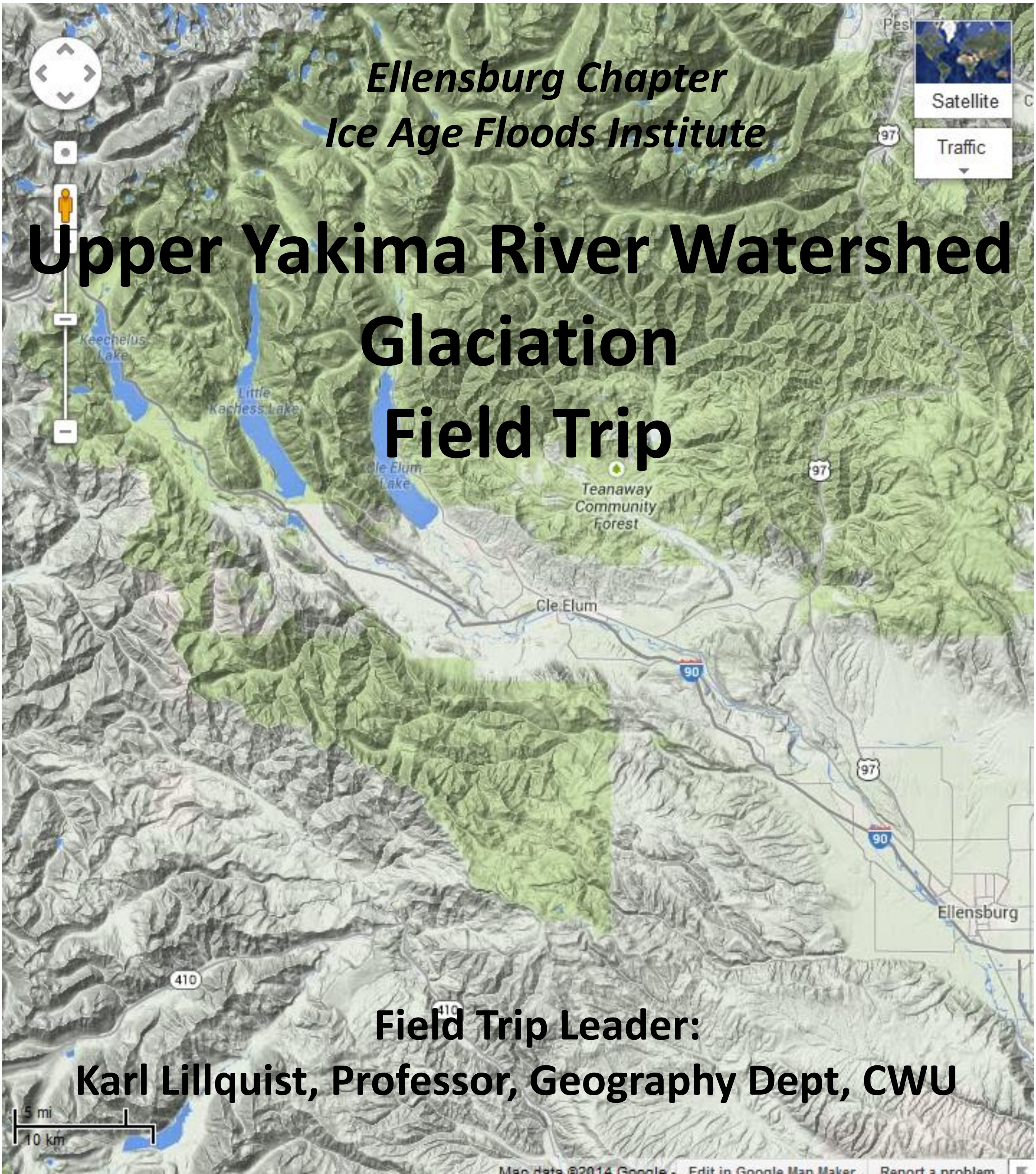
Ellensburg Chapter
Ice Age Floods Institute

Upper Yakima River Watershed Glaciation Field Trip



Field Trip Leader:
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28 September 2014

Preliminaries

Field Trip Overview

In the relatively recent geologic past, glaciers were common in the Upper Yakima River Watershed. Most of the glaciers are now gone but their impacts linger. Contemporary transportation routes, water quality and quantity, logging and farming practices, sites of mining operations, and recreation opportunities all are shaped by past glaciation. We will explore the landform and sediment evidence of glaciation in the Upper Yakima River Watershed ranging from Swauk Prairie to Snoqualmie Pass.

Tenative Schedule

10:00 am	Depart CWU
10:30	Stop 1--Swauk Prairie
11:15	Depart
11:45	Stop 2--Speelyi Beach, Lake Cle Elum (inc. restrooms & lunch)
1:00 pm	Depart
1:15	Stop 3– Cle Elum River Overlook
2:00	Depart
2:30	Stop 4—Swamp Lake
3:15	Depart
3:30	Stop 5—Exit 53, Snoqualmie Pass
4:00	Depart
4:05	Stop 6--Washington DOT Travelers Rest, Snoqualmie Pass (inc. restrooms)
4:20	Depart
4:30	Stop 7—Upper Parking Lot, Alpental
5:00	Depart
6:00	Arrive at CWU

Our Route & Stops

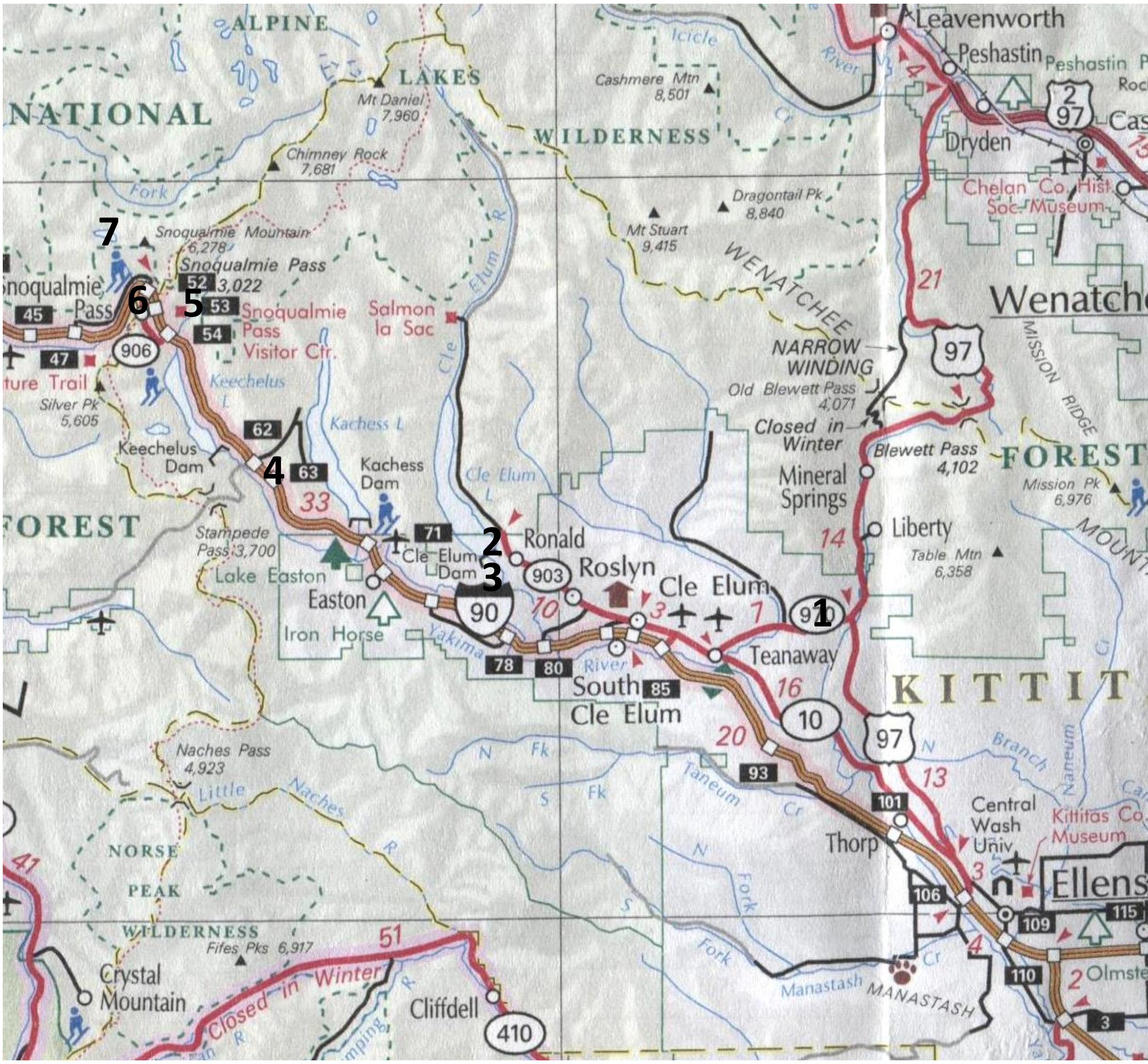


Figure 1. Field trip stops shown with bold numbers. Source: Washington State Department of Transportation.

Ellensburg to Swauk Prairie

- **Route**: Go west from CWU on University Way. At Ellensburg's West Interchange, head north approximately 16 miles on US 97 to its junction with WA 970 (Figure s 1 & 2). Turn west (right) at this junction and proceed approximately 0.5 mile. Turn north (right) onto Swauk Prairie Road and proceed about 1 mile to its junction with Micheletto Road. This is Stop 1.
- **Lithology & Structure**: Ellensburg lies near the western margins of the Columbia River Basalts. Our drive from Ellensburg begins on the floor of the Kittitas Basin syncline with downfolded Columbia River Basalts ~4000 feet below us (Figures 3 & 4). Mantling the Columbia River Basalts are volcaniclastic sediments of the Ellensburg Formation, alluvial fan sediments from the surrounding mountains , Yakima River alluvium, and loess. North of the junction of US 97 and WA 970 (i.e., Lauderdale or Virden) Teanaway Basalts are present.
- **Truncated Alluvium and Alluvial Fans**: In the Kittitas Basin, US 97 passes through eroded remnants of various aged alluvial fans (Figure 3). North of WA 10, US 97 parallels two escarpments. The western escarpment is formed in Thorp Gravels, Pliocene –aged alluvium deposited by the Yakima River. The eastern escarpment if formed in several different Quaternary-aged alluvial fan deposits. The northern part of the eastern escarpment is formed in Thorp Gravels deposited by tributaries to the Yakima River. The escarpments were created by Dry Creek erosion over time.
- **Thorp Gravels Pediments**: The Thorp Gravels likely accumulated in the Kittitas Basin syncline because uplift of Manastash Ridge lowered the slope of the Yakima River and tributaries to the Yakima River. This lowering reduced river and tributary velocity therefore causing aggradation. The age of these deposits is roughly 3.0-4.5 million years (Waitt, 1979). Thorp Gravel aggradation in the basin likely occurred in the form of large alluvial fans. Over time, these fans became stable (possibly because of slowing tectonic activity) developing thick calcium- and clay-rich B horizons in their soils. Subsequent erosion by side streams from the Wenatchee Range has dissected the once continuous Thorp Gravel deposits to leave erosional remnants (Figure 3). The surfaces of the Thorp Gravels has also been stripped down to the cemented and clay-rich horizons in many places leaving once-depositional surfaces now primarily erosional. These Thorp Gravels remnants could now be called pediments because of their erosional nature.
- **Wind**: The wind turbines seen along US 97 remind us of the pervasive windiness here. Flagged trees (or krummholz) at the top of US 97 also reflect the persistent growing season winds of the area.
- **Horse Canyon**: Horse Canyon lies west of US 97 and is best seen from the highest point reached by US 97 between Ellensburg and Lauderdale. The canyon heads at a low pass just north of this high point. An underfit, intermittent stream flows down the canyon to join Swauk Creek near its mouth. Water from the north side of the pass mentioned above flows north to middle Swauk Creek. The floor of the upper portion of Horse Canyon lies approximately 200 feet higher than the floor of Swauk Creek at Lauderdale Junction. The origin of this canyon is uncertain. Is it the result of glaciation, streams, landslides, or ???.
- **Swauk Creek and the Swauk Prairie Moraine**: West of Lauderdale, WA 970 ascends the abrupt distal face of the Swauk Prairie end moraine. The abruptness of this face is the result of Swauk Creek erosion of the moraine.

