Urban Hydrogeology of Calgary Field Trip

2026

WGF

WESTERN GROUNDWATER FORUM

Sponsored by:

Klohn Crippen Berger

May 29, 2026

Hosted by:

Kevin Parks

DEEP TIME ADVISORY SERVICES LTD.

Nigel Atkinson

AGS ALBERTA GEOLOGICAL SURVEY

Host Bios

Kevin Parks
M.Sc., Ph.D., P.Geo.

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Dr. Parks is an Alberta-educated geologist and hydrogeologist with over 40 years of public geoscience, regulatory, and industry experience in Canadian geology and hydrogeology. His career includes over two decades in public geoscience at the Alberta Geological Survey and Alberta Energy Regulator, where he was accountable for programs in groundwater mapping, energy resource-appraisal and statistics, and geological hazards. As well, Dr. Parks has provided expert advice on management of groundwater and subsurface pore-space in Canada, the UK, the Netherlands, the EU, and Australia. He has been a former chair and an ongoing contributor work to the Groundwater Resources Working Group of the United Nations Economic Commission for Europe's (UNECE) Expert Group in Resource Management since 2019. His career experience includes groundwater resources, contamination, and protection; oil and gas exploration and development; aquifer and reservoir characterization and modeling; oilsands mining and in-situ development; geothermal energy; geological hazards and induced seismicity. He has over 80 peer-reviewed papers, reports, regulatory documents, abstracts, and presentations on the geology of resource developments to his name. Dr. Parks is presently working with the Calgary geoscience community at large to locate and document outcrops showing our local geological heritage to new generations, as more of this heritage gets consumed by urban development each year.

Nigel Atkinson
M.Sc., Ph.D.

AGS
ALBERTA GEOLOGICAL SURVEY

Nigel is originally from Liverpool in the UK. After completing a B.Sc. at the University of Glasgow, Scotland, focusing on glacial geology and geomorphology, he came to the University of Alberta in 1996 to work on an M.Sc. and then Ph.D., examining the Quaternary glacial history of the northwest Queen Elizabeth Islands in Canada's High Arctic. After finishing his Ph.D. in 2005, he took a contract position at the Alberta Geological Survey to map the distribution and sedimentology of buried channel aquifers in the Fort McMurray region. On completion of this project, Nigel was offered a permanent position which involved a move to the Surficial Mapping Program. He has been involved with surficial mapping for the past 18 years, including 8 years as Manager of the Quaternary Geology Section. In this time, he has published 37 maps of Alberta's surficial and near-surface geology as well as thirty-two journal papers and reports on topics including the role of glacial tectonics on landscape evolution and regulatory geoscience, the application of high-resolution remote sensing technology for terrain sciences and high-latitude paleoclimate and ice sheet reconstruction. Outside of AGS, Nigel has maintained a close association with the University of Alberta, becoming an Adjunct Professor in the Earth Science Department, which has allowed him to supervise graduate students, as well as continue undergraduate teaching, both at field school and in the lecture theatre.

Overview

Step outside the meeting rooms and into Calgary's landscape, where the legacy of mountain building, great erosion, and glaciation is written in bedrock, tills, buried valleys, and meltwater deposits that still shape groundwater systems today. This field trip reveals how the bedrock landscape developed over the last 66 million years and how recent glaciers advanced, retreated, and reshaped the land. These events formed the valleys, ridges, and river systems that continue to influence the city's hydrogeology, infrastructure, and development.

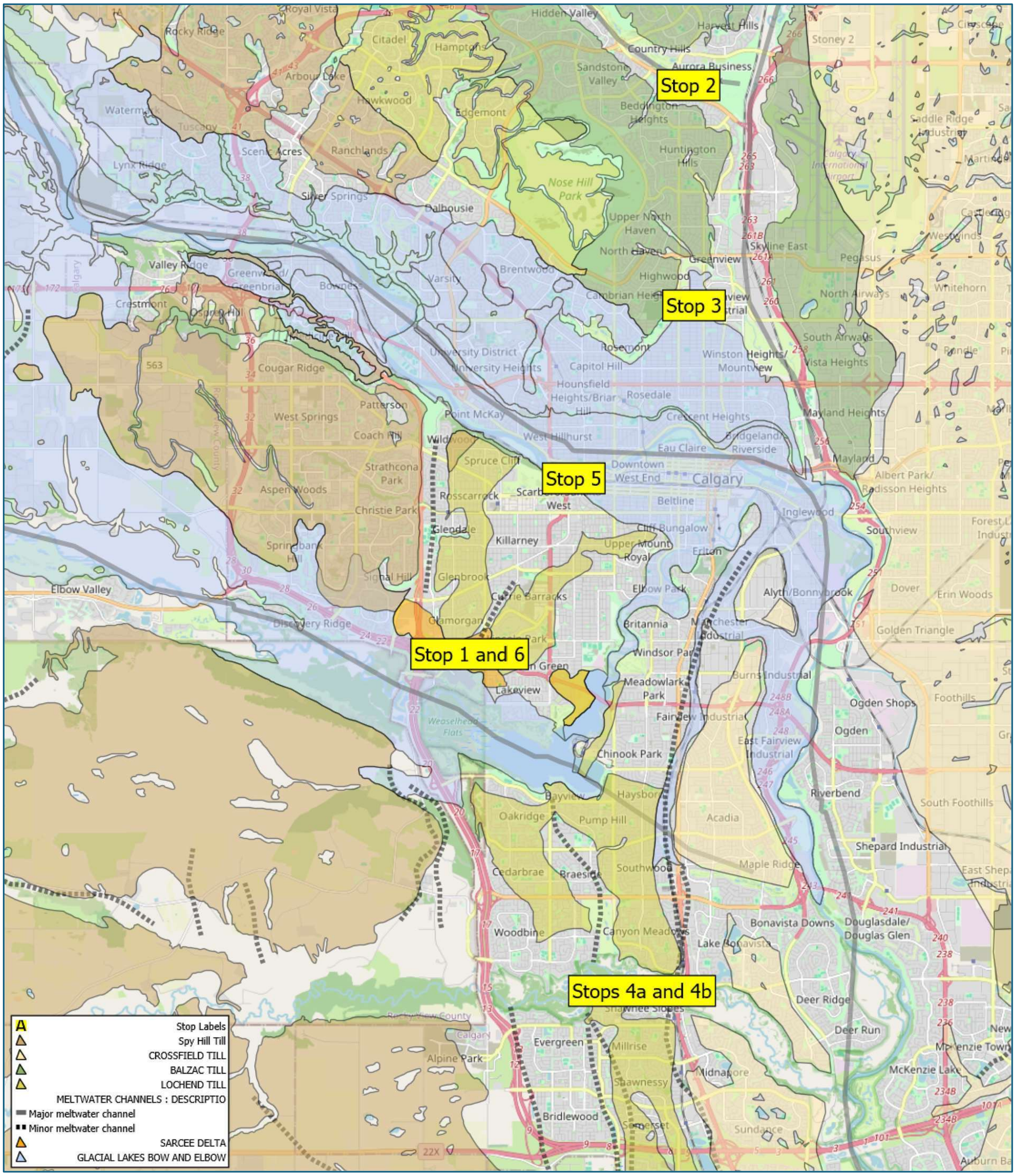
By integrating geomorphology, sedimentology, and hydrogeology, participants will gain a comprehensive view of Calgary's subsurface framework while tracing connections between geological processes and present-day hydrogeological challenges. The city's exposures provide powerful analogues for bedrock and glacial aquifers and aquitards across Alberta, offering practical insights into groundwater supply, dewatering, and groundwater surface water interactions.

More than a walk through the city, this is a chance to sharpen your field interpretation skills, link regional geological history to applied hydrogeology, and see firsthand how geology underpins Alberta's growth.

Itinerary

Site No.	Location	Approximate Drive Time to Next Stop (minutes)	1-way Walking Time (minutes)	1-way Walking Distance	Time Onsite Including 2-way Walking (minutes)	Arrival Time	Departure Time
Stop 1	Grey Eagle Resort	0	0	0	30	8:00 start	8:30
Stop 2	West Nose Creek Park Parking Lot at Split Rock, off Harvest Hills Blvd NW, north of Beddington Trail.	30	10	1 km (0.7 mi)	60	9:00	10:00
Stop 3	Highland Park Community Center at 3716 2nd Street NW	10	0	0	50	10:10	11:00
Stop 4a	Votier's Flat Parking, Fish Creek Park west	30	5	0.5 km (0.3 mi)	60	11:30	12:30
Lunch	Glennfield Day Use Area, Fish Creek Park east	15	0		60	12:45	13:45
Stop 4b	Glennfield Day Use Area, Fish Creek Park east	0	15	1 km (0.7 mi)	60	13:45	14:45
Stop 5	Pumphouse Theatre	30	0	0	60	15:15	16:15
Stop 6	Grey Eagle Resort via Sarcee Trail S.	15	0	0	0	16:30	end

Site Locations



Health and Safety

The safety of attendees and hosts are of utmost importance for a successful field trip. Prior to starting the day, attendance will be taken, and a verbal overview of the day will be provided. A hazard assessment will be completed prior to departure, however expected hazards are as follows:

Hazard	Ranking*	Mitigation
On Bus: Highway driving, parking	2	Bus driver to provide safety orientation for all staff when on bus of specific safety features. Attendees to listen/participate as required.
Loading / Unloading from Bus Uneven surfaces (Slips/Trips/Falls)	2	Attendees to wear appropriate footwear for a full day of walking, use and care when loading/unloading from bus. Use handrails as required. Use pathways when possible; remain vigilant about foot placement when navigating terrain. First aid kit carried by safety lead throughout the day.
Weather (Heat/Cold/Rain); changing conditions	3	Attendees must wear proper clothing to be outside all day (layer dressing recommended), weather report to be checked the morning of event. Water provided throughout the day.
Fatigue	3	Multiple breaks for bus ride to allow attendees to warm up/cool down and rest. Extra water bottles located on bus and with safety lead. Proper nutrition and intake is encouraged with opportunity for a group lunch.
Wildlife Engagement	3	Proper housekeeping to be maintained. Interacting with wildlife is not permitted. Staff have completed additional wildlife awareness training and will apply as required.
Separation from Group	3	Contact information for safety leads provided. Head count before/after leaving each site. Working as a group with known individuals for a 'buddy system'.

* Very Hazardous: 1; Hazardous with moderate risk: 2; Low Risk: 3;

In the event of an emergency, attendees will be able to contact a safety leads, who will be identified with a High-Visibility vest for the day or can contact city emergency services. We look forward to a lower impact field trip day. Should attendees have any questions they are welcomed to bring them forward throughout the day.

Safety Contacts: **Megan Watt (250) 613-6637**

Steve Sturrock (403) 860-7028

Allison Kendall (403) 863-8782

Stop 1 and Point of Departure: Grey Eagle Resort and View of the Rocky Mountain Front Ranges.

The Rocky Mountains in southwestern Alberta are part of the overall Canadian Cordillera. To understand the geology of Calgary, it is important to consider aspects of the geology and history of the eastern margin of the Canadian Cordillera. Figure 1.1 shows a map of structural belts in southwest Alberta and southeast British Columbia.

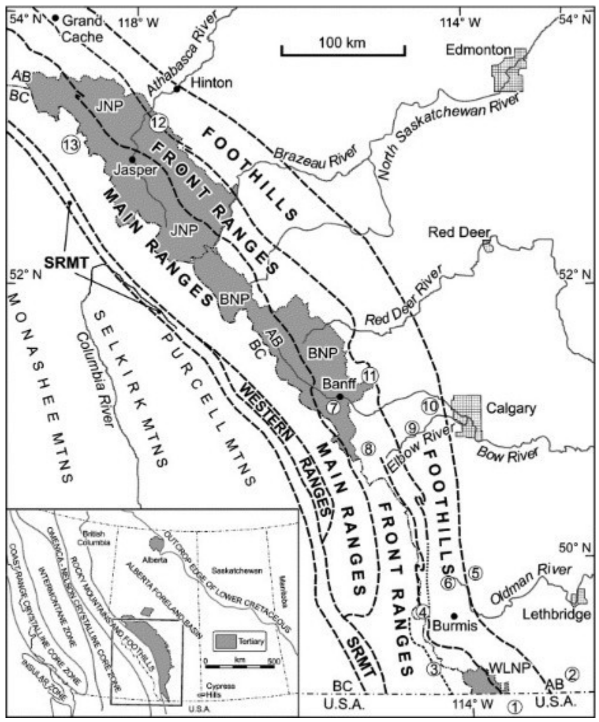


Figure 1.1: Structural belts of southwest Alberta and southwest BC. (Osborn et al., 2006).

From Grey Eagle, we see the Front Ranges in the distance and the Foothills in the foreground. Figure 1.2 shows the main mountains of the Front Ranges and Foothills visible from west Calgary.

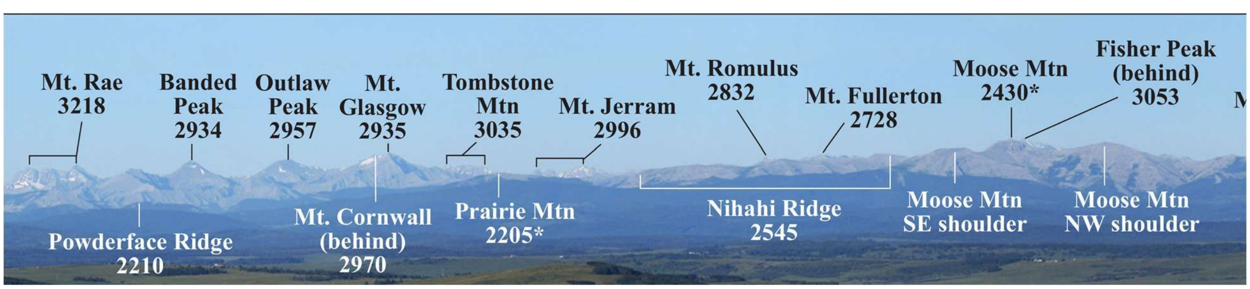


Figure 1.2: Visible mountains from Grey Eagle Resort. Extracted from Gadd, 2018.

The Canadian Cordillera was formed through the accretion of at least 500 km of new continental crust in the form of island arcs colliding with the North American craton along a long-lived east-dipping subduction zone. The collisions and associated wrench tectonics created the series of metamorphosed rock, intrusive/volcanic belts, and thrust-and-fold belts incorporating Proterozoic to early Cretaceous sedimentary rocks deposited on the previous passive continental margin (Figure 1.3).

