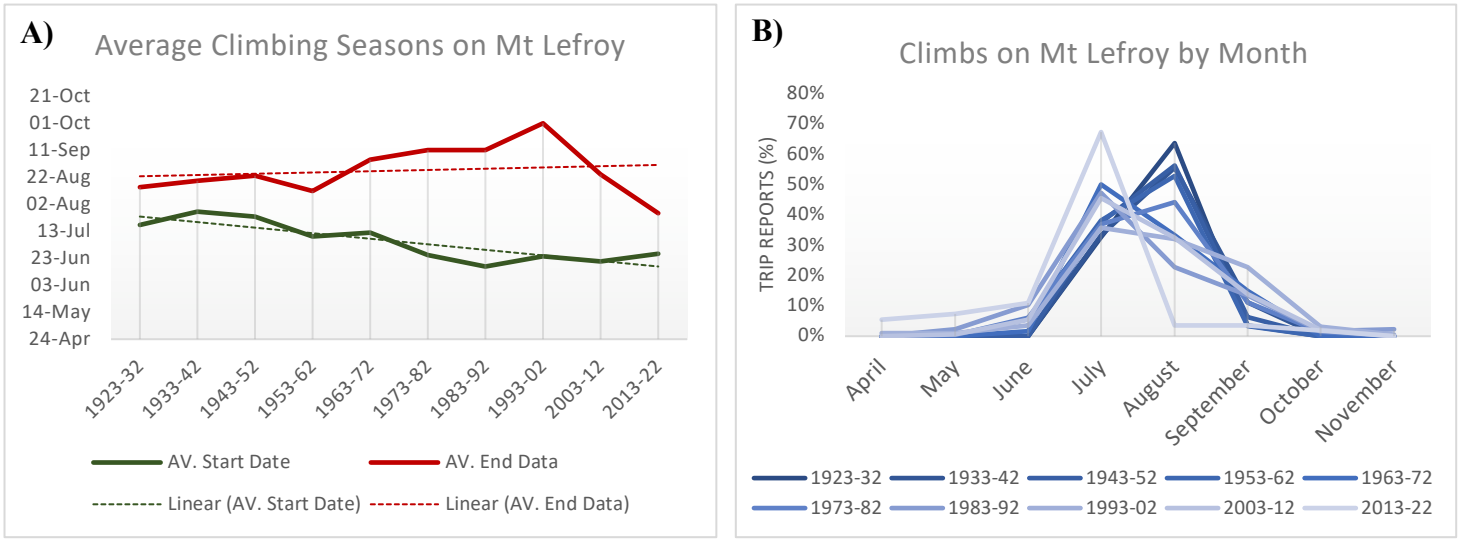


Figure 17. A) Average start and end date of the climbing season for Mt Lefroy. B) Percentage of reports that describe climbing Mt Lefroy according to month.

Observed changes in when mountaineers are climbing Mt Lefroy correspond fairly well with increases in rockfall and exposed ice/rock conditions on the route. Around the 1960's and 70's, when rockfall as well as exposed ice/rock first emerge, the Lefroy climbing season actually begins to expand on both ends, starting in June/ early July and pushing into September. This could be due to insufficient change in climbing conditions, ultimately not necessitating change in behavior, a phenomenon likely compounded by increases in popularity of climbing during this time, enhanced accessibility, and improved equipment. However, in the 1990's onwards, when the frequency of rockfall and encounters with bare ice/rock really start to increase a threshold appears to be crossed and the climbing season begins to substantially advance and shorten. This seasonal change in climber's behavior could be considered a temporal adaptation to climate-related changes, such as the loss of névé and increased reliance on seasonal snow for good climbing conditions.

With regards to Mt Victoria, climbers also appear to be employing temporal adaptations in the face of climate change. In the first decade Abbot Pass Hut was open, the average season for climbing Mt Victoria began July 16 and ended August 31. In the last decade of the hut however, the average season began on June 27 and ended on September 19. This change has resulted in an extension of the Mt Victoria climbing season, starting on average 19 days earlier and ending 19 days later (Figure 18A). This almost perfectly corresponds with increases in dry rock conditions on the SE ridge route; dry rock conditions have extended from late July/ early August in the 1920's to include June all the way through to September in the 2010's (Figure 18B). Again, in changing when they climb Mt Victoria, mountaineers have temporally adapted to climate-related changes but in contrast to Mt Lefroy it appears as though the season has lengthened on the SE ridge.