Ellensburg To Swauk Prairie

Figure 2. Overview of NW Kittitas Basin. Bold number indicates field trip stop. Source: Google Maps.

Ellensburg to Swauk Prairie

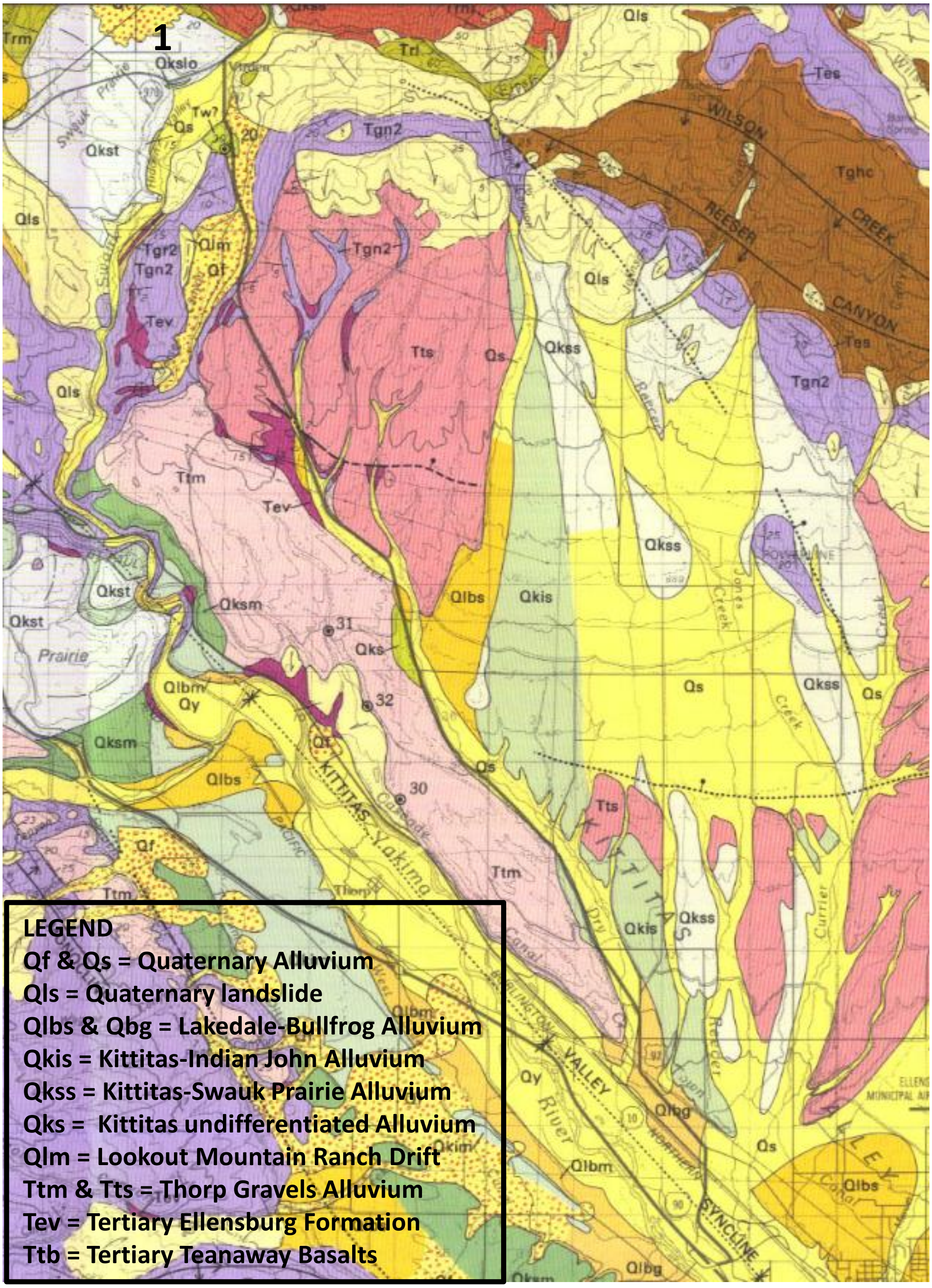


Figure 3. Geologic map of the northwest Kittitas Basin and surroundings. Bold number indicates field trip stop. Source: Tabor and others (1982).

Ellensburg to Swauk Prairie

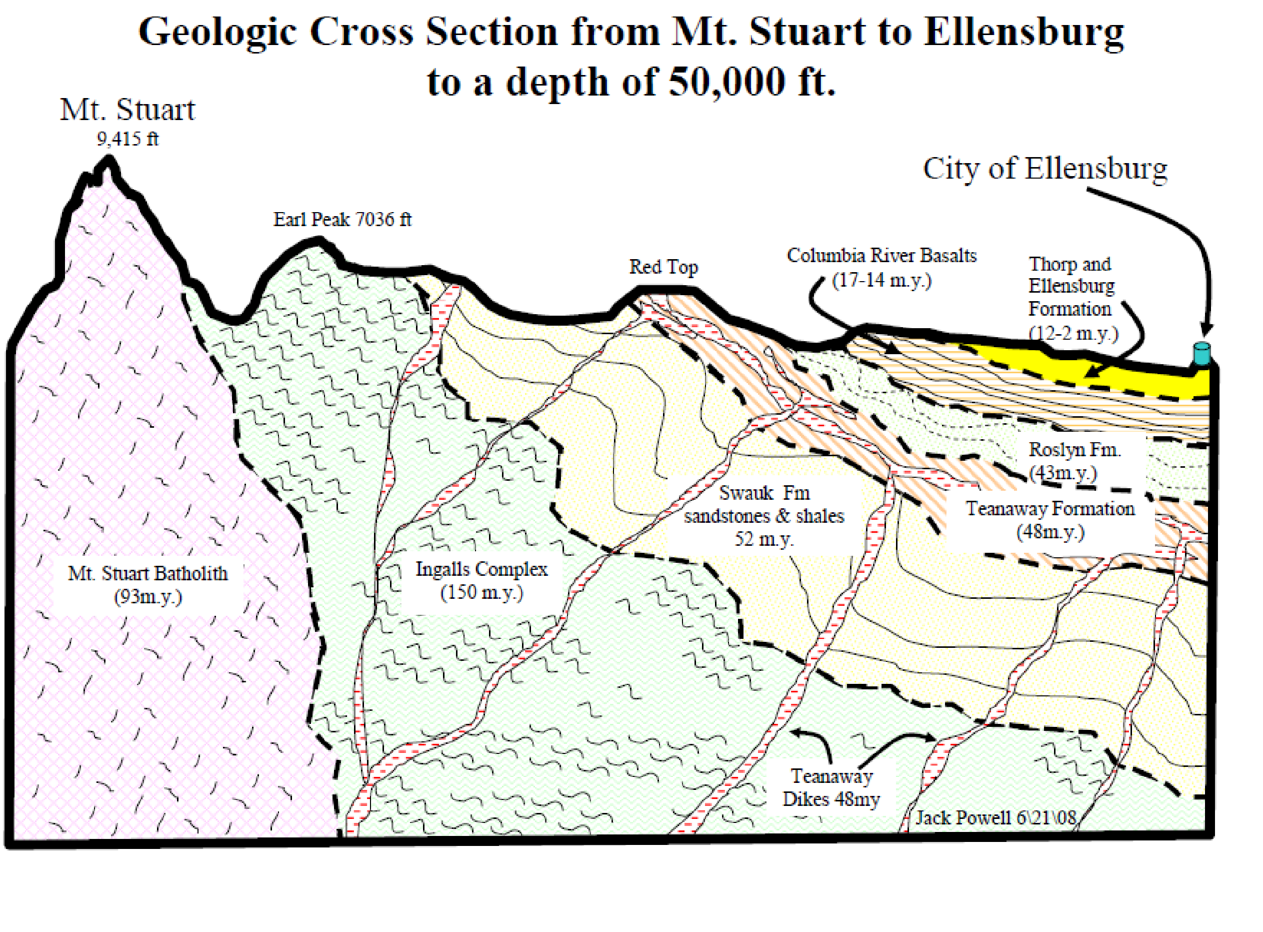


Figure 4. General geologic cross-section from Ellensburg to Mt. Stuart. Source: Jack Powell.

Stop 1—Swauk Prairie

- **Location**: We are standing near the junction of Swauk Prairie Road and Michelleto Road on Swauk Prairie.
- **Geologic Setting**: We are located on the margins of the Columbia River Basalts, Teanaway Basalts, Roslyn Formation, and Swauk Formation (Figures 3 & 4). Miocene Columbia River Basalts are mostly to our east with a finger protruding west as Lookout Mountain (Figure 5). Eocene Teanaway Basalts form Teanaway Ridge to our north. Eocene Roslyn Formation and Swauk Formation sedimentary rocks form Cle Elum Ridge to our west.
- **End Moraines**: Swauk Prairie is composed of end moraines from a long ago, alpine glaciation. End moraines, like their name implies, are ridge-like features that form at the end (i.e., terminus or snout) of a glacier. They typically form from debris falling off the edge of the ice therefore giving end moraine a "hummocky" appearance. End moraines indicate that a glacier occupied an area sufficiently long for such deposits to accumulate.
- **Swauk Prairie End Moraines**: The end moraines here are not classic, textbook features for several reasons. First, Swauk Prairie is not composed of one end moraine; rather, it consists of six end moraines, each of which arcs across the area (Figure 6) (Porter, 1976) and indicates a stillstand during ice retreat. We are standing just west of the outermost moraine shown in Figures 6. Second, the Swauk Prairie moraines are not textbook examples of such features because they are so old. These features are Middle Pleistocene in age, likely forming more than 500,000 years before present (Swanson and Porter ,1997). They are named the Swauk Prairie Subdrift of the Kittitas Glacation (Waitt, 1979). Because of their age, they have had much time to weather, erode, and be blanketed by loess. According to Natural Resource Conservation Service soil series descriptions for the area, loess thicknesses range from 2 to 4 feet atop the glacial till. It was this loess that allowed these lands to be extensively farmed over time. According to local farmer John Hanson, loess is thickest on the eastern (leeward) sides of ridges and in the swales.
- **Glaciers and End Moraines**: The Swauk Prairie end moraines represent the farthest downvalley extent of the Upper Yakima River Watershed glaciersduring the Kittitas-Swauk Prairie glaciation. Swauk Prairie moraines are thought to be the same age as those of Thorp Prairie (Figures 2 & 7). Therefore, the Kittitas-age glacier that deposited these features had split into two lobes near its terminus. The glacier that deposited these moraines formed from coalescence of the Cle Elum, Kachess, and Keechelus valley glaciers (Figure 8). At its maximum extent, >500,000 yr BP, this glacier was >40 miles long. Evidence exists for a pre-Kittitas glaciation –the Lookout Mountain Ranch in Horse Canyon and on the slopes of Lookout Mountain (Waitt, 1979). The Lookout Mountain Ranch and Kittitas glacations are differentiated by their relative positions, moraine topography, soil development, and percentages of surficial boulders (Table 1).
- **Glaciers, Outwash Terraces, and Ice Marginal Lakes**: The Swauk Prairie moraines are associated with outwash terraces remnants along lower Swauk Creek (Porter, 1965). Local resident Tom Lyon, when an employee with Washington Department of Transportation, observed laminated, blue-gray clay in the Swauk Creek valley near Lauderdale.(Figure 5). He interpreted these as glacial lake sediments depositedi n an ice marginal lake formed by glacier or moraine blockage of Swauk Creek and/or meltwater.