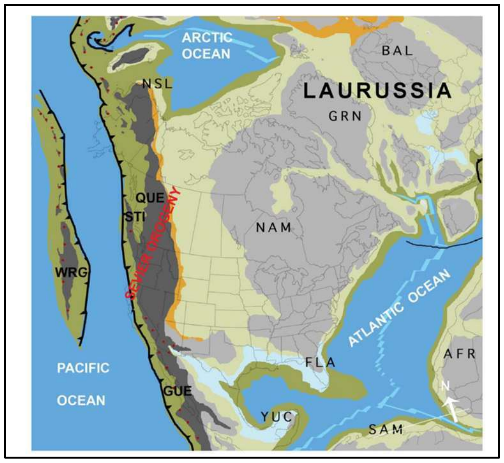


Figure 1.3. Plate tectonic setting of North America during the Early Cretaceous (Miall and Blakely, 2019, their Plate 19).

The deformation belts formed in a punctuated fashion in response to separate collisional events. They also become progressively younger to the east (Figure 1.4). The structural deformation in southwest Alberta ended in the Eocene Period, approximately 49-52 Ma.

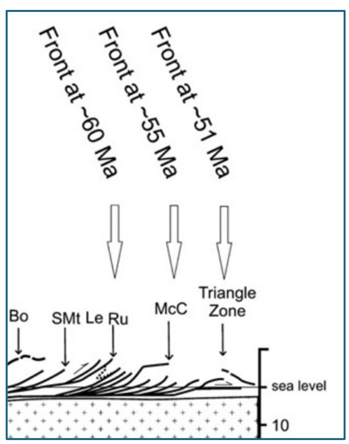


Figure 1.4. Extract from figure showing approximate estimates of progressively younger dates of deformation across the Front Ranges and Foothills belts west of Calgary. McC stands for the McConnell Thrust which is accepted as the boundary between the Front Ranges and the Foothills in Alberta. The Triangle Zone marks the boundary between the Foothills and the undeformed sedimentary rocks of the Alberta Plains to the east (Simony and Carr, 2011, their Figure 2).

Several aspects of the geology and history of the Cordillera are important to keep in mind for understanding the geology and hydrogeology of Calgary on this trip.

- The Precambrian crust underlying the sedimentary rocks of the Alberta Basin was flexed downwards to the west during mountain building, forming an elongate trench parallel to the mountain fronts. The mountains themselves were built of uplifted Precambrian to early Cretaceous rocks. These strata provided sediment that was transported eastward, gradually filling the trench in successive marine and non-marine cycles of clastic sedimentation. The bedrock we see in outcrops in Calgary are eroded late Cretaceous and early Paleogene remains of these cycles.
- The general configuration of the landscape in and around Calgary is pre-glacial and the product of 40 million years of continuous but punctuated erosion. This erosion removed 2-3 km of pre-existing Cretaceous to Paleogene rock from the Calgary area and more over the Front Ranges.
- While the rocks themselves are old, the alpine landscape of the Front Ranges and Foothills is actually relatively young and, like the landscape around Calgary, has had more than 5 km of pre-existing rock removed by 40 million years of erosion. However, the current alpine landscape characterized by steep cliffs, arêtes and cols, horns, and cirques was carved by glaciers during the Pleistocene.
- Advances of those alpine glaciers eastward from the mountains reached Calgary at about the same time that advances of continental ice sheets reached Calgary from the northeast spreading center near Hudson Bay. The interplay of these ice sheets during multiple episodes of advance and retreat left till sheets and glaciolacustrine deposits across Calgary. Meltwater channels marking rapid draining of ponded glacial meltwater created some of the dramatic relief on the Calgary landscape.
- The modern land surface and drainages occupy and eroding through this "palimpsest" Eocene and glacial landscapes during the present interglacial.

Stop 1 References

Gadd, B., 2018. Canadian Rockies Panorama West of Calgary. Photo-mosaic. Url: https://www.bengadd.com/downloads/panorama/. Accessed 04/2026.

Miall, A.D. and Blakey, R.C., 2008. The Phanerozoic tectonic and sedimentary evolution of North America. *Sedimentary basins of the world*, *5*, pp.1-29.

Osborn, Gerald, Glen Stockmal, and Rebecca Haspel, 2008. Emergence of the Canadian Rockies and adjacent plains: a comparison of physiography between end-of-Laramide time and the present day. *Geomorphology* 75, no. 3-4: pp.450-477.

Simony, P.S. and Carr, S.D., 2011. Cretaceous to Eocene evolution of the southeastern Canadian Cordillera: Continuity of Rocky Mountain thrust systems with zones of "in-sequence" mid-crustal flow. *Journal of Structural Geology*, *33*(9), pp.1417-1434.

Stop 2 West Confluence Park – Beddington Trail NW at Harvest Hills Boulevard NW.

This location highlights several key aspects of the Alberta landscape and Calgary's geological history.

Bedrock Stratigraphy

The sandstone bedrock exposed throughout the Calgary area is Paleogene in age. The bedrock stratigraphy is variously assigned to the Late Cretaceous to Paleogene Willow Creek, Scollard, Coalspur, Porcupine Hills, and/or Paskapoo Formations (Figure 2.1).

Identifying which formation is present is locally complicated by the interfingering of type lithologies of these formations, the absence of marker beds, and the lithological similarity between these formations in outcrop.

Lerbekmo and Sweet (2000) published the most definitive framework for Calgary bedrock stratigraphy in "Magnetostratigraphy and Biostratigraphy of the Continental Paleocene in the Calgary Area, Southwestern Alberta."

Using magnetostratigraphy, paleontology, and palynology as well as geological data from a series of local outcrops, they determined the sandstone outcrops in southwest Calgary (e.g., Fish Creek Park, Glenmore Dam) to be the Willow Creek Fm. The Paskapoo Formation, often name-dropped as the bedrock formation in north Calgary, is only found at the highest elevations at Winsport Park (formerly Calgary Olympic Park). The West Nose Creek outcrop (part of Lerbekmo and Sweet's composite "Nose Creek" outcrop assemblage) can be assigned to either the Porcupine Hills Formation or the Upper Scollard Formation. The lack of coals in the immediate area, which are more characteristic of the Upper Scollard Formation north of Calgary, suggest Porcupine Hills Formation a more appropriate formation assignment at this stop.

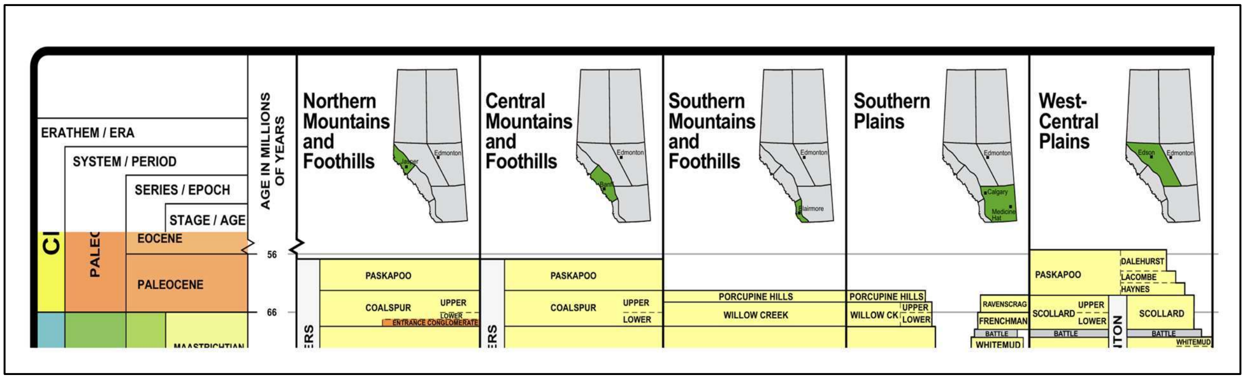


Figure 2.1. Calgary-relevant formations of the late Cretaceous to early Paleogene. Extracted from AGS (2019).

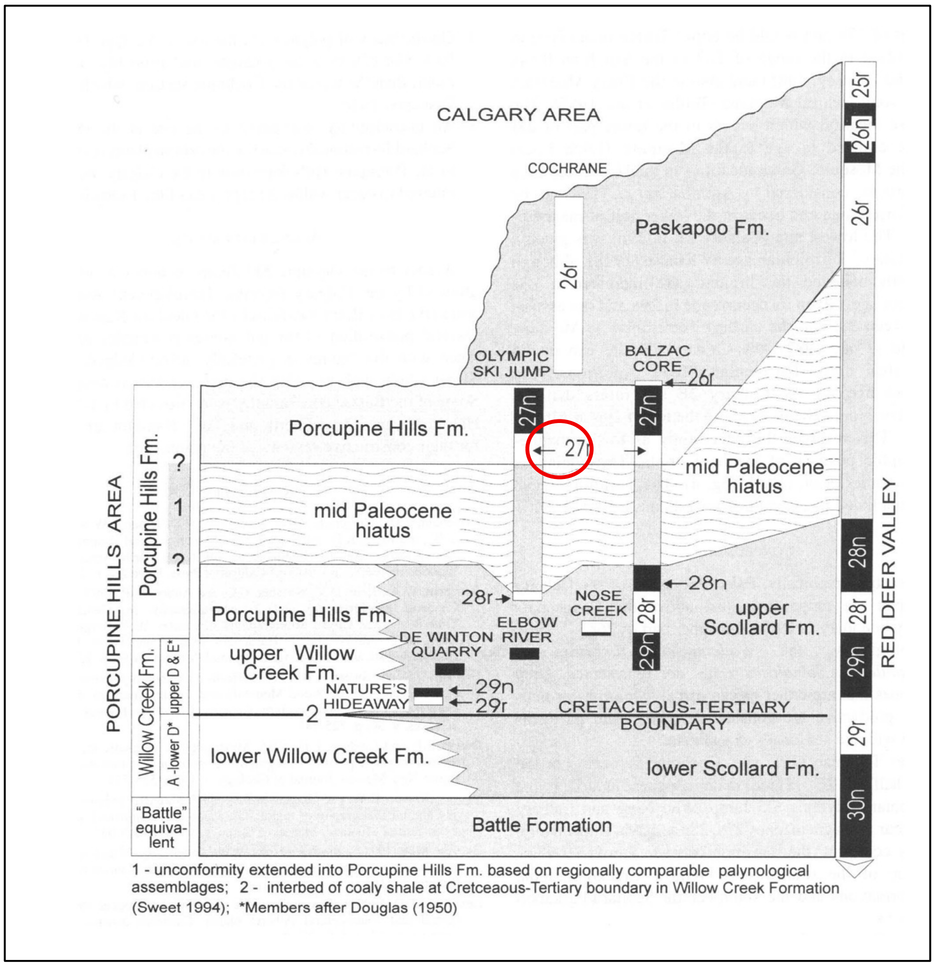


Figure 2.2: Magnetostratigraphic and paleontological assignment of rock at this stop being Porcupine Hills Formation (Lerbekmo and Sweet, 2000). Red circle highlights Stop 2.

Pană van der Pluijm (2015) use age-dating techniques on the thrust faults in the Rocky Mountains and correlated their origin to the sedimentary deposits associated with the events (Figure 2.3).

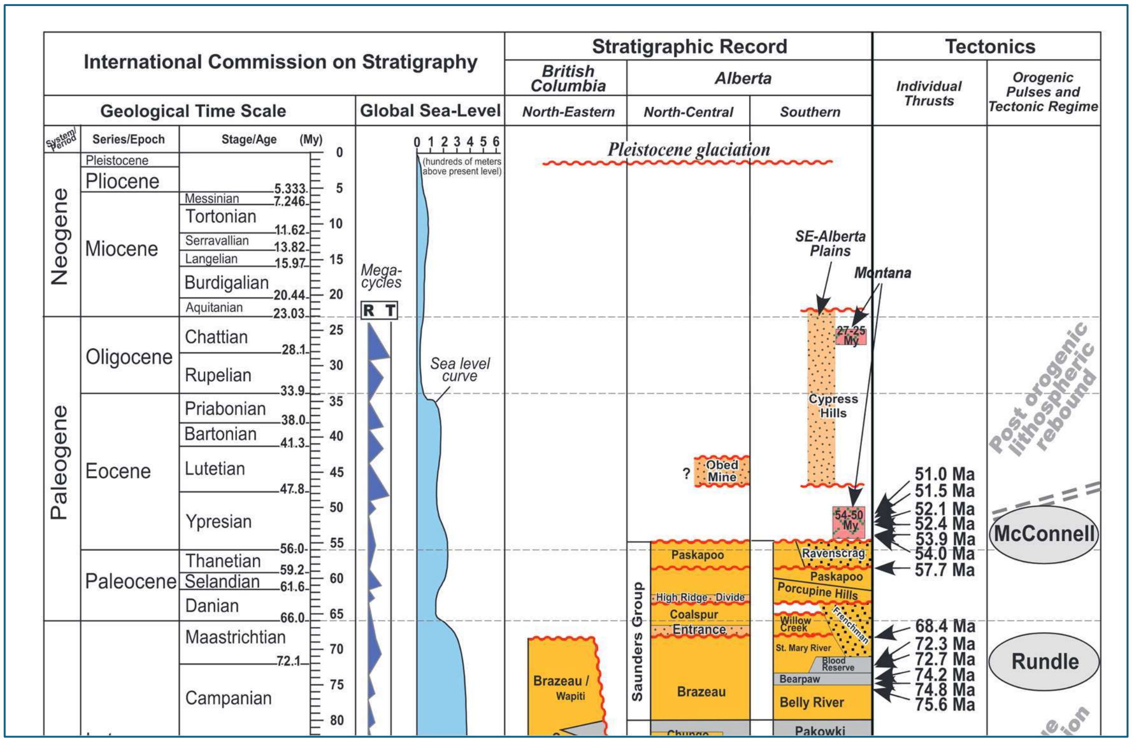


Figure 2.3: Age dating of thrust faulting correlated to stratigraphic record. Pană and van der Pluijm (2015).

The Nature and Age of the Local Land Surface

The local landscape is a palimpsest surface representing a diachronous unconformity. An unconformity means that the modern landscape is a surface of erosion that separates older rock and sediment from the modern age with significant gaps in time. A palimpsest surface means a landscape made up of overlapping traces from different periods, where older landforms and processes are still visible beneath newer ones. Diachronous means the actual land surface is not the same age everywhere. The rocks and sediments exposed at the land surface are also of different ages, but the age of the rock or sediment exposed is not the same as the age of the land surface itself.