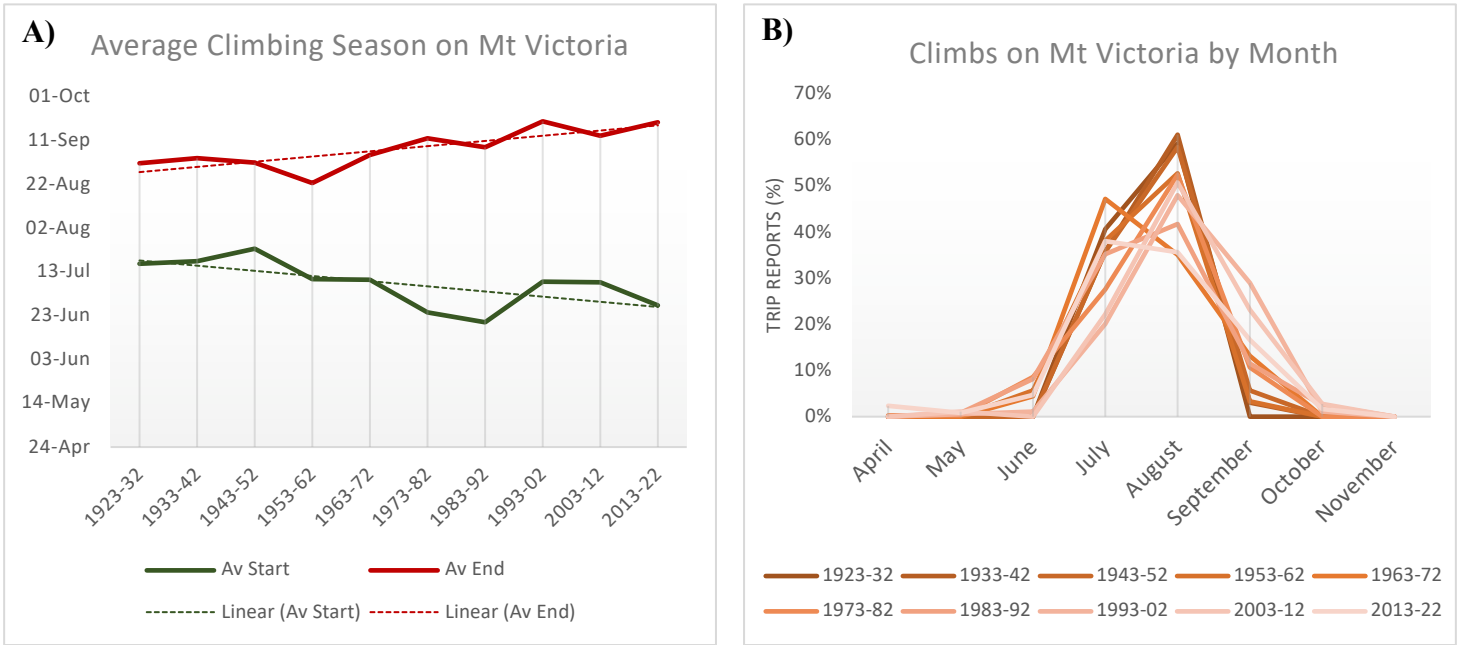


Figure 18. A) Average start and end date of the climbing season for Mt Victoria. B) Percentage of reports that describe climbing Mt Victoria according to month.

Conclusions

To conclude, climate change is resulting in rising temperatures and decreasing precipitation trends in Banff National Park. In the Abbot Hut area of Lake Louise, these changes have contributed to an increase in problematic crevasses, rock and serac fall, and encounters with exposed ice and rock leading to more hazardous and more challenging climbing conditions. In turn, this analysis of the Abbot

Hut registers has both provided insight into the vulnerabilities of the mountaineering to climate change and revealed empirical evidence of adaptation behaviors (i.e., spatial and temporal substitution). Improving understanding of these processes is critical to the development of effective and socially-environmentally just adaptation strategies for mountain guides, mountain professionals, and recreationalists alike.

Dissemination of Work

I plan to disseminate my research findings through four different avenues:

1. I have written an article for the Carin.
2. I intend to present my findings at a Whyte Museum event this summer.
3. I plan to publish my results in an academic peer-reviewed paper as part of my Doctorate Degree at the University of Calgary. My goal is to submit to a Special Issue Publication hosted by TEROS on 'Tourism and Adaptation to Climate Change' for which abstracts are due April 3, 2023, and full texts due July 3, 2023.

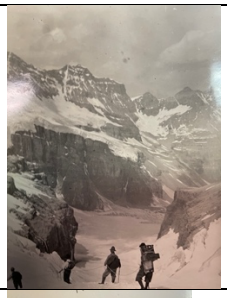
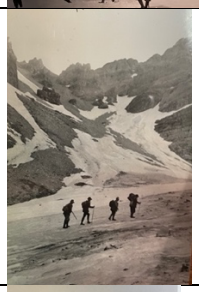
Expansion of Research – Future Continuation of Research Project

Future research efforts associated with this project are three-fold:

1. With regards to this specific project, I intend to continue to update my Abbot Hut database as more registers emerge and perform a more granular analysis at the annual level (as opposed to the decadal level) in effort to identify key moments of change throughout time.
2. Secondly, I would like to continue with my repeat photography efforts. Included below in Table 2, I have highlighted the images I would like to re-take that I could not last summer due to challenges associated with access to Lake O'Hara and an unexpected injury. The purpose of this to add to our understanding of how iconic climbing routes in the Lake Louise area have changed as a result of climate change.
3. Lastly, I would like to re-examine the registers to perform a socio-cultural analysis of mountaineering culture over time. While reading through these registers I noticed interesting trends in language used, the progression of mountaineering 'science', and the evolution of mountaineering culture.