Stop 1—Swauk Prairie

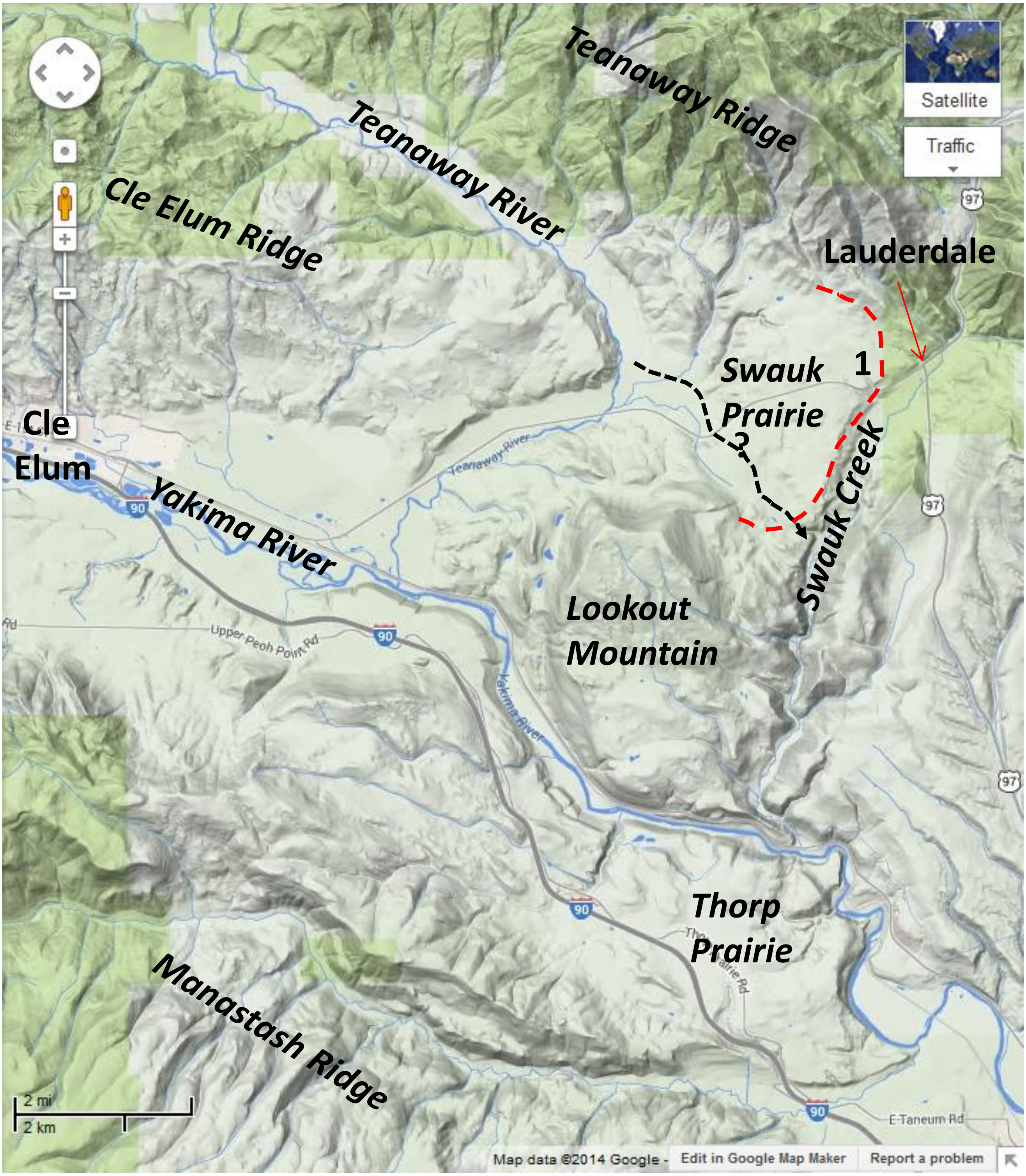


Figure 5. Overview map of Stop 1 and vicinity. Bold number indicates field trip stop. Dotted black line indicates possible pre-Kittitas path of Teanaway River. Dashed red line indicates approximate outermost moraine. Source: Google Maps.

Stop 1—Swauk Prairie

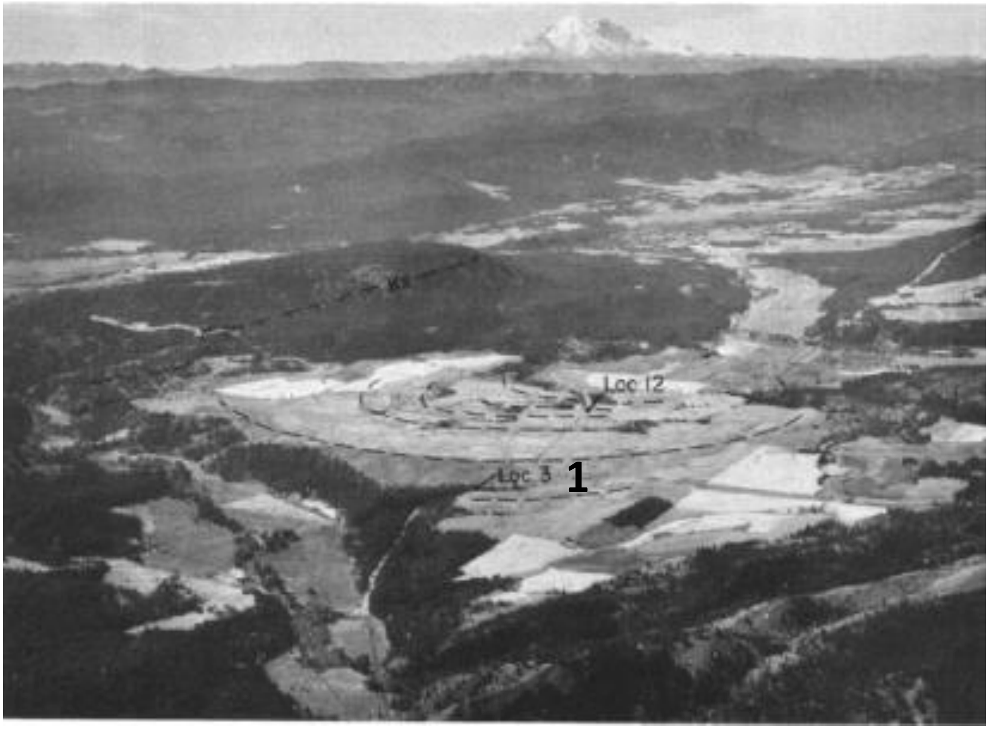


Figure 6. Oblique aerial view of Swauk Prairie and associated moraine crests (shown as dashed lines). View toward southwest. Bold number indicates field trip stop. Source: Porter (1976, p. 67).

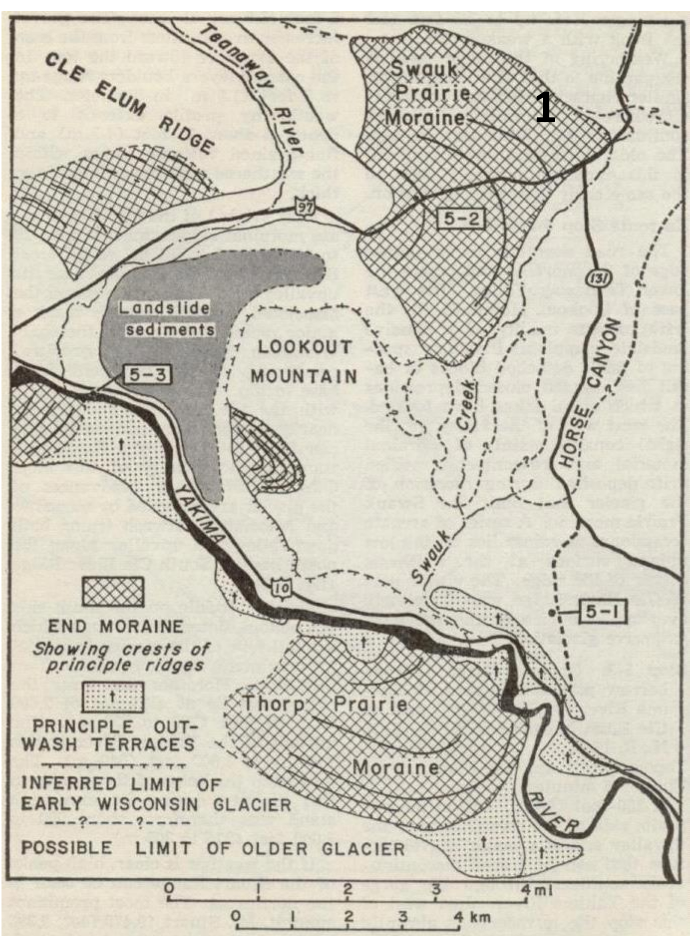


Figure 7. Middle Pleistocene glacial features in the vicinity of Lookout Mountain, Upper Yakima River Watershed. Bold number indicates field trip stop. Source: Porter (1965, p. 37).

Stop 1—Swauk Prairie

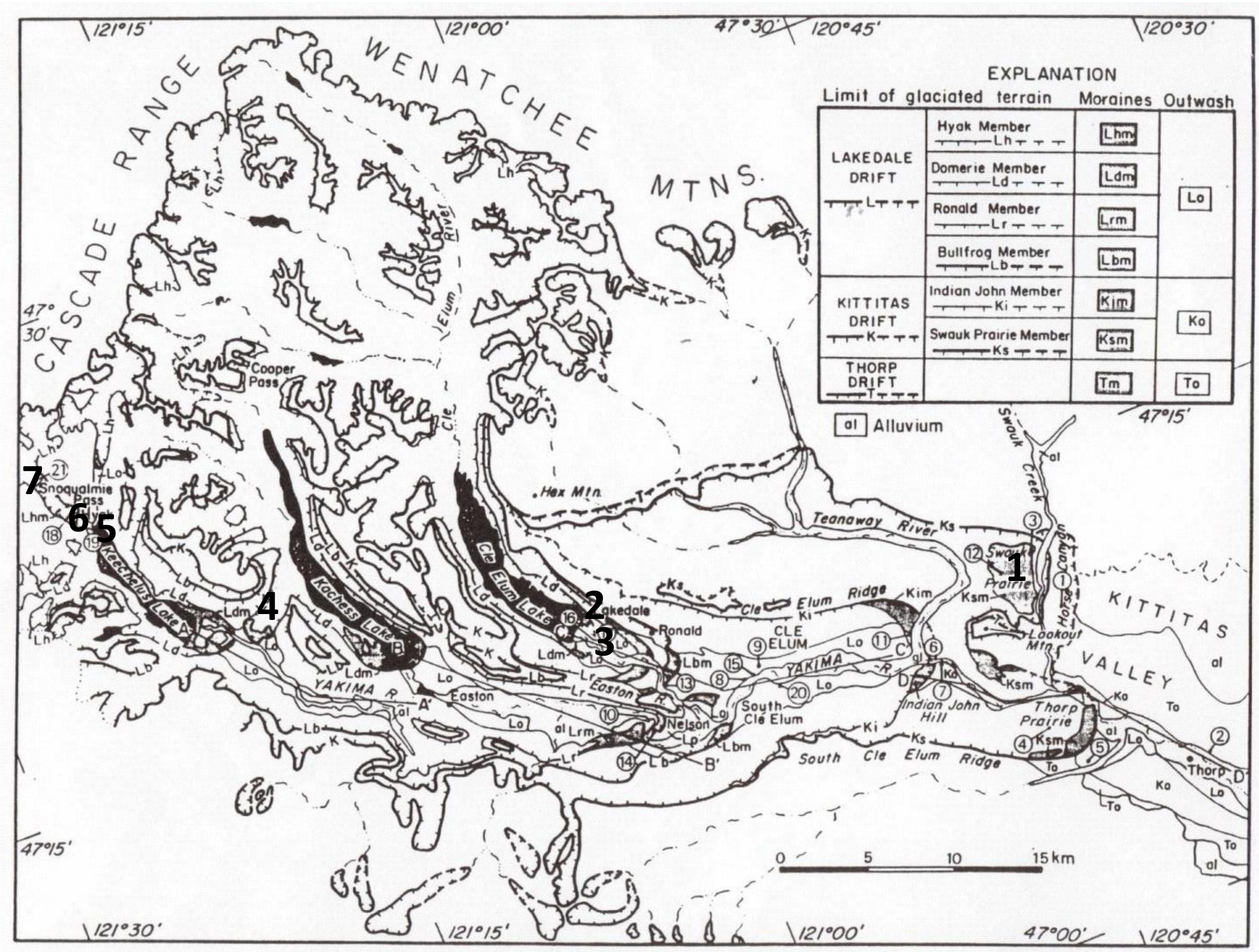


Figure 8. Glacial-geologic map of the Upper Yakima River drainage basin. Bold Numbers indicate field trip stops. Source: Porter (1976, p. 62).