The main line of evidence that the land surface in Calgary is a significant unconformity comes from estimates of the amount of rock and sediment eroded above the modern land surface. There are several reinforcing lines of evidence for a significant thickness of rock and sediment missing from the space above the modern land surface. One strong line of evidence comes from coal-maturation studies. Coal matures from organic matter deposited at surface to increasing states of coal maturity (lignite to bituminous to anthracite) with increasing burial at a predictable rate. Surfaces of equal coal maturity indicate maximum depth of burial and the difference between that maximum depth and the current depth indicates the amount of missing overburden (Figure 2.4).

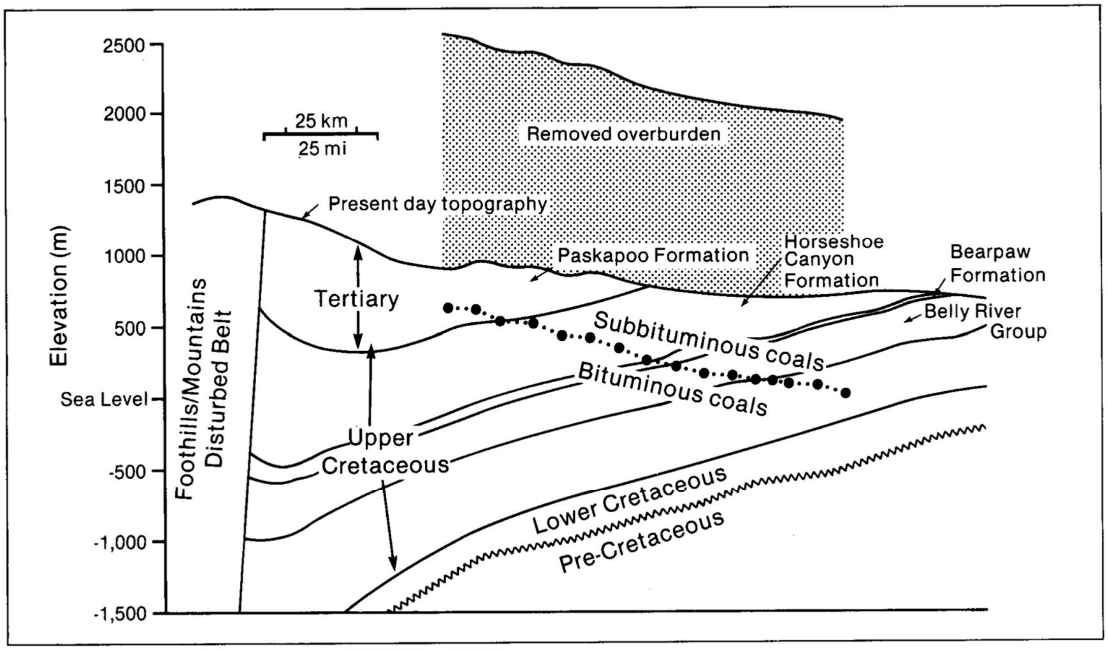


Figure 15. Cross section A-A′ trends northeast through the central plains area and shows both the reconstructed overburden and the west southwest dip of the coal-bearing units. The subsurface stratigraphy is modified after Gussow (1962)

Figure 2.4 Estimated amount of missing overburden based on coal maturity relative to modern depth of burial (Nurkowski, 1984).

The prime mechanism for the erosion of kilometers of overlying rock is believed to be lateral planation by meandering rivers emanating from the Rocky Mountains flowing to the east. These river systems crosscut the Alberta and Saskatchewan plains. As they meandered laterally back and forth across millions of years, they removed sediment and carried it downstream. Erosional removal was dominant in the late Paleogene to Neogene as the land rose due to cessation of plate-collisional thrust-sheets being loaded onto the crust causing it to sink, coupled with isostatic rebound due to the more buoyant earth's crust rising higher in the underlying mantle as it the crust became thinner by the erosional removal. There was probably a degree of thermal uplift as well due to the overriding of the North American continental plate over hot Farallon oceanic plate in the Neogene.

The lateral planation carved broad new floodplains but at times, for reasons not well understood, there were punctuated drops in fluvial base levels. These drops lead the rivers to incise downwards more than they cut laterally for some time until lateral planation resumed. Landscape elements, usually those armoured by river gravels of the previous bench, were left uneroded on the landscape, creating isolated remnants of older landscapes. Figure 2.5 shows a conceptual reconstruction of the sequence of landscape benches observed in Southern Alberta.

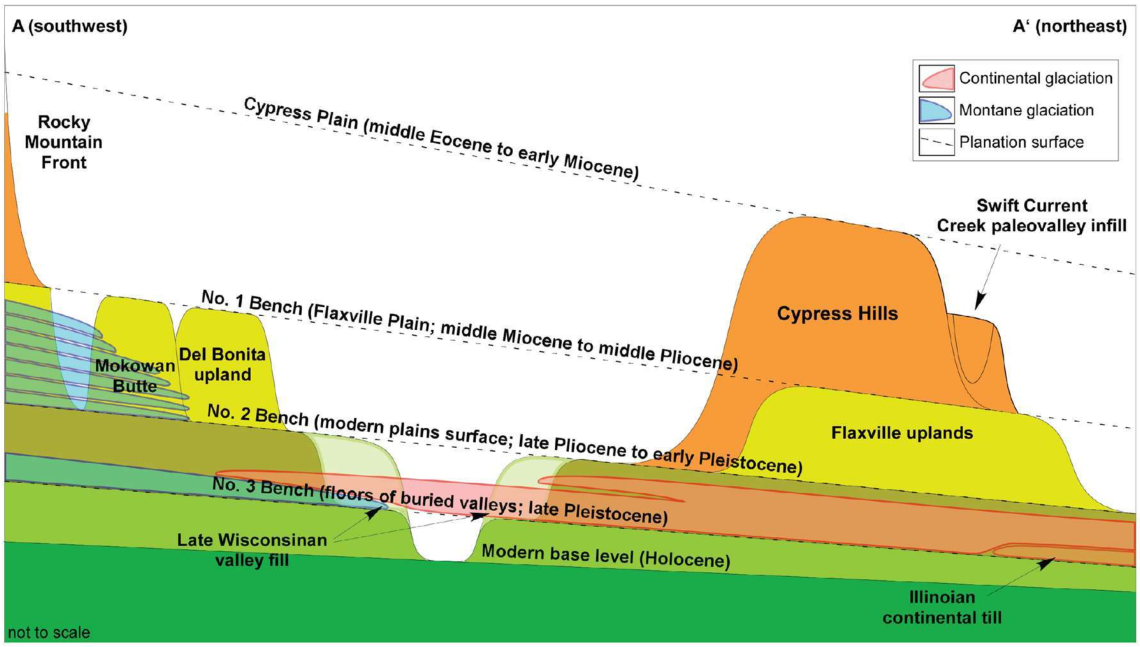


Figure 6. Diagrammatic cross-section A–A′ (Figure 3) showing major elements of the stratigraphic framework from the period 1985 to present.

Figure 2.5: Conceptual diagram of landscape benches in southern Alberta (Hartman, 2015).

The Calgary landscape can thus be explained as a palimpsest surface of at least five landscapes (from oldest to youngest):

1. A late Pliocene to early Pleistocene landscape whose lowest elevations are marked by the river gravels on the tops of Spy Hill, Nose Hill, and Signal Hill in Calgary (Osborn et al., 1991), remnants of early No. 2 Bench.
2. No. 2 Bench landscape at carved by lateral planation by the Bow and Elbow River and their tributaries before glaciation (Osborn and du Toit, 1991).
3. A late Pleistocene event of interglacial downcarving and minor lateral planation marked by buried preglacial or interglacial (pre-Illionian and/or pre-Wisconsian) bedrock valleys (No. 3 Bench). This bench is not visible in Calgary but known from maps of buried valleys east of Calgary (Andriashek, 2018). Where the modern Bow and Elbow Rivers crosscut these bedrock valleys, the modern riverbed elevations are below the No. 3 Bench elevations.
4. The latest Pleistocene to Early Holocene landscape formed by rapid erosion by glacial meltwater channels coinciding with the cyclic fill and spill of eastward retreating proglacial meltwater lakes (Moran, 1986; Wilson, 1987).
5. The modern landscape of modern river valleys and terraces of the Bow and Elbow River.

Figure 2.6 shows how these benches apply to the Calgary region.

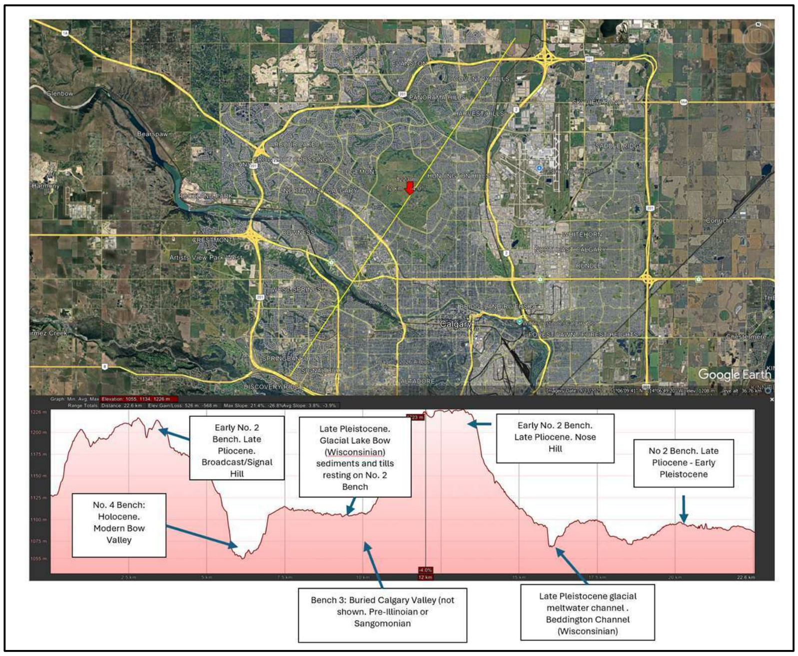


Figure 2.6: Google Earth topographic cross-section SW to NE across Calgary with surfaces labelled on major features recognized after Hartman (2015).

Bedrock Bedding and Jointing

The location has an outcrop of thick, massive fine-grained sandstone overlain by inclined to wavey, thin bedded sandstones (Figure 2.7). The outcrop is moderately weathered and enhanced by modern human ephemeral petroglyphs (i.e., graffiti).

Figure 2.7: Outcrop of Porcupine Hills Formation showing the bed-thickness to joint spacing relationship.

The bedrock is vertically and horizontally jointed with some small-scale, discontinuous fractures evident upon close inspection. In geology, a joint is a natural fracture (crack) in a rock along which there has been little or no measurable displacement parallel to the fracture surface. A joint forms when rock fails in brittle fashion under stress, usually tensile or extensional stress associated with erosional unloading.

The outcrop highlights the published observation that there is a relationship between tensile joint spacing and bed thickness, being either linear or non-linear, depending on the rock properties (e.g., Ji, 2023). In this outcrop, the joint spacing in the thin beds is definitely less than the joint spacing in the thick beds. As a corollary to this observation, it has been noted that in cases of orthogonal joint sets, the spacing may vary between the master joint set and orthogonal subsidiary joint sets in addition to the thickness-spacing relationship. Landscapers in west Calgary often use Porcupine Hills bedrock joint-blocks for decorative retaining wall without much shaping because of the regularity.

Groundwater Implications

The productivity of sandstone aquifers in shallow Alberta bedrock is often fracture or joint controlled. Average transmissivity may be estimated from dual-porosity models of aquifer-test response in wells, but one may need to consider that in near-surface bedrock this average may under-represent the transmission through thin beds with smaller joint spacing and thus more joints contributing to flow and transport though connectivity and surface area of joint blocks. A recent report from the USGS on fracture control on water-well productivity by Kozar et al. (2025) has well-documented examples.

The Split Rock Glacial Erratic

Above the outcrop is the Split Rock Glacial Erratic (Figure 2.8). The glacial erratics of the Calgary region are discussed in Stop 4.

Figure 2.8: The Split Rock glacial erratic at Stop 2, just above the outcrop discussed. Random walker for scale.

Stop 2 References

Alberta Geological Survey (2019): Alberta Table of Formations; Alberta Energy Regulator, URL: https://ags.aer.ca/publications/all-publications/alberta-table-formations.

Andriashek, L.D., comp. (2018): Thalwegs of bedrock valleys, Alberta (GIS data, line features); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Digital Data 2018-0001.

Hartman, G. (2015): Synthesis of a post-Laramide stratigraphic framework of the South Saskatchewan River Basin, Alberta, in support of hydrostratigraphic modelling; Alberta Energy Regulator, AER/ AGS Open File Report 2015-01, 36 p.

Kozar, M.D., McAdoo, M.A., Austin, S.H., and Wright, C.A., 2025, Factors affecting the distribution of water-bearing fractures in the bedrock aquifers of West Virginia: U.S. Geological Survey Scientific Investigations Report 2025–5044, 66 p., https://doi.org/ 10.3133/ sir20255044.

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Wilson, M.C., 1987. Chapter 10: Geological History of the Bow River Valley in the Calgary Region. In: Canadian Society of Petroleum Geologists (CSPG), 1987. Geology of the Calgary area. edited by Lionel E. Jackson, Jr. and Michael C. Wilson; illustrated by Angelique M. Gillespie.

Stop 3: Highland Park Resilient Landscaping Demonstration Hub and University of Calgary Rain Garden Monitoring Installation.

This location is the site of an experimental monitoring and research station from the University of Calgary. The focus of ongoing research is to understand and quantify storage and recharge rates below constructed rain gardens in the semi-arid and annually frozen landscape of Calgary. Rain gardens are a form of low-impact developments (LID) that can help moderate the hydrological impacts of increased runoff during storms in urban areas with large areas of impervious surfaces.

The results of this research program can help design implementations of managed aquifer recharge (MAR) through surface infiltration in southern Alberta.

Location Description

This site is located at the Highland Park Community Centre at 3716 2nd Street NW, Calgary. The rain garden is situated on the south side of the building (Figure 3.1).

Figure 3.1 Situation of Highland Park Rain Garden (figure courtesy of Alberta Low-Impact Development Partnership (ALIDP).

The instrumentation array and wells used are in Figure 3.2.