Table 2. Images to be re-taken this summer (subject to small changes depending on access, weather etc.)

Reference	Image	Description
Abbot Pass Hut. 1924. Rollin T. Chamberlin fonds. V22 / 80 / na66 – 280.		Abbot hut complete
PA 44- 84 // ACCN 2444		Abbot pass with Basil Gardom, Aemmer, Edward Feuz, Val Fynn 1911

PA 44- 85 // ACCN 2444		Abbot pass with Basil Gardom, Aemmer, Edward Feuz, Val Fynn 1911
PA 44 – 87// ACCN 2444		Abbot pass from O'Hara side with Basil Gardom, Aemmer, Edward Feuz, Val Fynn 1911
PA 44 – 119 / ACCN 244		Edward Feuz, Emily Yates, and unknown. Taken by Wilcox on Upper Victoria Glacier Background is of Lefroy 1922
PA 44 – 121 / ACCN 2444		Mt Victoria summit 1922 Edward Feuz, Emily Yates, and unknown. Taken by Wilcox

Appendix A: Research Materials Accessed

List of Figures:

1. Figure 2. Abbot Pass. 1929. Peter and Catharine Whyte fonds. V683 / III / A / 15 / PA - 18. Archives and Library, Whyte Museum of the Canadian Rockies.
2. Figure 9C. Abbot Pass. 1911. Edward Feuz fonds. PA 44- 85 // ACCN 2444. Archives and Library, Whyte Museum of the Canadian Rockies.
3. Figure 10. Alpine Club of Canada fonds. 1906-2017. Alpine Club of Canada. Alpine Club of Canada fonds. M200 / S6 / V14. Archives and Library, Whyte Museum of the Canadian Rockies.
4. Figure 14. Mount Victoria, Image Overlay, Mountain Legacy Project

List of Archival Materials Accessed:

Photographic Material:

1. Edward Feuz fonds. 1881-[ca.1976]. Feuz, Edward. Edward Feuz fonds. M93 / V200. Archives and Library, Whyte Museum of the Canadian Rockies.
    a. PA 44- 84 // ACCN 244 - Abbot pass with Basil Gardom, Aemmer, Edward Feuz, Val Fynn 1911
    b. PA 44- 85 // ACCN 2444 - Abbot pass with Basil Gardom, Aemmer, Edward Feuz, Val Fynn 1911
    c. PA 44 – 87// ACCN 2444 - Abbot pass from O'Hara side with Basil Gardom, Aemmer, Edward Feuz, Val Fynn 1911
    d. PA 44 – 119 / ACCN 244 - Upper Victoria Glacier, Edward Feuz, Emily Yates, and unknown.
    e. PA 44 – 121 / ACCN 2444 - Mt Victoria summit 1922 , Edward Feuz, Emily Yates.
2. Ernst (Ernest) Feuz fonds. 1908-1956. Feuz, Ernst. Ernst (Ernest) Feuz fonds. M131 / V71. Archives and Library, Whyte Museum of the Canadian Rockies.
3. J. Norman Collie fonds. [ca.1863]-1935. Collie, J. Norman. J. Norman Collie fonds. M279 / V62. Archives and Library, Whyte Museum of the Canadian Rockies.
4. Abbot Pass Hut. 1924. Rollin T. Chamberlin fonds. v22 / 80 / na66 - 280. Archives and Library, Whyte Museum of the Canadian Rockies.
    a. v22/ 80/ na66 – 280 – Abbot Pass Hut in 1929

Textual Material:

1. Chateau Lake Louise fonds. 1923-1953. Chateau Lake Louise. Chateau Lake Louise fonds. M180. Archives and Library, Whyte Museum of the Canadian Rockies.
    a. M180 / accn. 1074 - Abbot Hut Registers, 1923-1953
2. Alpine Club of Canada fonds. 1906-2017. Alpine Club of Canada. Alpine Club of Canada fonds. M200 / S6 / V14. Archives and Library, Whyte Museum of the Canadian Rockies.
    a. M200 / accn. 6623/ unprocessed – Abbot Hut Registers, 1954-2016.
3. Christian and Hans Kaufmann fonds. Copies made 1977. Kaufmann, Christian. Christian and Hans Kaufmann fonds. M385 / V321. Archives and Library, Whyte Museum of the Canadian Rockies.
4. Edward Whymper fonds. Copies made ca.1975. Whymper, Edward. Edward Whymper fonds. M309 / V728. Archives and Library, Whyte Museum of the Canadian Rockies.
5. Lloyd Margenson and John Linn Collections. M180. Archives and Library, Whyte Museum of the Canadian Rockies.

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