- **Glaciers in the Teanaway and Swauk Valleys**: The Kittitas-age glacier in the Cle Elum drainage overtopped Sasse Ridge near Hex Mountain and flowed down the middle portion of the Teanaway River Valley to join the main glacier near Swauk Prairie (Figure 8). However, glaciers that originated high in the Teanaway River Watershed did not reach Swauk Prairie because drier conditions this far east of the Cascade Crest precluded the development of large valley glaciers. Further east, there is no conclusive evidence that glaciers formed in the Swauk Creek Watershed including western Table Mountain (Tabor and others, 1982).
- **Swauk Creek-Teanaway River Interactions:** The underfit nature of Swauk Creek in its lower valley suggests that it was much larger in previous times. The Teanaway River bends sharply from its NW to SE path to a more NE to SW path near its mouth. These two pieces of evidence suggest that, prior to the Kittitas glaciation, the Teanaway River flowed into Swauk Creek, and that the subsequent deposition of the Swauk Prairie end moraine diverted the Teanaway to its present course.

Stop 1—Swauk Prairie

Episode	Mean Length (mi)	Area (mi2)	Maximum Thickness (ft)	Age
Present*	0.5	0.9	197	~1976 A.D.
Neoglacial	0.6	3.4	492	<11,000
Hyak	3.1	54	919	~11,050 ^{14}C; ~12,200-13,400 ^{36}Cl
Domerie	21	209	1181	~16,000-18,000 ^{36}Cl
Ronald	29	255	1345	~70,000
Bullfrog	31	278	1395	~190,000
Indian John	40	338	1640	???
Swauk Prairie	44	419	2083	~500,000
Lookout Mtn	?	?	?	?

Table 1. Length, area, and maximum thickness of glaciers over time in the Upper Yakima River Watershed. "Present" is as of ~1976. Source: Adapted from Porter (1976) and Swanson and Porter (1997). Tentative oxygen isotope stage (OIS) 4 (Ronald) and 6 (Bullfrog) of Swanson and Porter (1997) converted to OIS start dates of Lisiecki and Raymo (2005).

Swauk Prairie to Lake Cle Elum

- **Route:** From the stop on Swauk Prairie, continue west, then south back to WA 970. At this junction, turn west (right) onto WA 970. At Cle Elum's easternmost interchange, WA 970 becomes WA 903. Follow WA 903 through Cle Elum, Roslyn, and Ronald to the south end of Lake Cle Elum. Here, take Lake Cabins Road to Speelyi Beach on the shores of Lake Cle Elum. Park in the gravel along the road or pull into the parking area just east of the beach entrance. This is Stop 2 (Figure 9).
- **Swauk Prairie Moraine**: As we reach the junction of Swauk Prairie Road and WA 970, notice the large erratic on the south side of the highway. This is a reminder of the size of boulders transported by the glacier, many of which are buried by loess. West on WA 970 but before Teanaway Road, the arcuate nature of the innermost moraine is very evident. By this point, you will have travelled through all six of the subtle moraine crests identified by Porter (1976) (Figure 6).
- **Lookout Mountain**: Large rotational landslides fringe the upper slopes of Lookout Mountain and likely pushed the Teanaway River to the west and north (Figure 9). Most are likely late Pleistocene (i.e., >11,000 years old) features. Weak interbeds between the basalts probably played a role in the landsliding as did a wetter climate, and perhaps undercutting by the Teanaway River and shaking associated with a large earthquake.
- **Teanaway and Yakima River floodplains**: Notice how the Teanaway River follows the toes of the large landslides (Figure 9). These landslides likely extended further into the Teanaway River Valley but have been truncated by the Teanaway River. Once around the west end of Lookout Mountain, the Teanaway River is free to flow south to join the Yakima River. WA 970 crosses a remnant of the Indian John subdrift of the Kittitas glacation just east of Lambert Road. This subdrift is similar in age but younger than that of Swauk Prairie. It is named after the prominent moraine exposed near the Indian John Rest Area on I-90. Lake sediments found in boreholes near Cle Elum suggest that a proglacial lake filled the valley sometime after depositon of the Swauk Prairie moraines and before the Lakedale moraines. Moraines or landslides may have impounded the lake (Porter, 1965).
- **Outwash Terraces**: In Cle Elum, we ascend from the Yakima River floodplain onto late Pleistocene glacial outwash terraces. These are from the Lakedale Glacation which was significantly younger—late Pleistocene—than those deposits seen downvalley. We will intermittently follow outwash terraces to Lake Cle Elum.
- **Roslyn Formation & Coal Mining**: The Oligocene Roslyn Formation is a non-marine, sandstone with coal interbeds in its upper portion. This is the coal that led to the development of the Upper Kittitas County coalfields centered on Roslyn and Ronald. Coal development began here in the late 1800's. By late 1886, the Northern Pacific Railroad had shipped its first load of coal out of the area. (Saunders, 1914; Tabor et al, 1982). Roslyn coal was renowned for its high quality and was used to power the railroads as well as heat cities throughout the Pacific Northwest. Northern Pacific locomotives and stationary engines from Butte and Helena, Montana to the Stampede Tunnel used Roslyn coal (Campbell and others, 1915). Central Washington University once heated campus buildings with Upper County coal and many older homes in Ellensburg (including ours) were first heated with Upper County coal.

Swauk Prairie to Lake Cle Elum

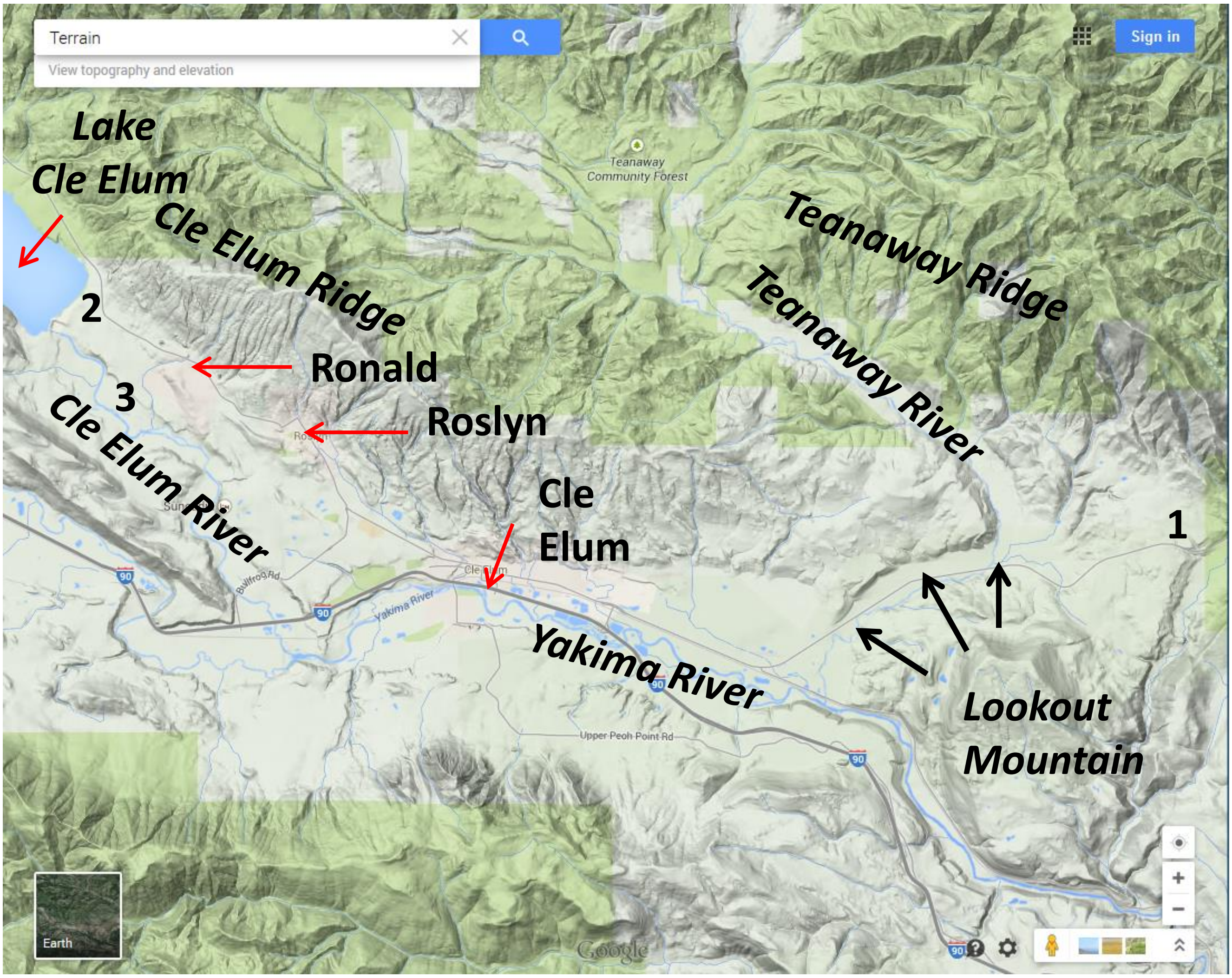


Figure 9. Area between Swauk Prairie and Lake Cle Elum. Field stops shown with bold numbers. Bold arrows indicate landslides. Source: Google Maps.

- **Lakedale Moraines**: The Late Pleistocene glacier (Lakedale) proceeded as far downvalley as Roslyn (Figure 12) (Porter, 1976). These were the Lakedale—Bullfrog moraines. The more recent Lakedale—Ronald moraines terminated near Ronald. The "corrugated" feel of the road as we turn off WA 903 and follow Lake Cabins Road to Speelyi Beach reflects the outermost Lakedale--Domerie moraines.

Swauk Prairie to Lake Cle Elum

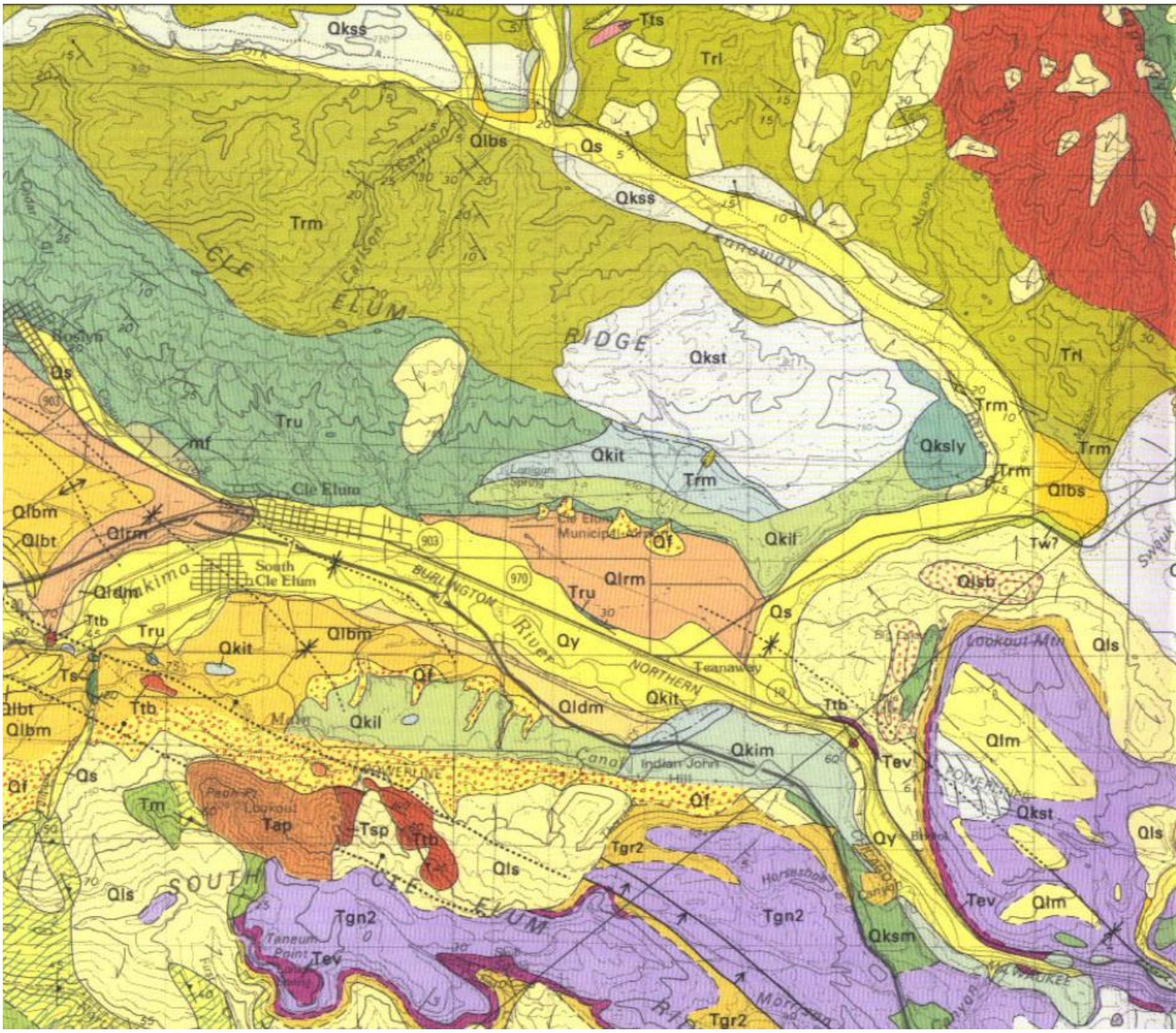


Figure 10. Geologic map from Swauk Prairie to Cle Elum. Source: Tabor and others (1982).