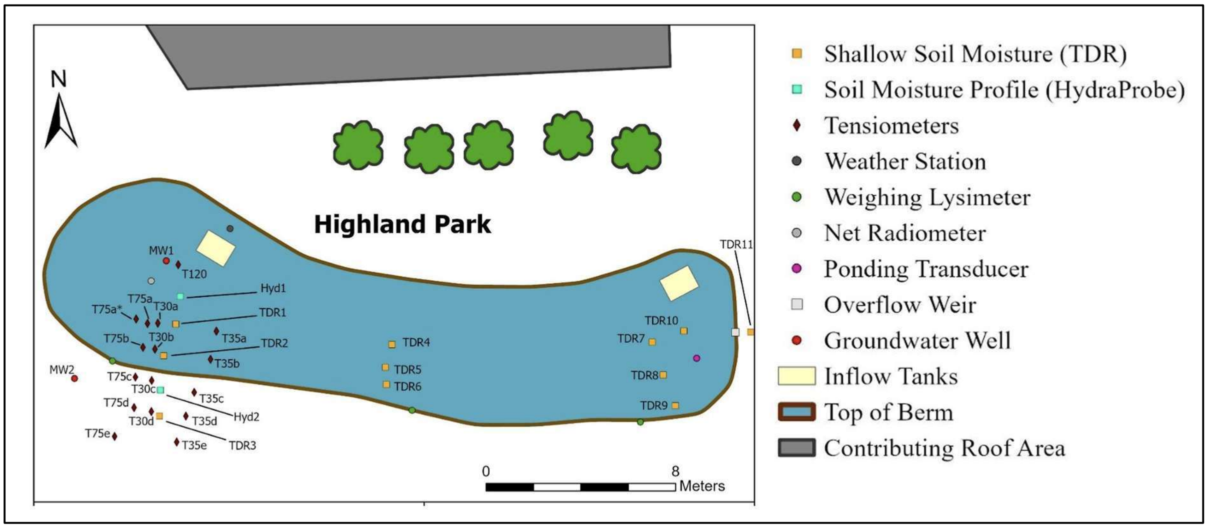

Figure 3.2: Instrumentation and wells at Highland Park raingarden (from Igl, 2025).

The surficial geology at this site is reported as Calgary Formation glaciolacustrine silt and clay (Figure 3.3). The location is on the southeast flank of Nose Hill, so the bedrock will be rising to the north. There may be till below the Calgary Formation at the site, which could be either Lochend Formation or Balzac Formation, or both, as their trends crosscut this area (see maps in Stop 4).

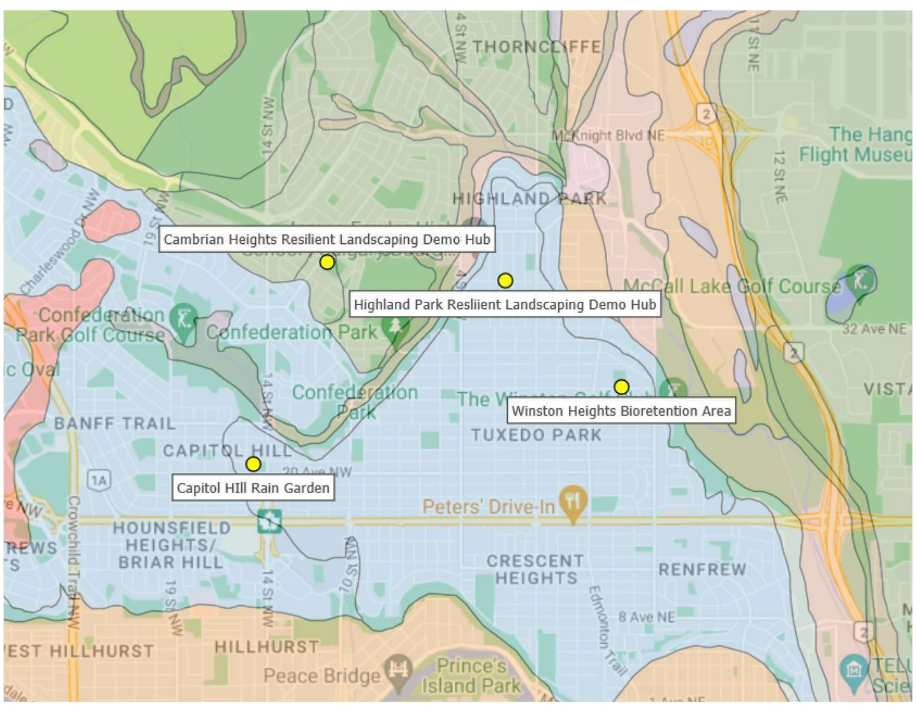

Figure 3.3: Surficial geology in the vicinity of the Highland Park Community Centre. From Moran, 1986.

The site was constructed in 2021 (Figure 3.4). Water is captured on the roof of the adjacent community hall and fed into the rain garden, which has been monitored for several years. Artificial rainfall events were also simulated with trucked-in water to test extreme precipitation events. The hydrophysical properties of the site are characterized in Ilg (2025). High infiltration rates of 21 mm/hr were observed at Highland Park. Ilg (2025) notes that this rate is higher than what has typically been planned for in the region, allowing large volumes of stormwater to seep into the native soil, rather than accumulate as standing water at the surface or overflow out of the garden.

Figure 3.4: Research Installation at Highland Park Community Centre. Photo provided by ALIDP.

Ilg (2025) also records that recharge resulted in a groundwater mound to form beneath the garden during precipitation events, lasting for approximately 1 to 5 days following an event. On one occasion the groundwater level increased by ~1 m beneath the garden, and the mound was observed to extend out laterally at least 1.5 m from the garden on several occasions. Shallow lateral flow in the unsaturated zone extended 2 to 3 m from the edge, suggesting a 3-m setback be used between rain gardens and underground infrastructure in similar locations.

Managed Aquifer Recharge (MAR) by Surface Infiltration

Managed aquifer recharge (MAR) is the suite of technologies for the purposeful and beneficial introduction of water from the surface into aquifers. Recent reviews of MAR include the works of Dillon et al. (2020), McCurry and Pyne (2022), Parker et al. (2022), Owen et al., (2025), and Sinshaw et al. (2026). Surface infiltration is as simple as filling an impoundment with water of acceptable chemical quality and allowing it to infiltrate vertically into an unconfined aquifer (Figure 3.5) for recovery at a later time or an offsetting location.

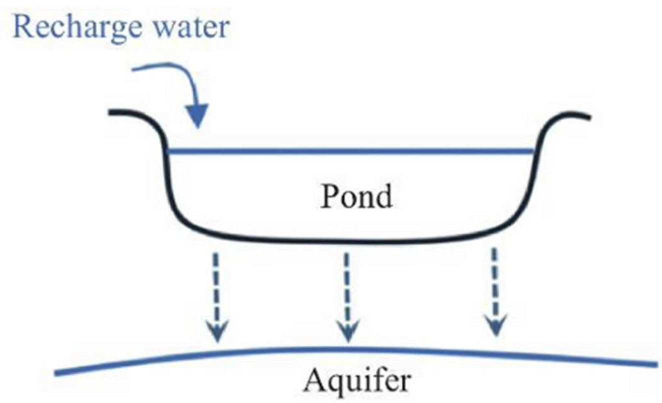

Figure 3.5: MAR by surface infiltration (Dillon et al., 2020).

Advantages of surface infiltration MAR include low-cost construction and operation and ease of access for remediation (e.g., of biofouling). Disadvantages include the need for water loss by lateral flow away from the pond; need for potentially large surface areas (a function of infiltration rate and vertical heterogeneity) and the needs for control of water-table mounding that could impact subsurface structure or lead to groundwater flooding.

The National Groundwater Association (NGWA) Managed Aquifer Recharge work group is preparing a "Best Suggested Practice for Surface Infiltration". Watch https://www.ngwa.org/what-is-groundwater/groundwater-issues/managed-aquifer-recharge for more information.

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Stop 4: Glacial Stratigraphy of Calgary – Fish Creek Provincial Park

The Calgary area is characterized by at least four recognized till sheets. Till can be defined as unsorted sediment deposited directly by glacier ice without reworking by meltwater or wind. It commonly contains a mixture of clay, silt, sand, gravel, and boulders, and it is typically unstratified. Note the term diamict is also used for unstratified sediment of varying grain size but has no connotation of a glacial origin.

During the Pleistocene Epoch of the early Quaternary Period (starting around 2.6 Ma), the earth entered an age of continent-scale glaciation, particularly in the Northern Hemisphere. Earth had been getting cooler and drier throughout the Neogene Period due to factors like the tectonic drift of the Antarctic continental plate to the south pole, the rise of the Tibetan Plateau as the Indian plate collided with the Asian plate, burial of carbonates of the former Tethys Ocean below the Bengal Fan, and the closure of east-west Pacific to Atlantic oceanic currents by the creation of the Isthmus of Panama joining North and South America. Once these conditions were established, the driver of glacial cycles became controlled by carbon cycles, volcanic eruptions, and the albedo of glaciers coupled with the orbital mechanics of the Earth's axial tilt relative to the sun, the wobble of earth around its axis, and the eccentricity of Earth's orbit.

There were many episodes of glacial advance and retreat during the Pleistocene. In North America, the major episodes are divided into Pre-Illionian glacial (2.6 Ma to 300 ka), the Illinoian glacial (300 ka to 130 ka), the Sangamonian interglacial (130 ka to 85 ka), the Wisconsian glacial, and the Holocene interglacial (11.7 ka to present). We see some evidence for Illinoian or even pre-Illionian glacial advance of continental ice sheets into Alberta, but mostly we see the results of Wisconsonian glaciation in the Calgary area overtop the pre-glacial No. 2 bench palimpsest landscape and No. 3 bench (Sangamonian?) buried valleys.

In detail, we see the interplay between east-flowing glacial advances from the nearby Rocky Mountains (Montane ice) and southwest-flowing glacial advances from the distal Keewatin spreading center of the continental-scale ice sheet located near Hudson Bay (Laurentide ice) (Figure 4.1).

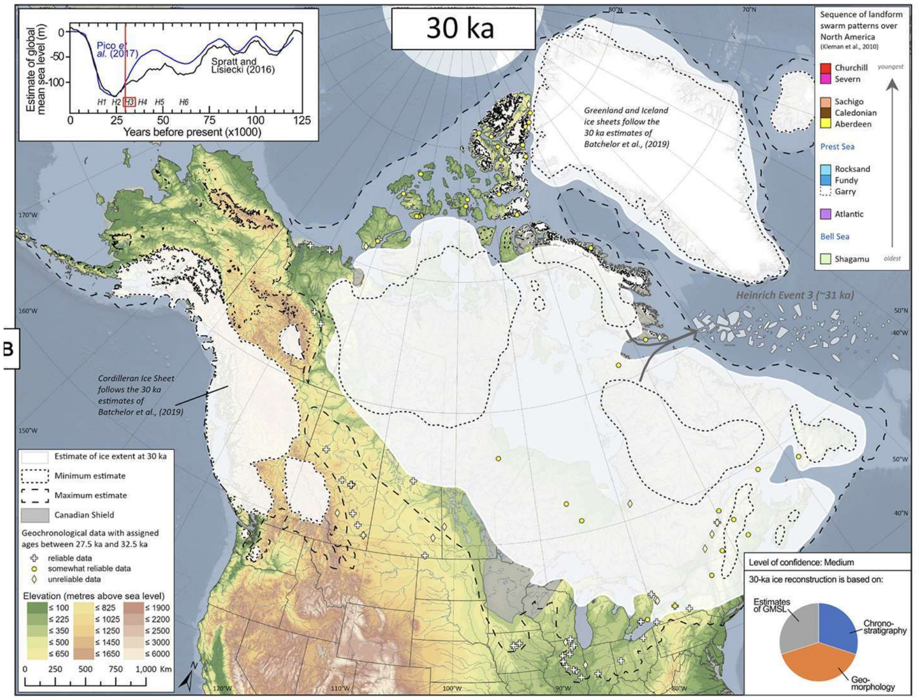

Figure 4.1: Reconstruction of North American ice coverage, 35 ka. Dalton et al. (2022).

The till stratigraphy was originally defined by Tharin (1958) and mapped in detail by Moran (1986). The stratigraphy is captured in Figure 4.2 from Moran (1986).

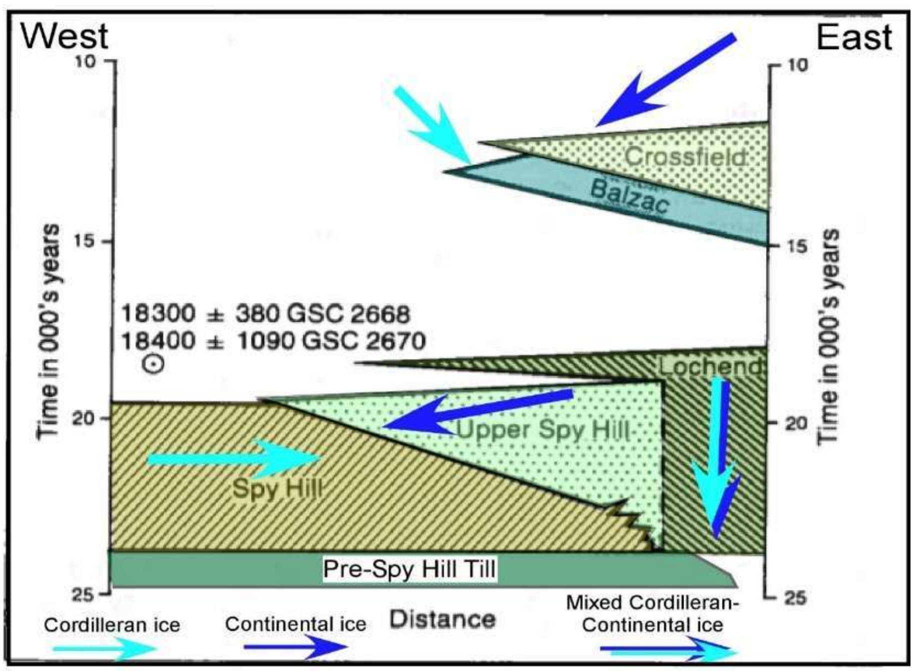

Figure 4.2: Conceptual east-west time:distance diagram for Late Wisconsinian glaciation, Calgary area. Moran (1986).

The general understanding today is as follows, leveraging the schema of Tharin (1958) and Moran (1986) plus the detailed maps in Moran (1986). Note that more work has been undertaken to refine and improve on our understanding of the glacial history of southern Alberta beyond this schema (e.g. Jackson et al., 2008; Utting and Atkinson, 2019).

The glacial stratigraphy of Calgary is complicated by the recognition that there were multiple short-lived episodes of glacial advance, melting and retreat, and readvance by the same ice sheets or ice lobes. Some of this complexity is evident in Figure 4.3, which shows glacial flowlines in the Calgary area. It is generally accepted that these till formations were all deposited during the last (Late Wisconsinan) glacial cycle.

- Pre-Spy Hill Till: Eastward- flowing montane ice extends along the Bow Valley, covering parts of Calgary. The age of this advance is unknown. Assumed early Wisconsinan?
- Lower Spy Hill Till: Eastward flowing Montane ice extends along the Bow Valley, covering parts of Calgary.
- Upper Spy Hill Till: Moran (1986) noted the rare occurrence of granitic or gneissic clasts at the top of the Spy Hill Till. Rocks of these lithologies are diagnostic of eastern sourced tills (from the Canadian Shield up-ice). For this reason, the Upper Spy Hill Till is recognized as a separate unit though it is dominantly the same as the Lower Spy Hill Till in appearance. This diamict is also covered by glaciolacustrine sediment, demonstrating the eastward fluvial drainage along the Bow was being blocked by SW flowing Laurentide ice at this time. This is consistent with the transport direction of shale-rich till (again indicative of an eastern source of sediment) which was deposited across the Paskapoo Formation east of Calgary. This continued SW Laurentide ice flow eventually extended across the Calgary area, depositing the Upper Spy Hill Formation.
- Lochend Till: As advancing Laurentide ice divides continued to evolve and migrate, a progressive shift in SW ice flow, likely involving a slight change in provenance explains the emplacement of the Lochend till, possibly immediately prior to the Laurentide and Cordilleran ice sheets becoming fully converged during the Last Glacial Maximum.
- Balzac Till: Once full convergence was established, the SSW flowing High Plains paleo-ice stream, which comprised mutually deflected Laurentide and Cordilleran ice extended across the Calgary area, depositing the Balzac till. The Glacial Erratics Terrane is usually associated with the Balzac Till.
- Crossfield Till: During deglaciation and the "unzipping" of the convergent Laurentide and Cordilleran, lobes of Laurentide ice blocked regional drainage routes,

impounding a succession of temporally and spatially transgressive proglacial lakes. These lobes also periodically readvanced, explaining the emplacement of Crossfield till over the Balzac till.

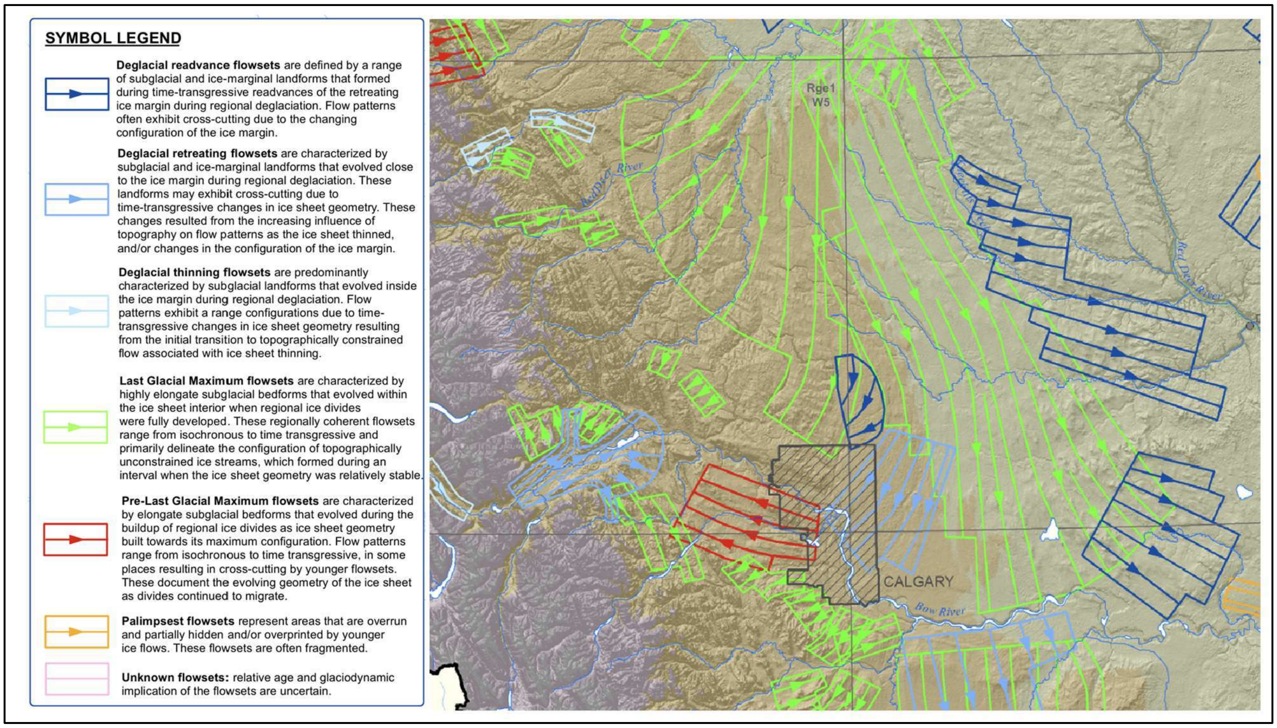

Figure 4.3: Extract of glacial flowlines in the Calgary area. From Atkinson and Utting, 2021.

Spy Hill Till

The Spy Hill Till is found across the west side of Calgary (Figure 4.4) but exposures are rare. It can be seen in the eroded banks of Fish Creek, along the informal path rising on the east bank above Fish Creek Park Bridge Number 5 (Figure 4.5). There may have been some fluvial reworking of the till before the steep meltwater channel of Fish Creek was formed (Benham et al., 2019) at this exposure. Another possibility is that this is a lodgement till and the apparent orientation of clasts reflects basal ice directions. Nevertheless, this is still one of the few exposures of the Spy Hill Till accessible anywhere in Calgary. This trip won't go to this site as it is a 1.5 km walk west from the parking lot. Access is also signed as "Use at Your Own Risk" and is on a steep bank that is progressively becoming more unstable over the years.

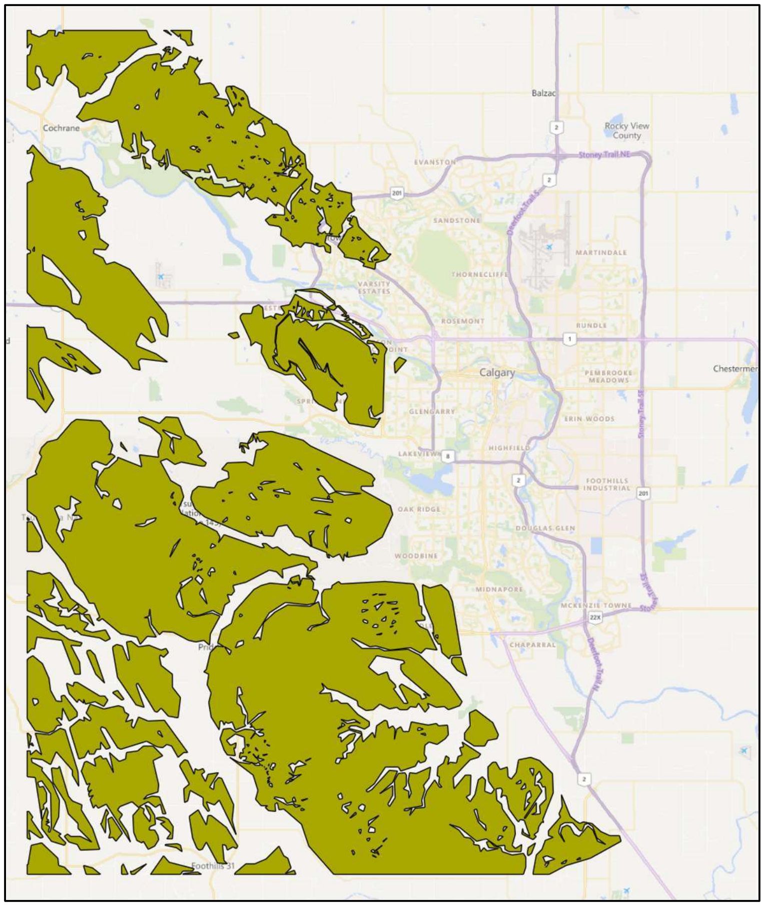

Figure 4.4: Distribution of Spy Hill Till from Moran (1986).

Figure 4.5: Spy Hill Till (Upper) on bank above Fish Creek Park at Bridge Number 5.

Lochend Till

The Lochend Till is exposed in a cutbank near Votier Flats parking lot and picnic area (Figure 4.6). Visible at the top of the outcrop are 2-3 m of layered silt deposits of the Calgary Fm. (Figure 4.7). These represent glaciolacustrine sediment deposited in Glacial Lake Calgary that formed at the end of the last glaciation. Beneath these stratified sediments are about 8 m of dark grey sediment interpreted to as the Lochend Fm. The formation is described as an association of diamict (till, defined by stones in outcrop face) and layered sediment (Moran, 1986). Evidence of layering may be faintly visible in this outcrop, attesting perhaps ice-proximal glaciolacustrine sedimentation. The Lochend till has a silty texture and contains higher sand content than either the underlying upper Spy Hill till or the overlying Balzac or Crossfield tills. The pebble fraction contains dark grey carbonate (limestone, dolostone) clasts from mountains as well as crystalline clasts from the Shield and has the greatest amount of montmorillonite and least illite of tills in the Calgary area. More diagnostically, the ratio of crystalline to carbonate fragments in the very coarse sand fraction is higher in the Lochend Fm. Till than that of either the Spy Hill or overlying Balzac Fms. (but lower than that of the Crossfield Fm.).

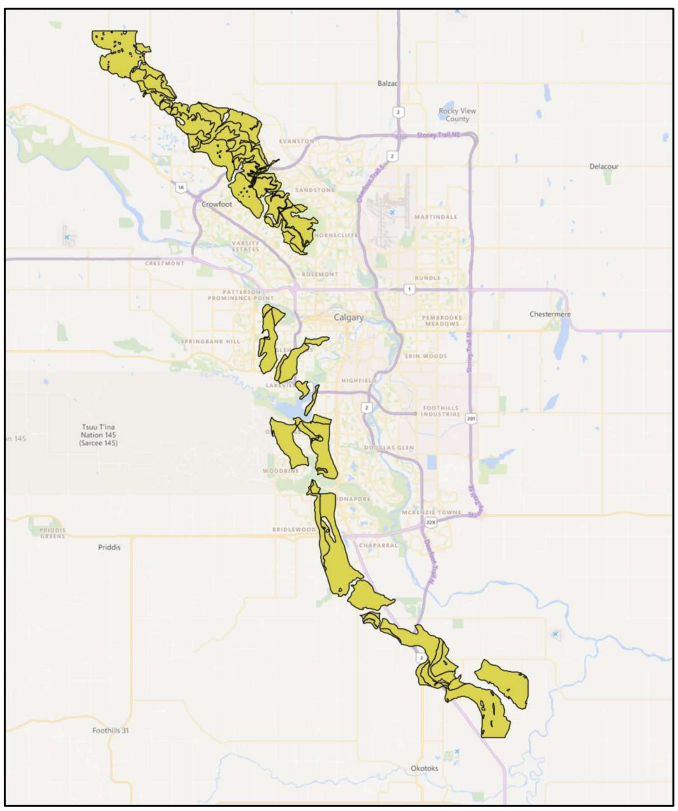

Figure 4.6: Lochend Till exposure at surface in Calgary region from Moran (1986).

Figure 4.7: Outcrop of Lochend Till overlain by Calgary Fm silt on south bank of Fish Creek, about 5 minutes south of Votier's Landing parking.

Crossfield Till

The Crossfield Till is exposed on the north side of Fish Creek east of McLeod Trail S, below Canyon Meadows Drive SW (Figure 4.8). The outcrop is interpreted as the Crossfield Formation, which is composed of sandy till and silt lenses or layers (Figure 4.9). The marked difference in color between the outcrop of till at this site compared to that at the previous site (Lochend till) can be attributed in part to the higher overall sandiness of the till, as well as the greater amount of crystalline fragments containing iron-rich minerals that weather to a rusty-buff brown. Also evident on further inspection are linear pock marks on the outcrop face that may represent burrowing of cliff-dwelling birds, such as swallows. These preferentially select looser, unconsolidated silt and fine sand layers for nesting. Depending on the outcrop appearance at the time of visit, there may be evidence of stratified Glacial Lake Calgary sediments resting atop, though it may be difficult to differentiate from sandy beds nested within the till.

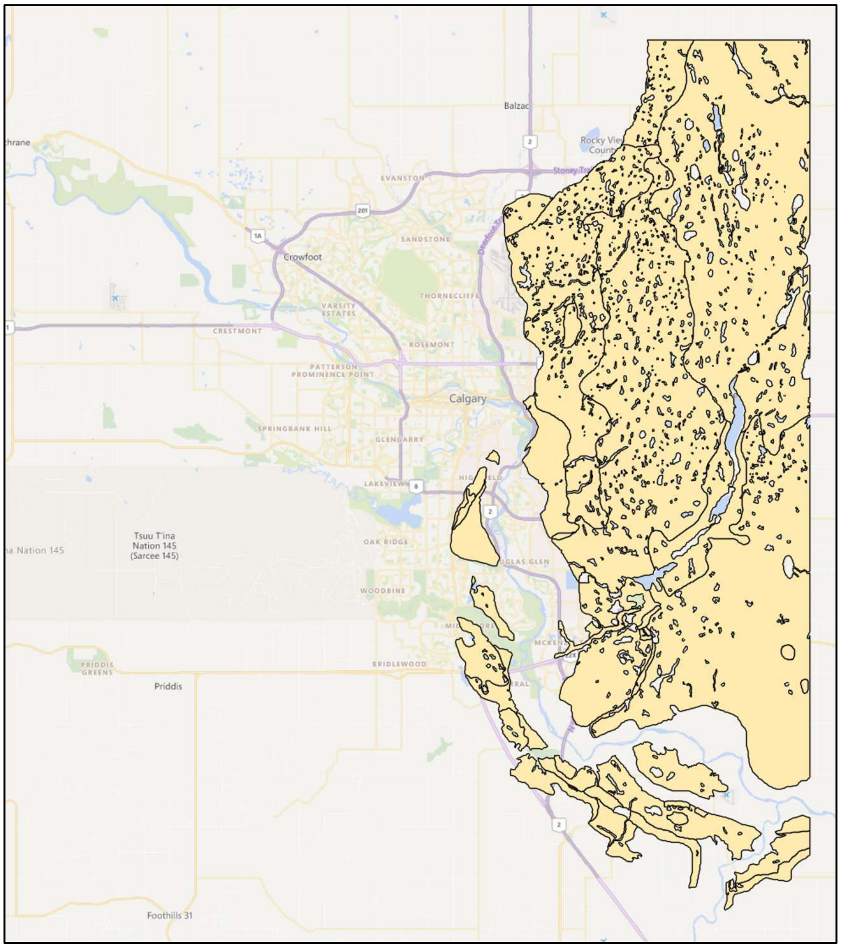

Figure 4.8: Crossfield Till exposure at surface in Calgary region from Moran (1986).