LEGEND
Qy & Qs = Quaternary Alluvium
Qls & Qlsb = Quaternary Landslide
Qldm = Quaternary Lakedale-Domerie Qutwash
Qlrm = Quaternary Lakedale-Ronald Outwash
Qlbm = Quaternary Lakedale-Bullfrog Outwash
Qkil = Quaternary Kittitas-Indian John Till
Qkil = Quaternary Kittitas-Indian John Outwash
Qkil = Quaternary Kittitas-Indian John Lake Sediments
Tev = Tertiary Ellensburg Formation
Tgn2 = Columbia River Basalt—Grande Ronde
Ttb = Tertiary Teanaway Basalts
Tru & Trm = Tertiary Roslyn Formation

Swauk Prairie to Lake Cle Elum

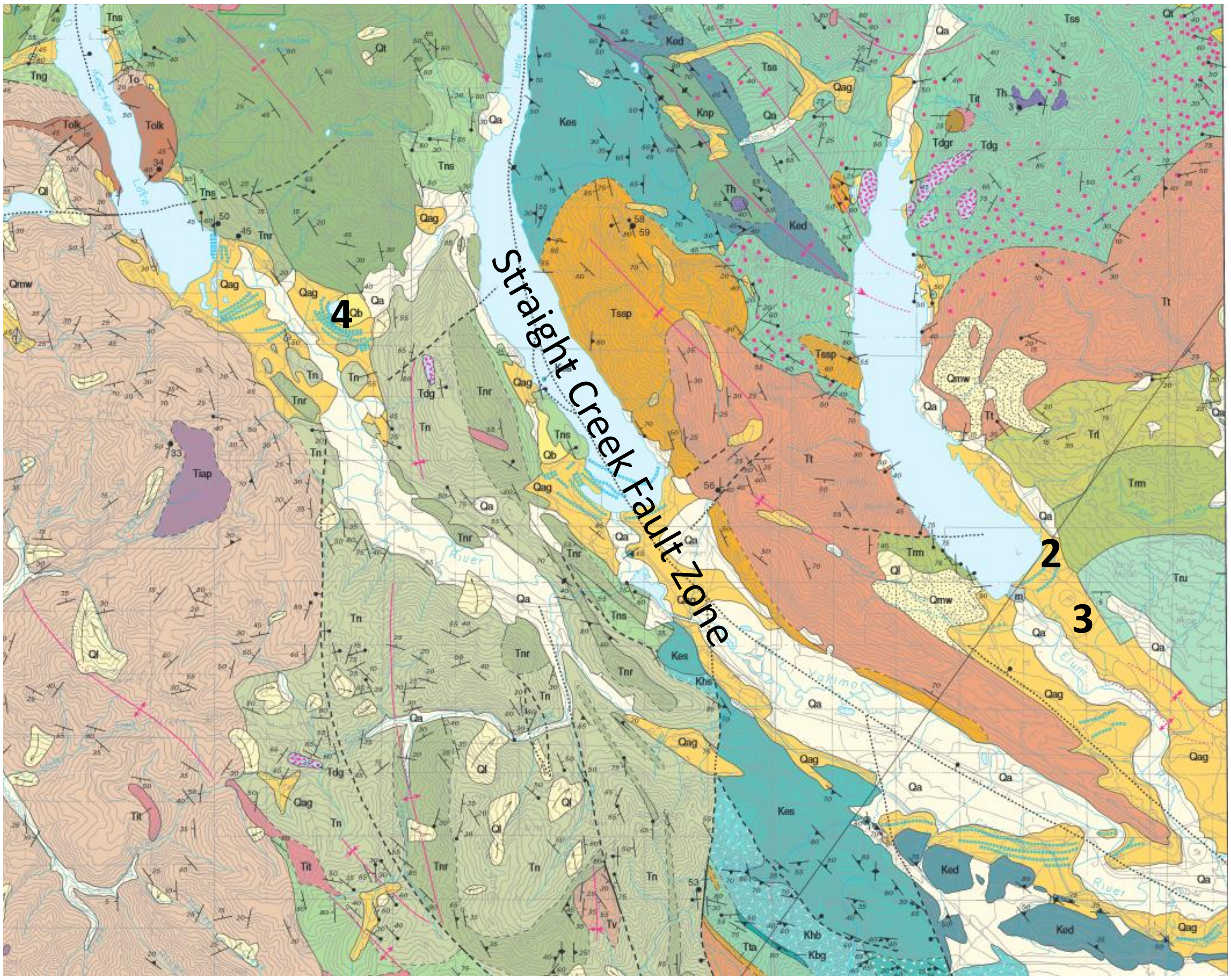


Figure 11. Geologic map covering area from Cle Elum to Swamp Lake. Field trip stops indicated with bold numbers. Source: Tabor and others (2000).

LEGEND
Qa = Quaternary Alluvium
Qag = Quaternary Alpine Glacial Deposits
Qb = Quaternary Bog
Ttb = Tertiary Teanaway Basalts
Tn, Tnr, Tns, Tnbg = Tertiary Naches Formation
Tru, Trm & Trl = Tertiary Roslyn Formation
Kes & Ked = Cretaceous Easton Metamorphic Suite

Stop 2—Lake Cle Elum

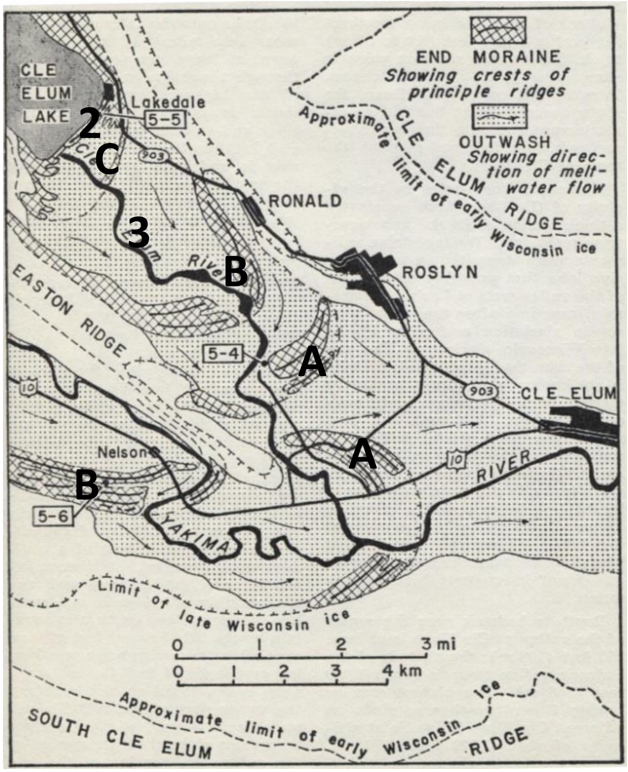
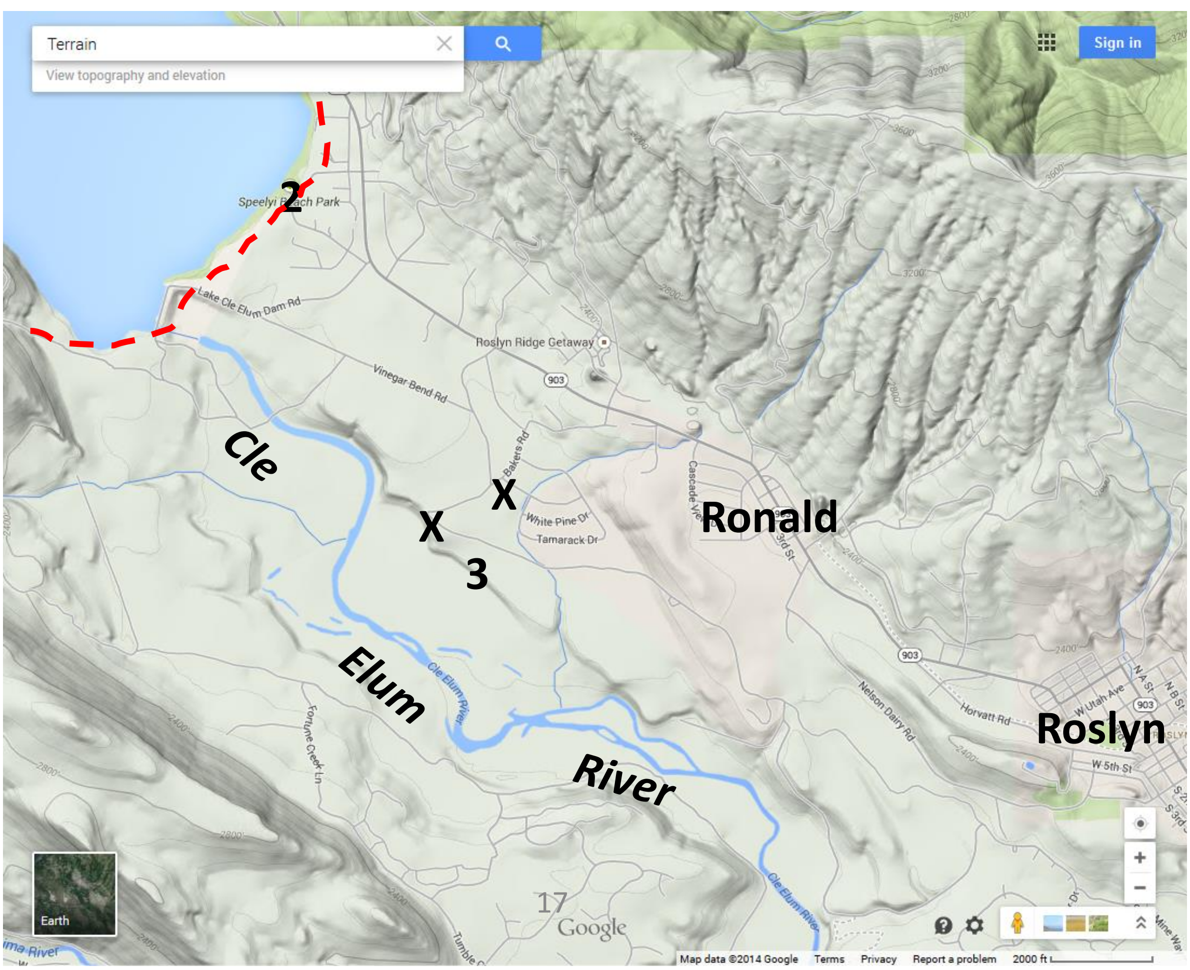


Figure 12. Moraines and outwash between Cle Elum and Lake Cle Elum. A = Bullfrog moraines, B = Ronald moraines, and C = Domerie moraines. Field stops indicated with bold numbers Source: Porter (1965).

Figure 13. Topographic setting of field stops 2 and 3, lower Cle Elum River Valley. Bold numbers indicate field trip stops. Bold X indicated large gravel pits. Source: Google Maps.