Figure 4.9: Outcrop of Crossfield Till on north side of Fish Creek, just below Canyon Meadows Drive SW.

The Foothills Erratic Terrane

The Glacial Erratic Terrane in Alberta is a linear association of quartzite boulders that can be traced along a line from the Hinton area eastward into the High Plains Ice Stream where it was diverted south into the Calgary area (Figures 4.10, 4.11).

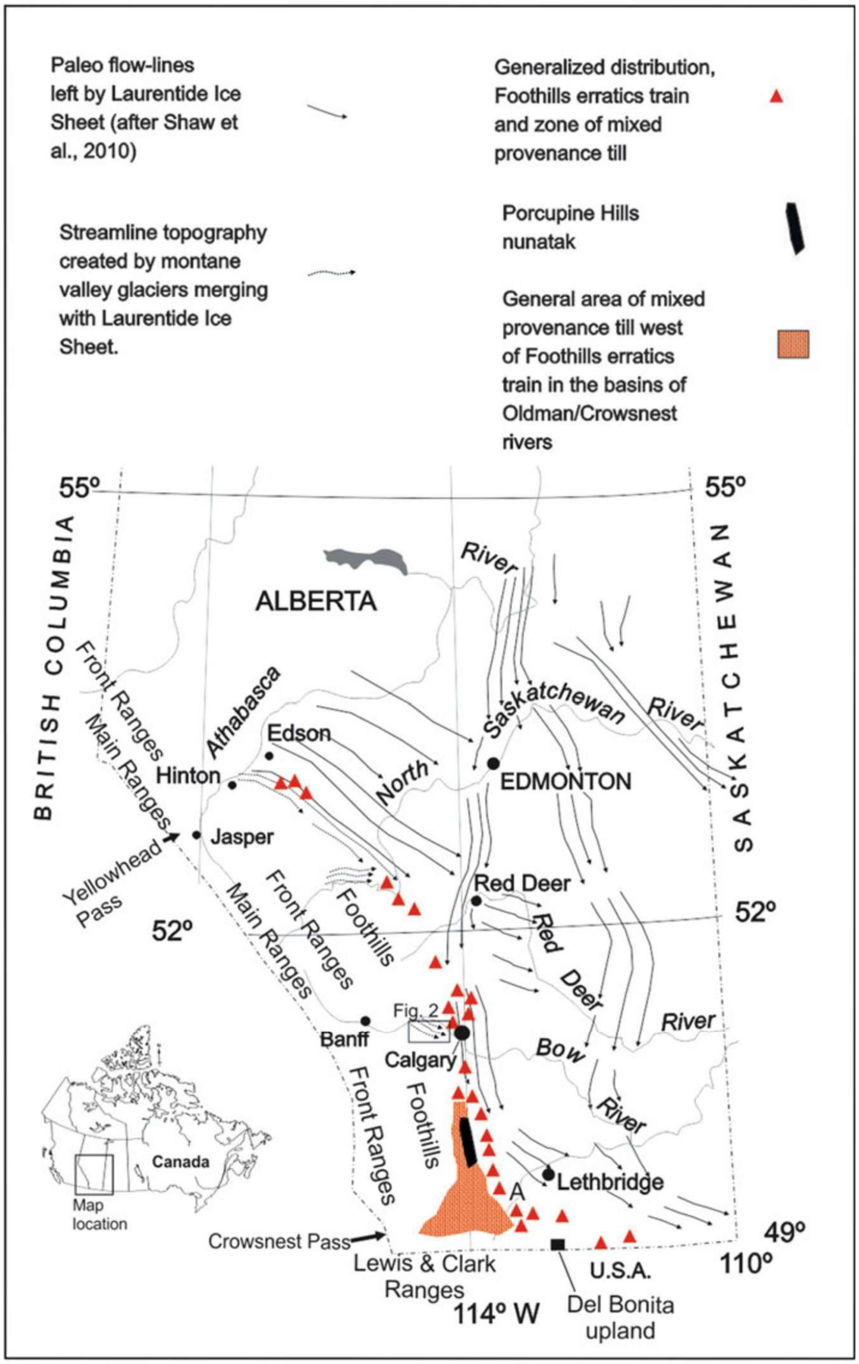

Figure 4.10. Origin of Foothills Erratic Terrane relative to Wisconsinian ice streams. Jackson (2016).

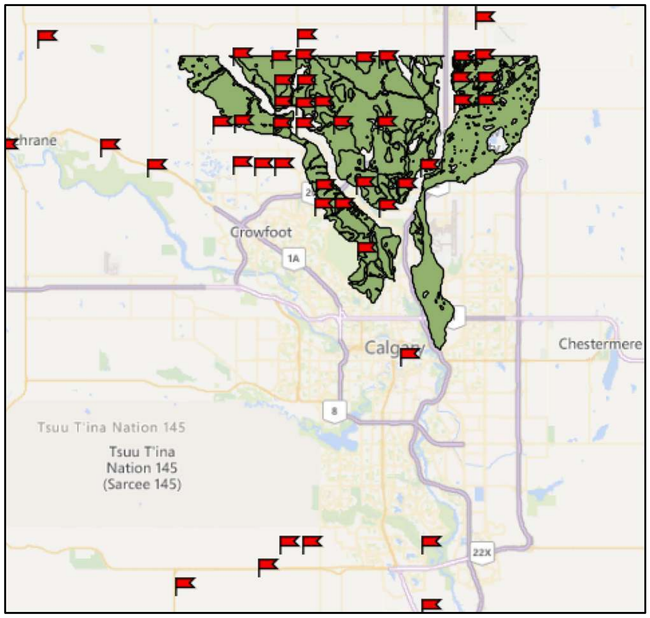

Figure 4.11. Location of glacial erratics in Calgary area and mapped extent of Balzac Till. Moran (1986), AGS (2014).

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Stop 5: Surface-Groundwater Interaction. Calgary West Village

At this stop, we discuss the interaction between the Bow River and Elbow River and the modern alluvial sediments on the Holocene floodplain and terraces adjacent to them.

Groundwater Flooding

The City of Calgary is updating its flood risk mapping to include a groundwater flooding fringe (Figure 5.1). Groundwater flooding refers to groundwater tables rising high enough to either enter a building's basement or other subterranean structures directly or via backflow in water or sewer lines, or directly above the land surface. Groundwater flooding in Calgary is discussed in Abboud et al. (2018).

This map is compared to the surficial map of Moran (1986) that illustrates the extent of coarse-grained fluvial sediments in the same area (orange).

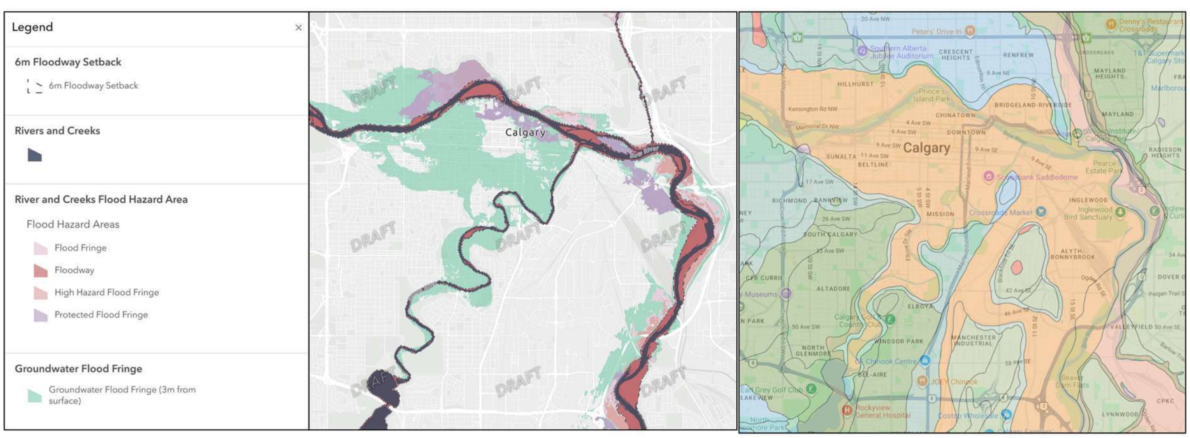

Figure 5.1: Comparison of draft flood area map, downtown focus (https://engage.calgary.ca/rivervalleys/rivervalleysp3s2) with surficial deposits of the same focus area from Moran (1986).

From the City of Calgary FAQ [Calgary River Valleys Project - Phase 3 Engagement | Calgary River Valleys Project | Engage](https://engage.calgary.ca/rivervalleys/rivervalleysp3s2)

"The City conducted the Calgary River Valleys Groundwater Study. The study involved:

- *Mapping groundwater levels during flood events in river valley areas.*
- *Estimating impact.*
- *Exploring options for resilience measures.*

- *Developing a new groundwater risk overlay zone for Calgary.*

The study showed that during major floods (1 in 100-year events), groundwater levels rise and can impact areas beyond the current flood hazard areas, and that many buildings in Calgary, especially older ones in established communities, are vulnerable to river flood-related groundwater risks.

The Groundwater Flood Fringe shows the area where a 1:100 river flood could raise groundwater to within three metres of the surface. A depth of three metres was chosen because it is the area where groundwater is more likely to impact a conventional residential basement (typical basement depth, especially in newer buildings, is 2.4-2.7m or 7-8 ft).

The groundwater risk area was determined using a state-of-the-art 3D computer model that simulates both river levels and groundwater levels. The model looks at river flow, groundwater flow through the aquifer under the river valley, and also the possible contribution to the groundwater table from heavy rain that infiltrates into the ground. To verify the model's accuracy, the groundwater levels from the model were calibrated (or checked against) recorded groundwater levels in wells throughout the city's river valleys, during both low/normal river flows and high river flows (e.g. the 2013 flood).

To provide extra confidence in the groundwater levels from the model (which are proposed to be used as the groundwater Designated Flood Elevations), we modelled a large number of scenarios where we changed the assumptions used in the model and looked at the variation in resulting groundwater elevations. Through this "uncertainty analysis," we selected the 90th percentile groundwater elevations, which means we can be confident that the DFE covers the vast majority of possible groundwater elevations during a 1:100 flood.

On the Elbow, the 1:100 river flood event used to model and map groundwater included the mitigation provided by the Springbank and Glenmore Reservoirs. This means the model used a 1:100 mitigated flow below the Glenmore Dam of 150m3/s (i.e. the river channel is full, but no overland flooding into communities).

The bigger the flood event, the more water is held back in the reservoirs, and the more water that needs to be released back to the river after the river starts to recede. This means that flows in the river will be higher for longer (up to several weeks), as water is released. This increases the groundwater impact for larger flood events versus smaller *flood events, even if SR1 and Glenmore Reservoirs can hold the downstream river flow to 150m3/s for all floods up to the 1:200 flood event."*

The Canada Creosote Site

The area at Stop 5 includes the Canada Creosote site. A wood preserving facility known as Canada Creosoting Company operated from 1924 to 1962 (Figure 5.2). The plant used coal tar, creosote, and other mixtures to treat raw lumber and poles. Wood preservatives used at the site included creosote and coal tar which can include PAHs, pentachlorophenol, dioxins, furans, and petroleum hydrocarbons. Zinc chloride was also use at the plant. The liquids were stored in storage tanks and the process water and sludges were stored in pits.

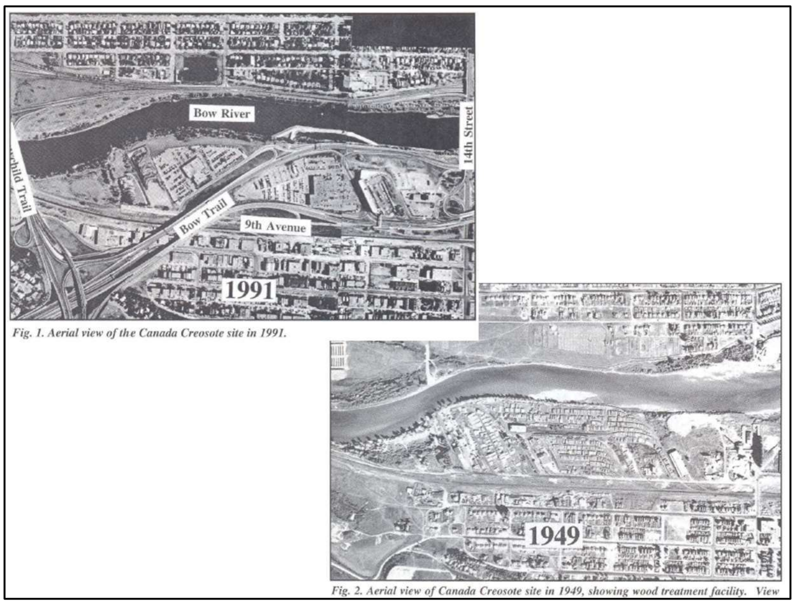

Figure 5.2: Aerial photographs showing Canada Creosote site during operations and when remediation began.

The site was included on a list of orphan industrial sites in Alberta investigated by Alberta Environment in the 1980s. Site investigations discovered both DNAPL and LNAPL plumes in the coarse gravel alluvium resting on bedrock. In 1989, creosote was observed to be emerging as distinct blobs and pools on the bed of the Bow River adjacent to the site, accelerating plans to contain and remediate the site at taxpayers' expense.

After examination of remedial options, containment was chosen to be the least-risky and most cost-effective solution for site management. Extraction and treatment of the DNAPL and LNAPL plumes was not viewed to be effective given the technology of the time.

The remedial strategy consisted of building a 640-m combined bentonite slurry wall and secant pile wall, keyed into competent sandstone bedrock below the alluvial gravels along the south bank of the Bow River (Figure 5.3, 5.4). The wall could not be configured to completely enclose of the plumes because of surface-use by a central bus depot and several car dealerships as well as restrictions due to subsurface utilities and the nearby CPR main line.