Stop 2—Lake Cle Elum

- **Location**: Speelyi Beach is located on the south end of Lake Cle Elum.
- **Who was Speel-yi?:** Speel-yi was the coyote of Native American folklore who saved the people of the Cle Elum River Valley from starvation by killing Wish-Poosh, the terrible beaver. The epic battle between the two resulted in the gaps in the ridges south of Ellensburg and the formation of the Yakima River channel. The killing of Wish-Poosh made Speel-yi a most reverred god of the Native Americans of the area.
- **Geology**: Roslyn Formation sedimentary rocks comprise Cle Elum Ridge. Basalts of the Teanaway Formation make up Easton Ridge to the west.
- **Moraine Topography**: A topographic cross-section of innermost Lakedale--Domerie end moraine is very evident at the Speelyi Beach boat launch, and is especially well-developed west of the boat launch paralleling the shoreline (Figure 13). Note the relatively sharp crest of this moraine relative to the Kittitas-Swauk Prairie moraine. The difference is primarily the result of age. Boulders from this innermost moraine date to approximately 16,000 yr BP (Swanson and Porter, 1997).
- **Moraine Stratigraphy**: Stratigraphy exposed in the wave-eroded moraines that impound the lake reveal stony glacial till as well as deformed, fine-textured, laminated sediments. Porter (1965, 1969) interprets the latter as representing an ice marginal lake whose sediments were deformed by fluctuations of the Cle Elum Valley glacier. Perhaps this ice marginal lake was impounded on its downvalley end by moraines that we passed through on Lake Cabins Road.
- **Lake Cle Elum Origins**: Lake Cle Elum is a moraine-dammed lake in a U-shaped *glacial trough* (Figure 14). The moraine that dammed this valley is part of a series of moraines that we passed through on Lake Cabins Road. Russell (1900) was the first to associate Lake Cle Elum with a glacier origin attributing the dam to moraine or outwash. However, Russell, in his brief exploration of the Upper Yakima , did not recognize that earlier Cle Elum drainage glaciers had extended further downvalley. Waves at high levels of Lake Cle Elum have eroded the moraine to form a gravel beach. The fine sediments of the moraine form the finer beach sediments, were pulled offshore into the deeper lake, or have accumulated downwind of the lake as loess.
- **Cle Elum Valley Glacier**: The valley glacier that shaped the Cle Elum River Valley was likely the largest of the three main glaciers in the Upper Yakima River Watershed. From the innermost Domerie moraine, this glacier extended approximately 25 miles up the Cle Elum River Valley to Deception Pass (Figure 14). It received glacial ice from literally hundreds of cirques that coalesced into three main ice lobes—mainstem Cle Elum, Waptus, and Cooper. Thorp and French Cabin Creek basins also provided significant ice input into the Cle Elum trough (Figure 14). The large size of the Cle Elum Glacier was the result of the overall size and relatively high elevations of the watershed, and the fact that its head lay at the Cascade Crest, ensuring that plenty of snowfall was present to feed the glacier.
- **Glaciation in the Eastern Cascades**: While significant in size, the Cle Elum Glacier was small compared to those that occupied the Wenache (i.e., Wenatchee), Chiwahwah (i.e., Chiwawa), Chelan, and Methow drainages to the north (Figure 15).

Stop 2—Lake Cle Elum

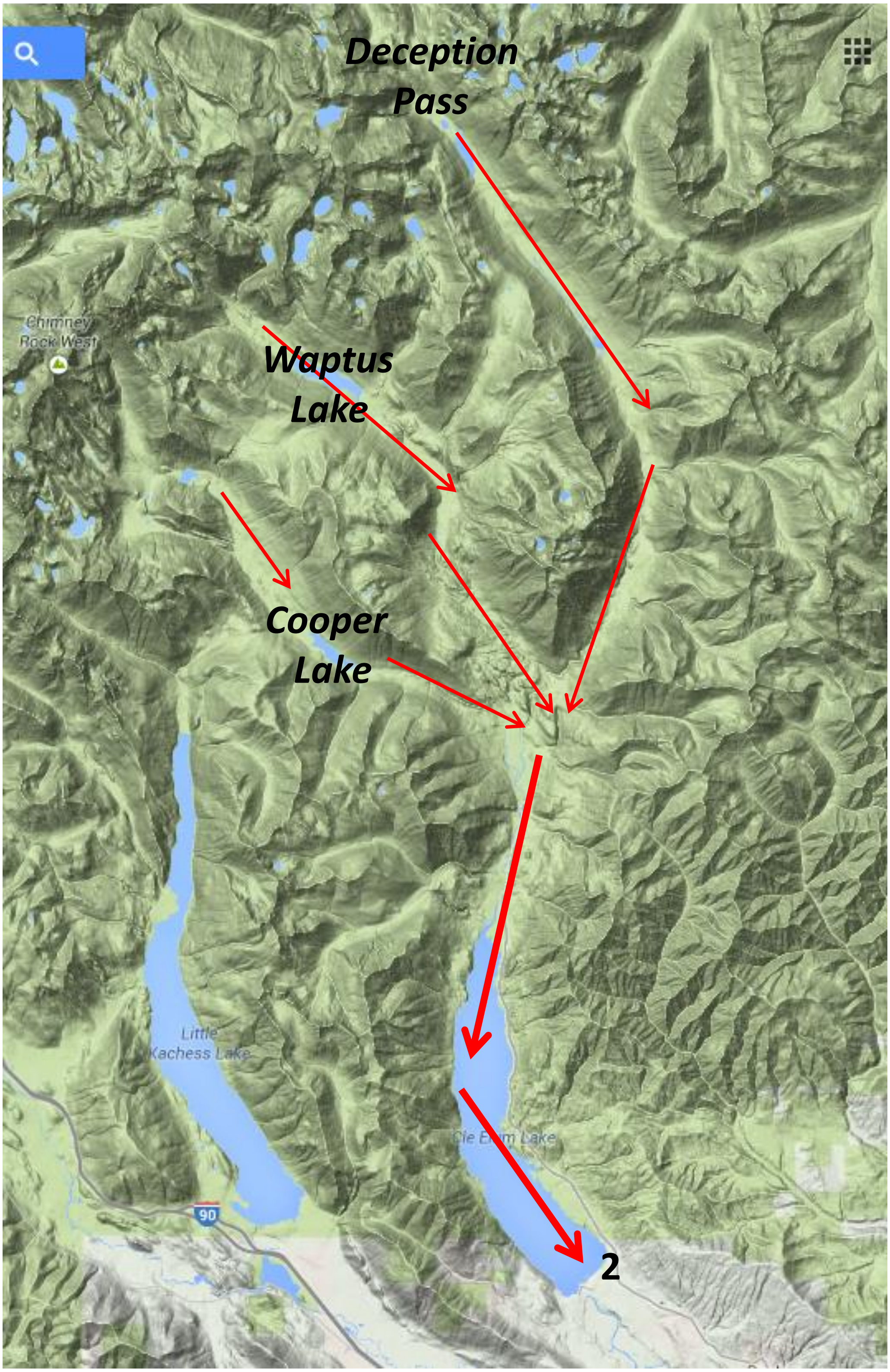


Figure 14. Primary sources of glacial ice in the Cle Elum River Watershed. Arrows indicate ice movement direction. Source: Google Maps.

Stop 2—Lake Cle Elum

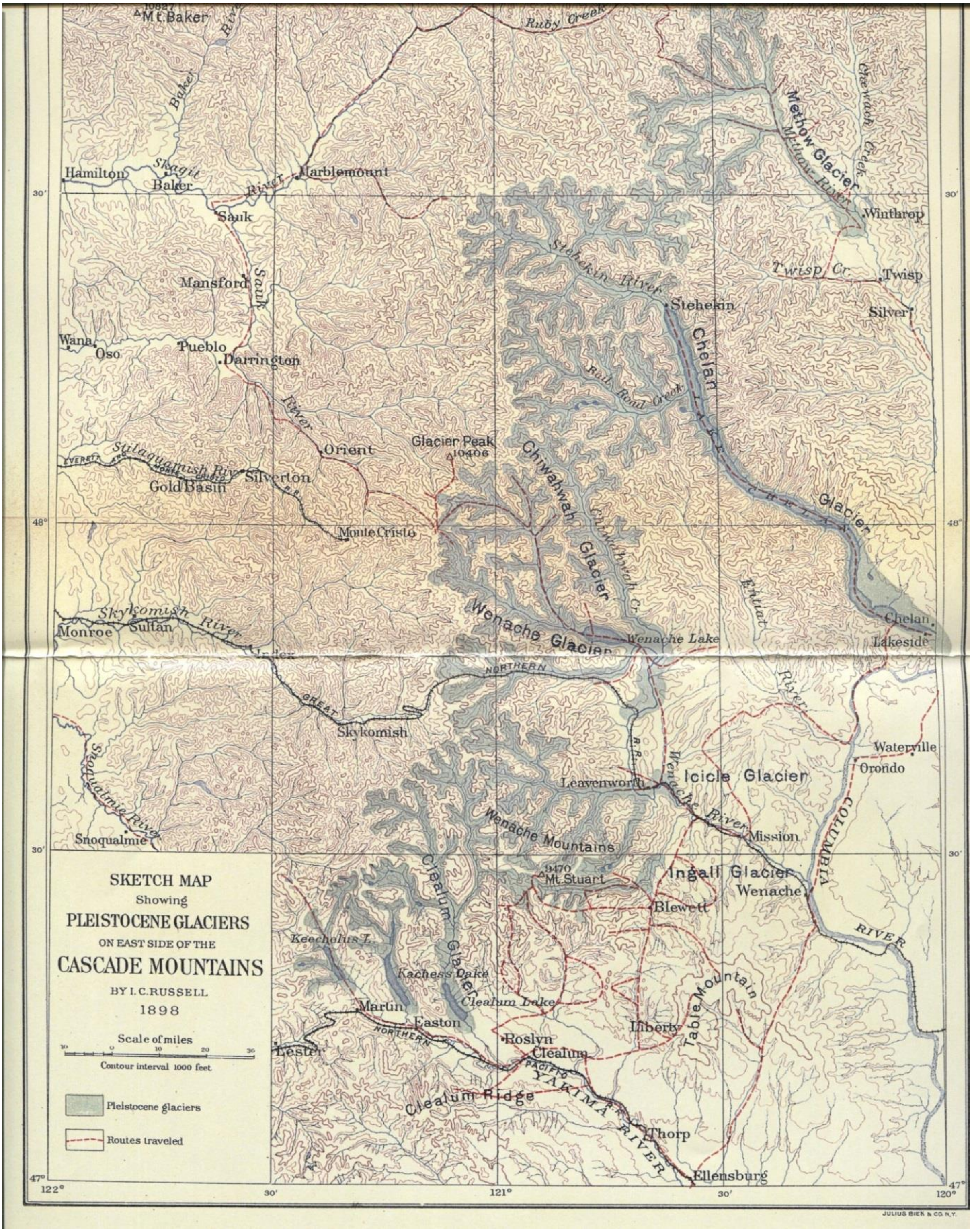


Figure 15. Sketch map showing the extent of Pleistocene glaciers in the Eastern Cascades. Source: Russell (1900, XVIII).