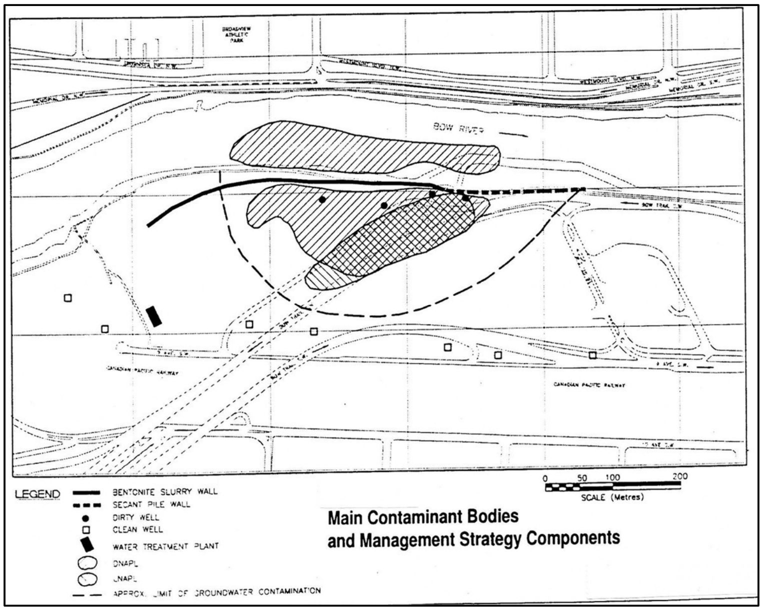

Figure 5.3. Original drawing showing final containment design-option chosen by Alberta Environment.

Figure 5.4: Construction of the containment cutoff wall.

The presence of the cutoff wall will create groundwater mounding due to natural flow gradients from the southwest towards the river and upward discharging gradients from the bedrock contributing baseflow to the river. The solution for groundwater mounding was to use a series of interceptor wells to capture a) as much “clean” groundwater upgradient of the DNAPL plumes and a series of mound-control wells to capture as little “dirty” water from above the DNAPL pools on bedrock as possible (Figure 5.5). An onsite water-treatment plant serves to treat the water from the dirty wells.

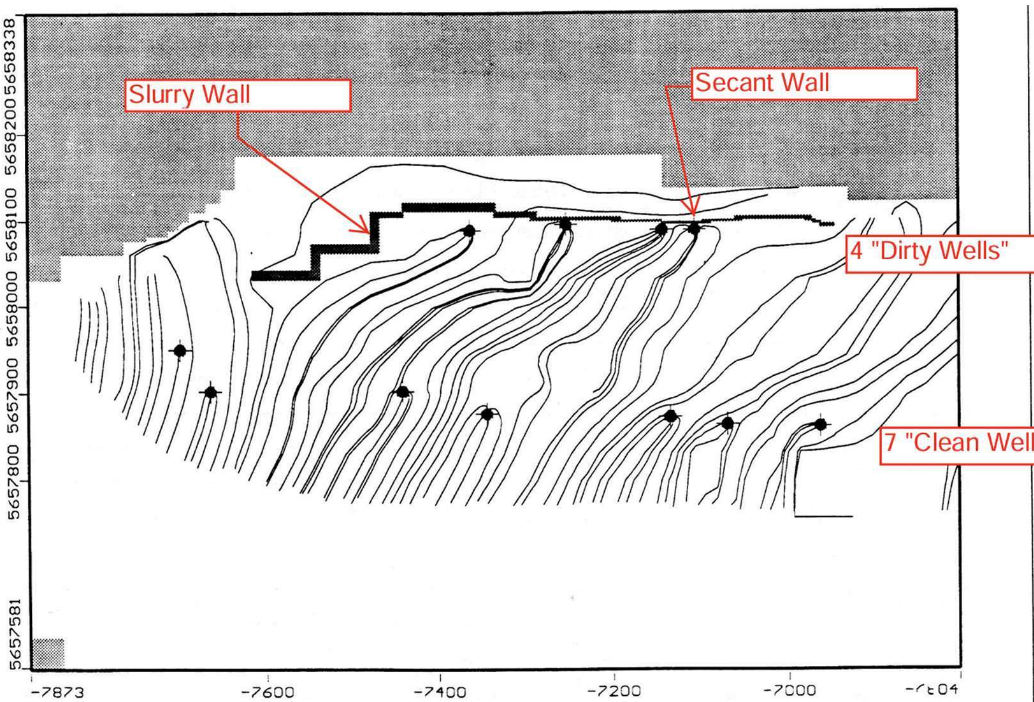

Figure 5.5: Capture-zone modeling used to locate clean and dirty wells to control groundwater mounding behind the cutoff wall.

The number and locations of clean wells were very restricted by the major water, electrical, and natural gas utility corridors running east-west on the south margin of the site. Wells or their drawdown cones could not significantly encroach on the CPR right-of-way.

Following these actions, creosote later was discovered on the north side of the Bow River. No industrial activity was ever recorded there so the source has been presumed to be from the Canada Creosote site sometime in the past or when creosote began to emerge on the bottom of the Bow River. The timing was never resolved. Health-based risk assessments were conducted on the north side of the Bow River and they indicated no remedial measures were required.

Stop 5 References

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Stop 6: Meltwater Channels and Spillways: The Sarcee Trail Spillway and Delta at Grey Eagle Resort.

Stop 6 includes the transit from Site 5 back to the point of departure at the Grey Eagle Resort.

Meltwater Channels and Proglacial Lakes

The long-term evolution of the landscape in Calgary introduced at Stop 2 has been extensively modified by glacial meltwater channels and spillways. Some of these features are now occupied by modern rivers and streams while others are dry features on the landscape. Figure 6.1 shows thalwegs of major buried and surficial valleys that have been carved into the top of bedrock.

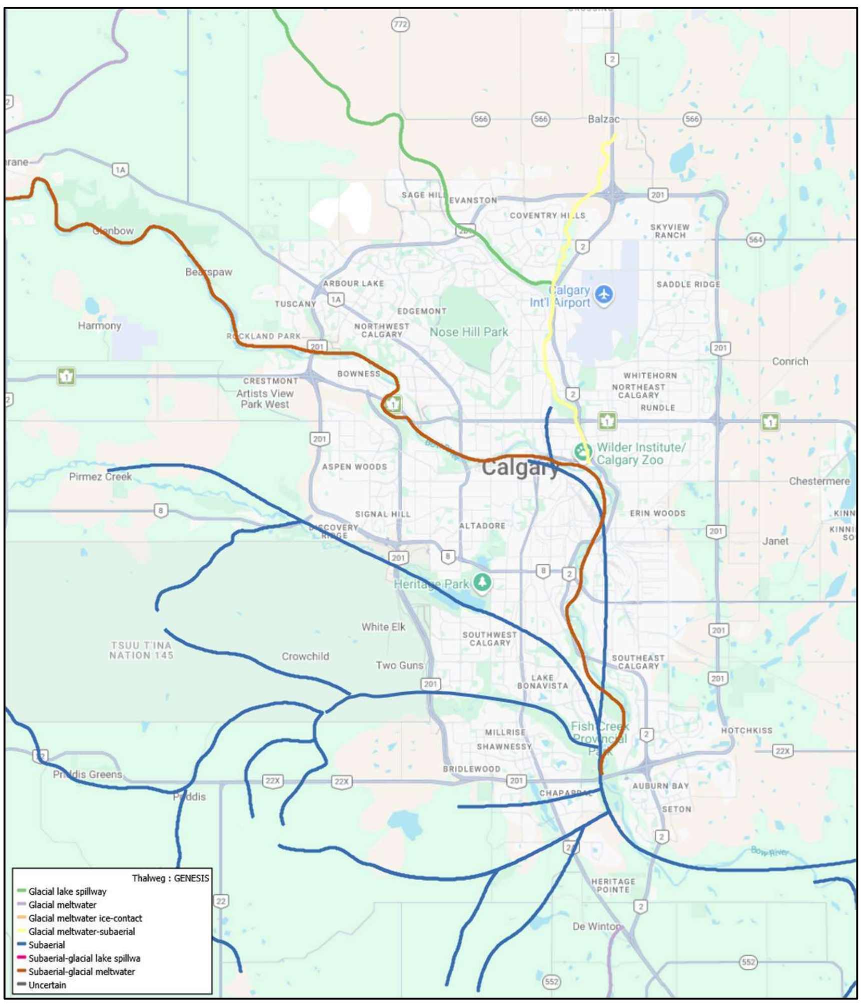

Figure 6.1: Thalwegs of bedrock valleys in the Calgary region. Andriashek (2018).

The bedrock valleys include pre-glacial (No. 2 Bench), interglacial (No. 3 Bench?), deglaciation meltwater channels, and Holocene (No. 4 Bench) features.

Figure 6.2 shows the identified glacial meltwater channels in the Calgary region (Atkinson et al., 2018). Note some bedrock valleys were reoccupied by meltwater channels.

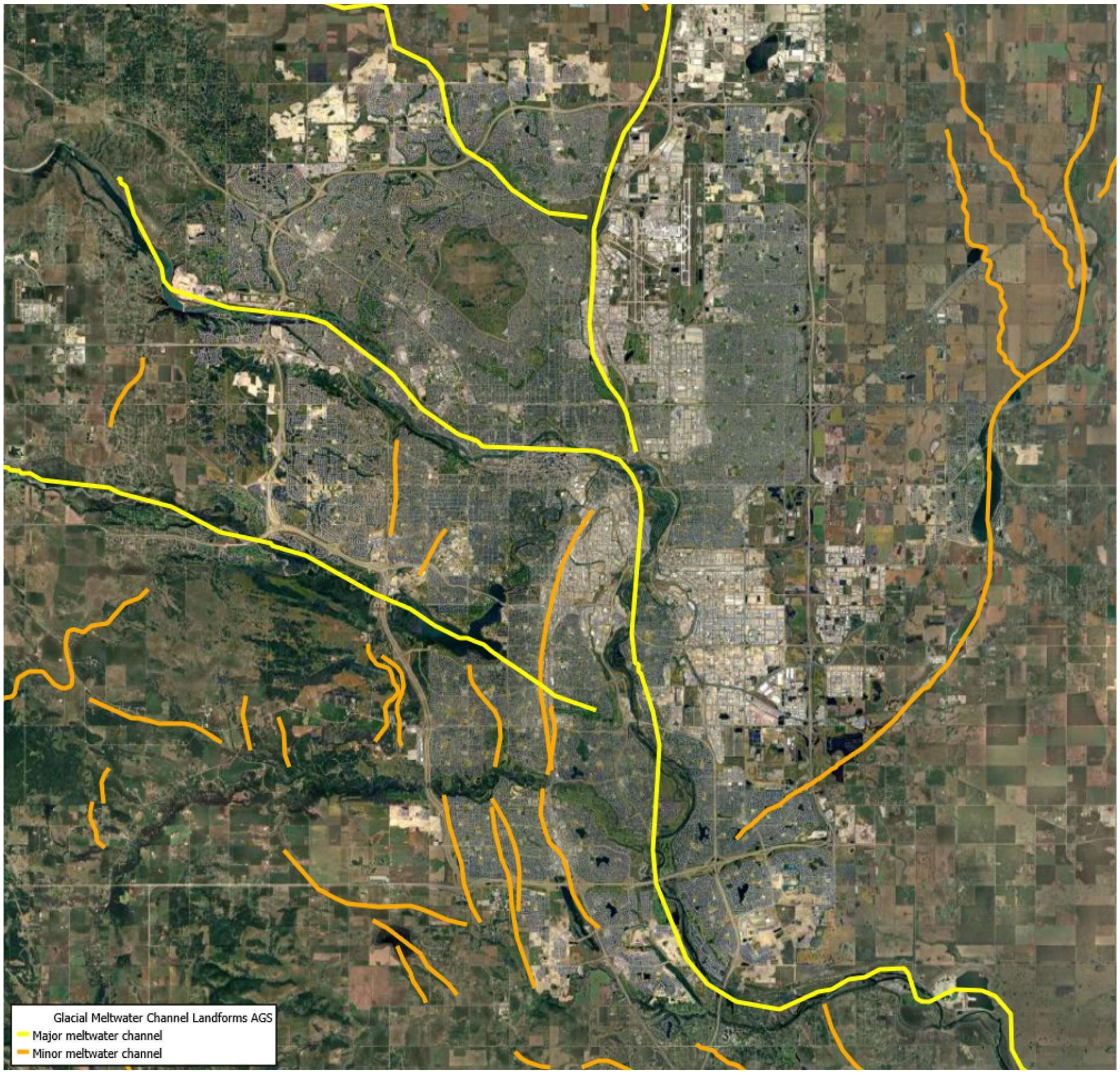

Figure 6.2: Meltwater channels in the Calgary region (Atkinson et al., 2018)

Meltwater channels formed in response to the fill, spill, and drainage of proglacial lakes. The Laurentide ice sheets in Alberta advanced upslope from the east, so when they and the Montane glaciers melted, natural eastward drainage was periodically blocked by the remnant Laurentide ice. This created large proglacial lakes along the ice front that would pond, fill, and eventually drain through a low spot revealed by ice retreat. The process continued throughout deglaciation (Figure 6.3).

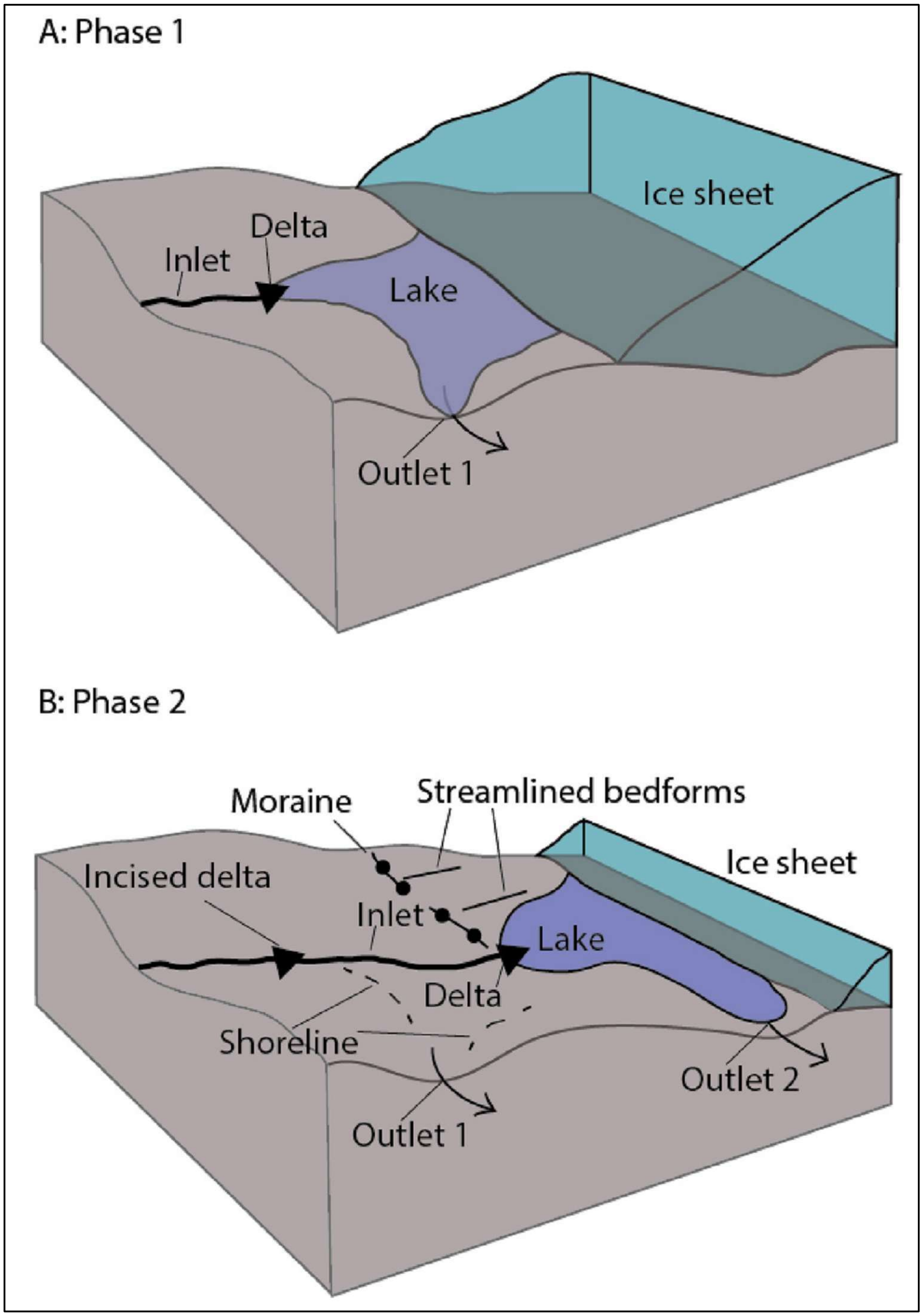

Figure 6.3. Conceptual model of a reverse-gradient retreating ice sheet impounding multi-stage proglacial lakes. A: In Phase 1, a proglacial lake has formed in a pre-existing basin or river-valley and drains through Outlet 1. Headward erosion would deepen the channel, lowering the lake level until further ice retreat enabled the lake to migrate into a lower basin (B: Phase 2) which subsequently drained through a new outlet (Outlet 2). From Utting and Atkinson (2019), their Figure 3.

The sequence of deglacial lake formation and drainage, coupled with the creation of meltwater channels is very complex. Figure 6.4 shows a reconstruction of proglacial lakes in the Calgary region during one part of deglacial time.

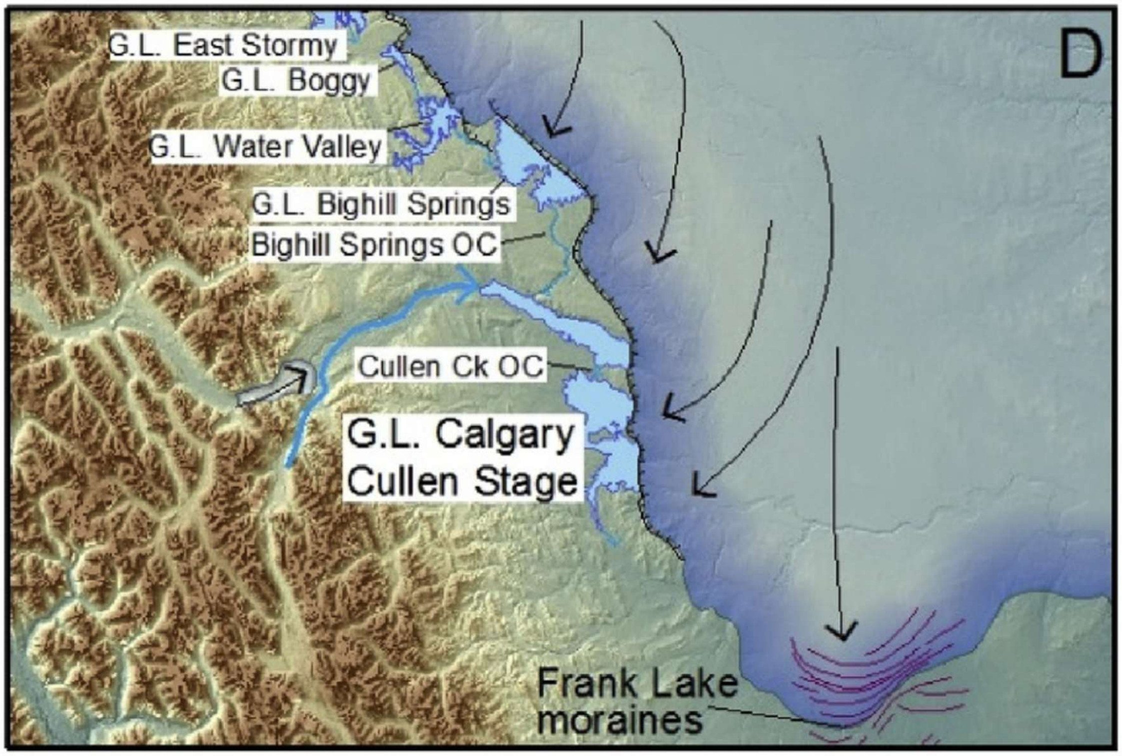

Figure 6.4. Reconstruction of proglacial meltwater lakes in Calgary region (Utting and Atkinson, 2019).

The West Calgary Meltwater-Channel and Sarcee Spillway Complex

Moran (1986) and Wilson (1987) recognized a complex of meltwater channels and a major spillway in west Calgary. Figure 6.5 extracted from Moran (1986) shows the position of meltwater lakes in west Calgary at Lochend time. Note that at this time, two separate preglacial lakes referred to as Glacial Lake Bow and Glacial Lake Elbow were present. Blockage of both proglacial lakes by a readvance of the Lochend ice led the higher Glacial Lake Bow to spill its south bank and flow southward into Glacial Lake Elbow.

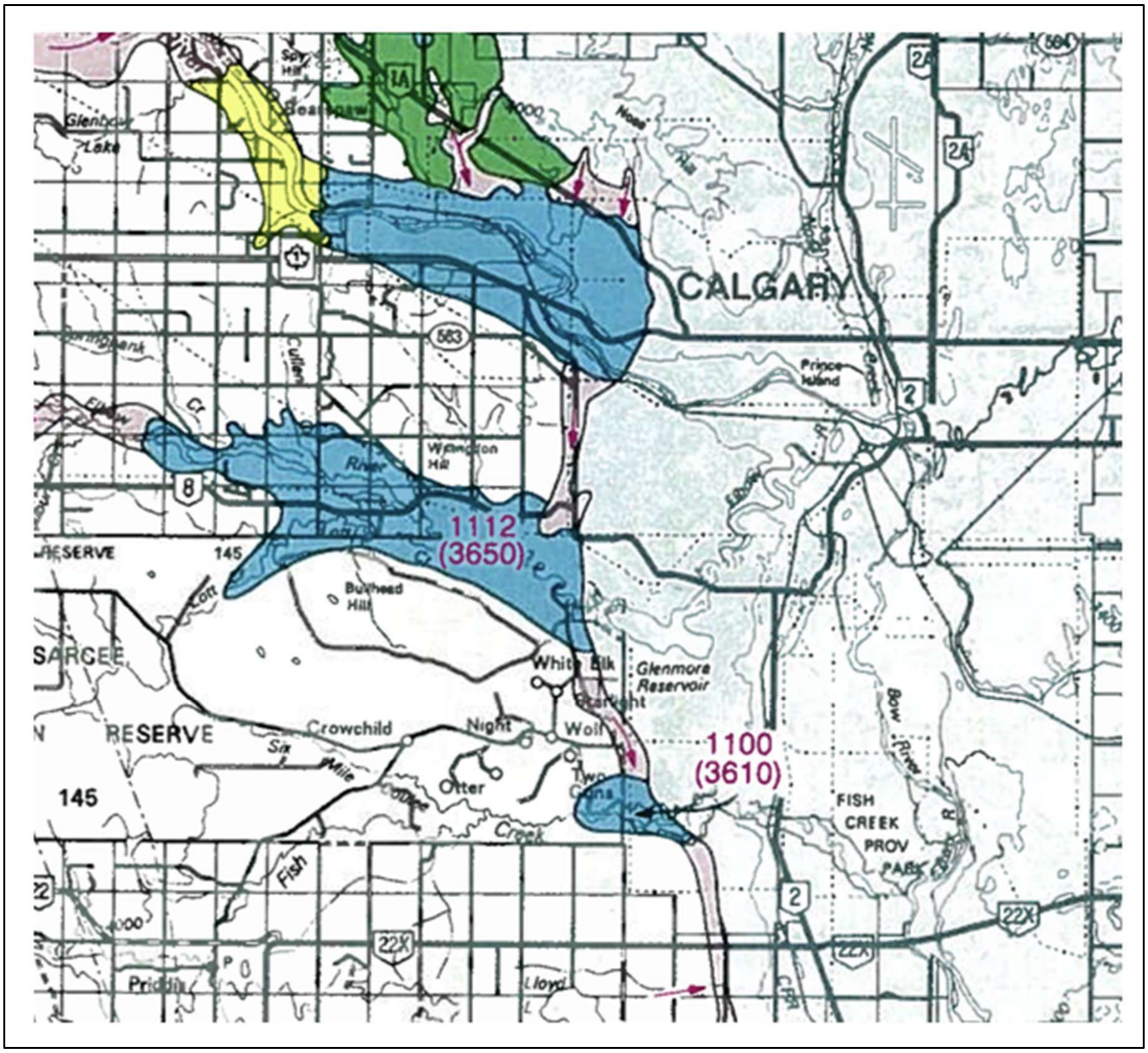

Figure 6.5. Location of Sarcee Spillway that partially drained Glacial Lake Bow southward into Glacial Lake Elbow, forming the Sarcee Delta at the spillway terminus (Moran, 1986, from his Figure 29).

Figure 6.6 clearly shows the Sarcee Spillway on a high-resolution digital terrain model. The spillway is now occupied by Sarcee Trail South. Figure 6.7 shows a photograph of Sarcee Trail South looking north next to an AI-imagined reconstruction of the Spillway when it was active.

Figure 6.6 also shows the mapped distribution of gravels at the terminus of the Sarcee Spillway from Moran (1986). The gravels are called the Sarcee Delta and were formerly sites of gravel pits. The Grey Eagle Resort sits atop the Sarcee Delta, overlooking what was probably excavated pits now under redevelopment (Figure 6.8).

Figure 6.6 also shows minor preglacial meltwater channels as mapped and named by Wilson (1987). He noted that these channels post-dated the Sarcee Spillway.

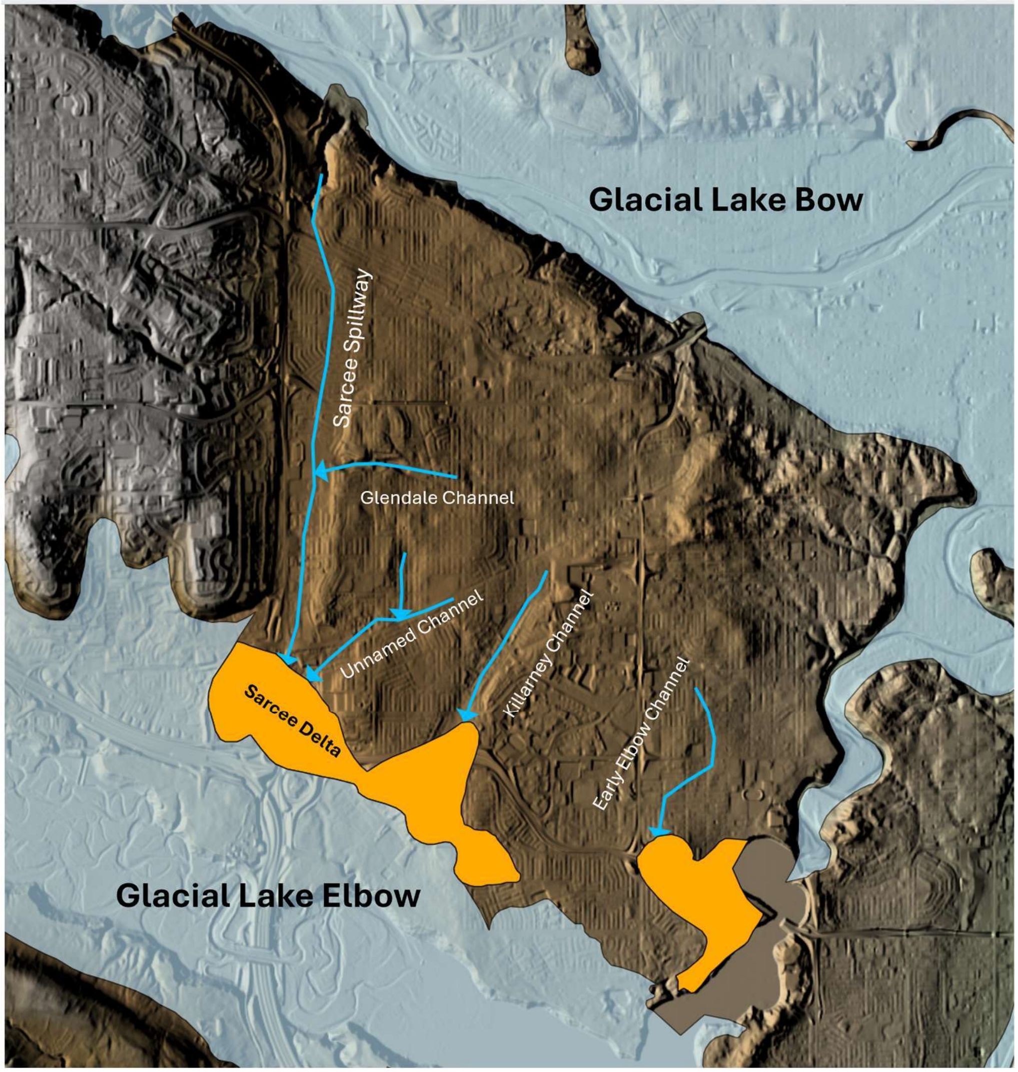

Figure 6.6: West Calgary meltwater channels and Sarcee Spillway-Sarcee Delta complex.


Figure 6.7 Sarcee Spillway looking north today and as imagined during the spillway formation – Signal Hill bedrock on left, Lochend ice wall on right.

Figure 6.8 Current excavation into Sarcee Delta gravels below Grey Eagle Resort (on left).

Stop 6 References

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