Stop 2—Lake Cle Elum

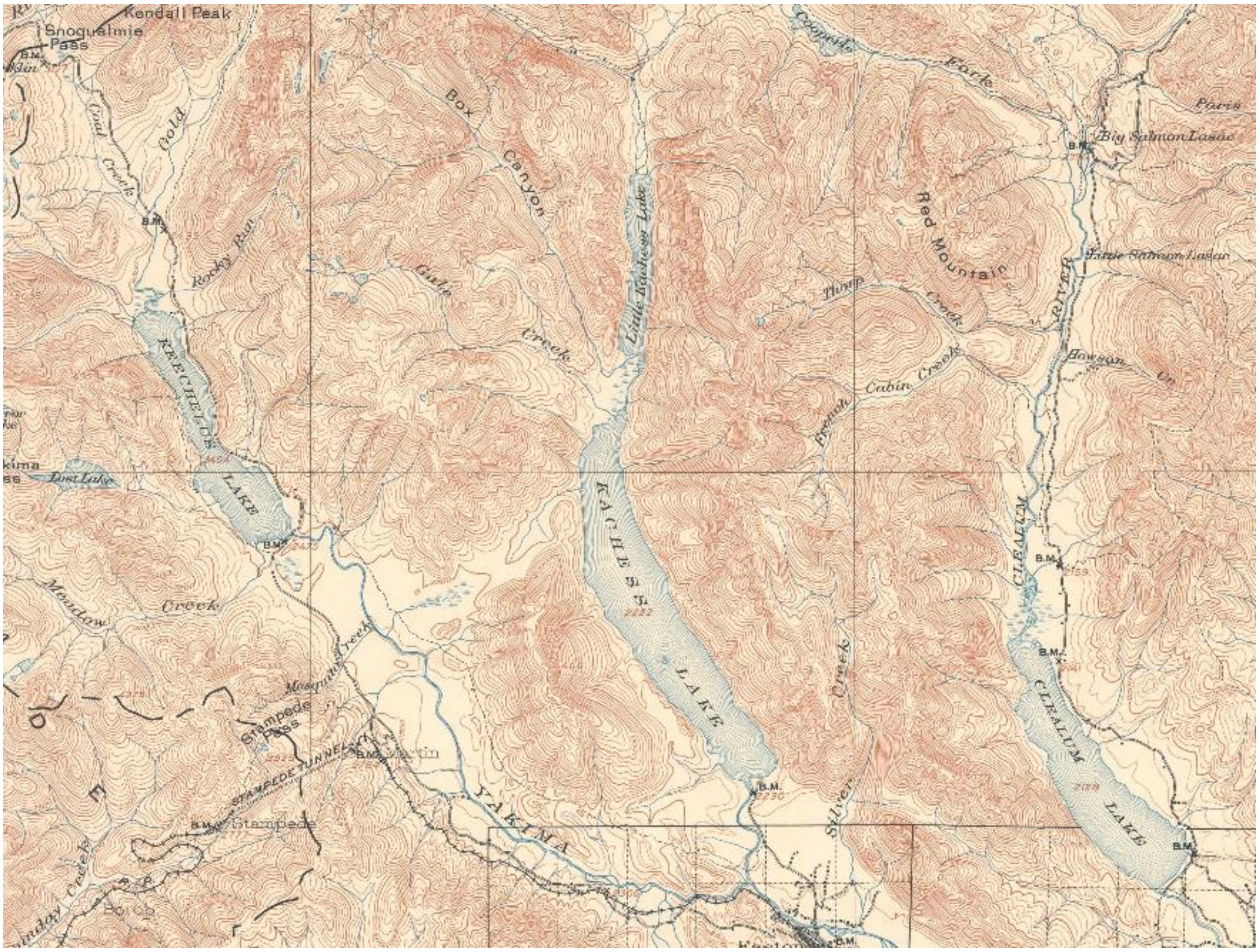


Figure 16. Glacial lakes Keechelus, Kachess, and Cle Elum as of 1900-1901. Source: Smith and Calkins (1906).

- **Lake Cle Elum & Structure**: Lake Cle Elum is one of three large glacial lakes in the Upper Yakima River Watershed located in NW-SE trending valleys (Figure 16). When combined with Lake Wenatchee and Lake Chelan to the north, the NW-SE orientations suggests a structural impact on the valleys.
- **Lake Cle Elum as an Irrigation Reservoir**: In 1931, the U.S. Bureau of Reclamation built a permanent, earthen dam at the Cle Elum River outlet (Dick, 1993). Water from this lake plays an integral role in irrigating upper and lower Yakima River Valley farms.

Lake Cle Elum to Cle Elum River Overlook

- **Route**: Return to WA 903 via the loop of Lake Cabins Road. Turn south (right) and proceed for about 1 mile to Morel Road. Turn west (right) onto Morel and almost immediately turn right ton Baker Road. Follow this road to where it becomes gravel. We will park here and walk to the escarpment overlooking the Cle Elum River. .

Stop 3—Cle Elum River Overlook

- **Location**: We are located atop an escarpment overlooking the Cle Elum River.
- **Glacial Outwash**: The presence of ample rounded gravel and two large, deep gravel pits combined with our location downvalley of glacial moraines indicates that we are on glacial outwash. Glacial streams are notoriously sediment loaded with every size from clay to boulders. Glacial outwash, especially close to the source, is typically coarse (i.e., sands to boulders) while the clays and silts end up downvalley to subsequently settle out in ice marginal lakes or are literally flushed out of the watershed.
- **Glacial Outwash & Aggradation**: Aggradation in alpine glacial settings results in outwash plains. Outwash fills valley floors, often leaving them quite planar in a cross sectional sense and with a gentle slope downstream . Aggradation here led to several hundred feet of sorted sands and gravels in places. Saunders (1916) first recognized the effects of sediment charged glacial meltwater in aggrading Upper Yakima River valley floors.
- **Post-glacial Incision & Terrace Formation**: Post-glacial streams typically carry far less sediment than their glacial counterparts. As a result, they tend to erode rather than deposit sediments. The post-glacial Cle Elum River eroded this outwash plain leaving the escarpment ("riser") and the terrace ("tread") (Saunders, 1916). While it may be difficult to envision the relatively small Cle Elum River eroding this impressive escarpment, remember that it had ~15,000 years to do so, and that the outwash, while large in caliber, is not cohesive. The Cle Elum River accomplished this by eroding vertically as well as laterally.
- **Outwash Terrace-Moraine relationships:** Outwash terraces grade to moraines (Figure x). Can distinguish particular glacial episodes by tracing the outwash back to a particular moraine. …
- **Sand & Gravel Mining:** Sand and gravel operations thrive in areas of glacial outwash. Four, large sand and gravel operations are or were in recent operation on the lower Cle Elum River and just downstream of the mouth of the Cle Elum River. All are in glacial outwash.

Stop 3—Cle Elum River Overlook

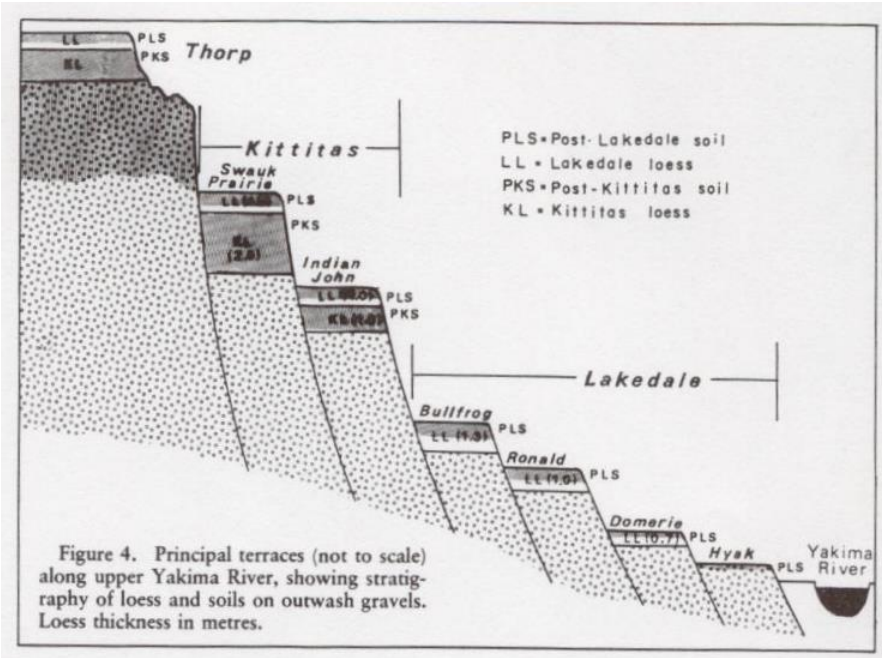


Figure 4. Principal terraces (not to scale) along upper Yakima River, showing stratigraphy of loess and soils on outwash gravels. Loess thickness in metres.

Figure 17. Principal terraces along upper Yakima River, showing stratigraphy of loess and soils on outwash gravels. Figure not to scale. Loess thickness in meters. From Porter (1976, p. 64).

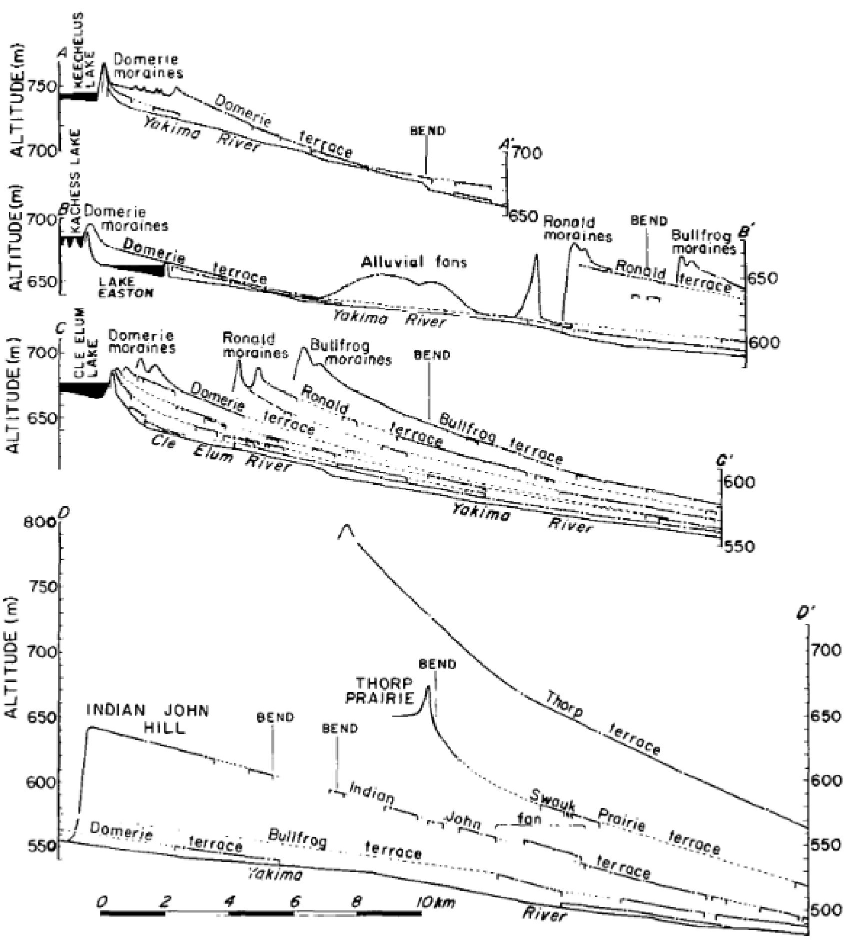


Figure 18. Long profiles of terraces along the upper Yakima River Valley between Keechelus Lake and Ellensburg. Source: Porter (1975, p. 64).

Cle Elum River Overlook to Swamp Lake

- **Route**: Return on WA 903 through Ronald and Roslyn to the round-about south of Roslyn. Here, take Bullfrog Road to I-90. Drive I-90 westbound to Exit 62—Stampede Pass/Lake Kachess. Take this exit . At the stop sign, turn north (right) and follow the road toward Lake Kachess. Within approximately one mile, we will park alongside the road off the pavement and on the gravel shoulder.
- **Outwash terraces**: From our stop on Lakedale—Domerie terraces, we cross Lakedale—Ronald and Lakedale—Bullfrog outwash terraces as we descend I-90.
- **Moraines**: Just each of the mouth of the Cle Elum River, I-90 climbs from the Cle Elum River floodplain to pass through Lakedale-Bullfrog moraine. This is the farthest downvalley extent of the late Pleistocene Lakedale glacier from the Keechelus and Kachess drainages. The combined glacier ice from these two drainages apparently resulted in this glacier extending further downvalley than the Cle Elum River glacier.
- **Outwash Terraces, Moraines, Alluvial Fans & the Yakima River**: The planimetric (i.e., view from above) form of the Yakima River has been shaped by post-glacial outwash terraces , moraines, and alluvial fans . A remnant of Lakedale-Ronald terrace pushes the Yakima River south just west of the Bullfrog Weigh Station on I-90.   Terrace remnants and Lakedale --Ronald moraines push the river north where it sits snug against Easton Ridge above this point.   These terraces and moraines are from the combined Lake Keechelus and Kachess glaciers. Also, west of Nelson, alluvial fans from Big Creek and Little Creek push the Yakima River north against Easton Ridge (Porter, 1969).
- **Kachess Lake Moraines**: At Easton, we pass very near the Lakedale--Domerie moraines that impound Lake Kachess. Russell (1900) was the first to recognize that a glacier had once occupied what is now the Kachess Lake basin. Unlike Lake Cle Elum, it is not the innermost Lakedale—Domerie moraines that impound Lake Kachess; rather, it is one of the outermost Domerie moraines (Figure 13).   Lake Kachess was the first of the lakes to be developed for irrigation with a temporary dam in 1904 followed by a more permanent earthen dam in 1912 (Parker and Storey, 1916).
- **Ice Sculpted Hills**: Wet of Lake Easton, the Yakima River parallels, then cuts through a series of parallel, streamlined hills. I-90 mostly skirts the northern end of these hills as it ascends the flanks of Amabilis Mountain. Porter (1969) interprets these as glacial ice sculpted hills. These hills are composed of volcanic and sedimentary rocks of the Naches Formation, and are oriented with the long axis of the Kachess Valley and the Keechelus Valley (Figure 19).
- **Valley Gradients**: Campbell and others (1916) noted the elevation difference between the floor of the Kachess Valley and that of the mainstem Yakima River just upstream of Easton. Why is Lake Kachess approximately 350 feet lower than Lake Keechelus? This elevation difference occurs very near the Straight Creek Fault which exposes rocks of different types on either side of this transcurrent structure (Figure 11). Perhaps those different types of rocks have different erodibilities.

Cle Elum River Overlook to Swamp Lake

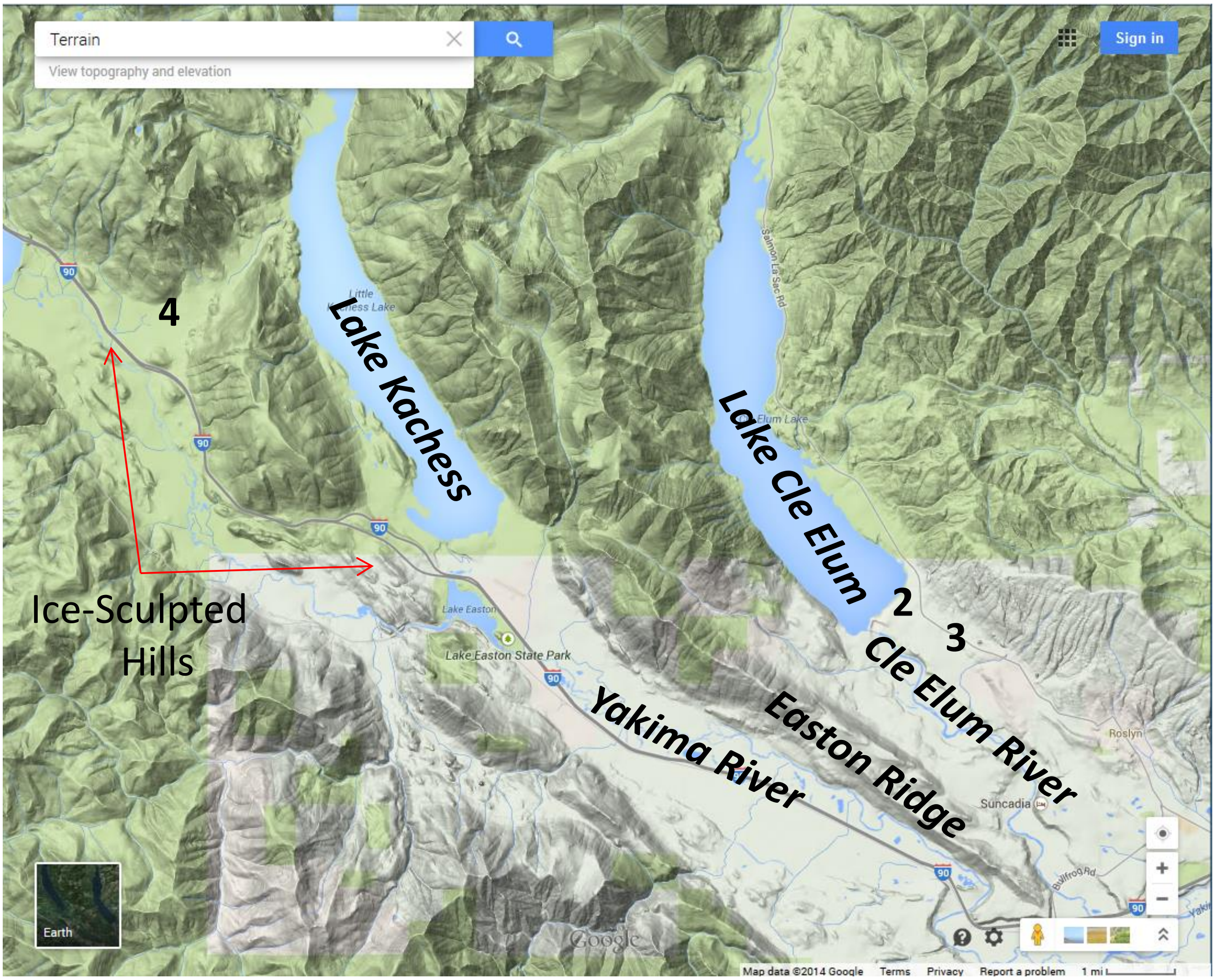


Figure 19. Topography from Cle Elum River Overlook to Swamp Lake. Bold numbers indicate field stops. Source: Google Maps.

Stop 4—Swamp Lake

- **Location**: We are located at a pullout on the south end of Swamp Lake. A faint trail leads to the edge of Swamp Lake.
- **Geologic Setting**: We are located west of the Straight Creek Fault. Therefore, the Swauk, Roslyn, and Teanaway formations are to the east, and we are within the volcanic and sedimentary rocks of the Naches Formation.
- **Glacier Origins**: The glaciers that shaped this area formed in cirques on Rampart Ridge at the heads of Box Canyon and Mineral creeks, at the head of the Kachess River on Chickamin Ridge, and in No Name and Silver creeks on Kachess Ridge (Figure 20). This area was glaciated by at least three major glacial episodes, two in the early? to mid Pleistocene (Lookout Mountain Ranch and Kittitas), and one late Pleistocene (Lakedale.). This is the smallest of the three primary watersheds of the Upper Yakima River Watershed but yielded the longest of the natural lakes in the watershed (i.e., 6 miles long vs. ~ 4 miles for Lakes Cle Elum and Keecheulus) (Smith and Calkins, 1906).
- **The Main Kachess Lake Trough**: In Lakedale time, much of the glacier moved south, then southeast down the existing trough to terminate at the end of what is now Lake Kachess (Porter, 1976) Like at Lake Cle Elum, Lake Kachess is of a glacial origin impounded by Lakedale--Domerie moraines (Figure 21).
- **Swamp Lake Valley**: The valley occupied by Swamp Lake, here informally called "Swamp Lake Valley", currently has creeks running out of opposite ends. One creek (Swamp Creek) flows into the Yakima River below Lake Keechelus. The other (Lodge Creek) drains into Lake Kachess. This anomalous valley was first recognized by Campbell and others (1915). It appears to be the result of the Kachess Glacier overtopping a pass separating Keechelus Ridge and Amabilis Mountain, and moving southwest toward the downstream end of Lake Keechelus (Porter, 1965). (Figures 20 & 21). We do not know when this first occurred—Lakedale, Kittitas, or Lookout Mountain Ranch times? However, a series of Lakedale--Domerie moraines formed just north of I-90 with the innermost creating the hydrologic closure necessary for the formation of Swamp Lake. We are standing on the flanks of this innermost moraine.
- **Swamp Lake**: Swamp Lake is more swamp than lake. A core taken from the swamp revealed the following layers from top to bottom: living sedge roots (12 inches); brown muck (36 inches); brown fibrous peat (12 inches); pumicite (2.5 inches); and black muck (9.5 inches); bluish-gray clay (Rigg, 1958). The "pumicite" is likely 6850 yr BP Mazama tephra (Porter, 1965)indicating that Swamp Lake was in place prior to the eruption of Mt. Mazama (Figure 22). I interpret the bluish clay as deposits as representing an ice marginal lake that was present in the basin following glaciation. Perhaps this lake was the predecessor to Swamp Lake.
- **Early to Mid-Holocene Climate**: A core from a bog near the downstream end of Lake Kachess reveals volcanic ash at a depth of ~10.5 feet (Hansen, 1947). This is likely the same tephra seen at Swamp Lake (Mazama?) (Porter, 1965). Pollen samples from the core suggest a shift toward cooler, more moist conditions above the tephra (Hansen, 1947).

Stop 4—Swamp Lake

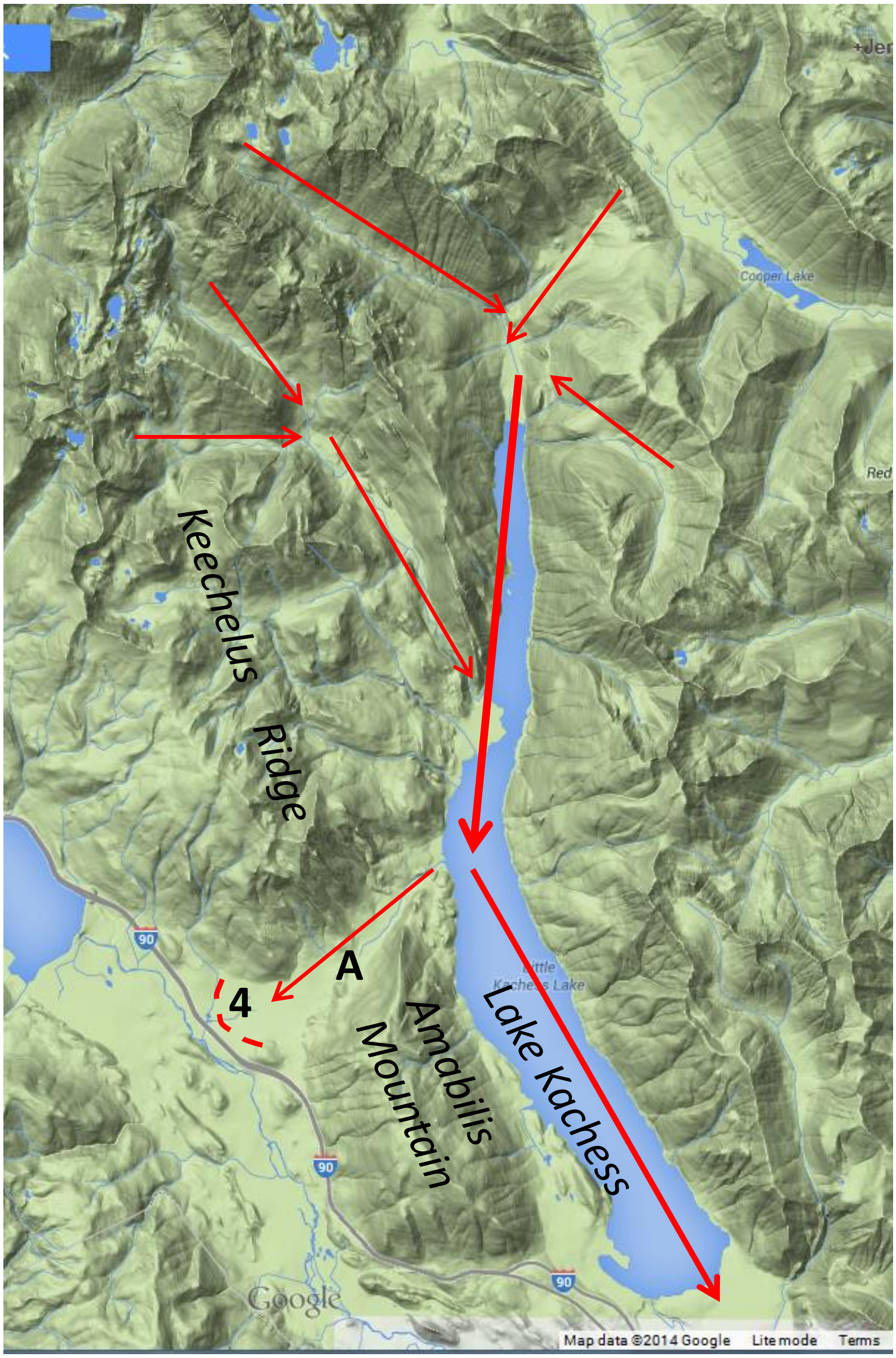


Figure 20. Sources of glacial ice in the Kachess Watershed. Arrows indicate ice movement direction. Bold number indicates field trip stop. Dashed line indicates approximate location of Lakedale moraine impounding Swamp Lake. Letter A indicates location of post-glacial landslide that has modified "Swamp Lake Valley". Source: Google Maps.

Stop 4—Swamp Lake

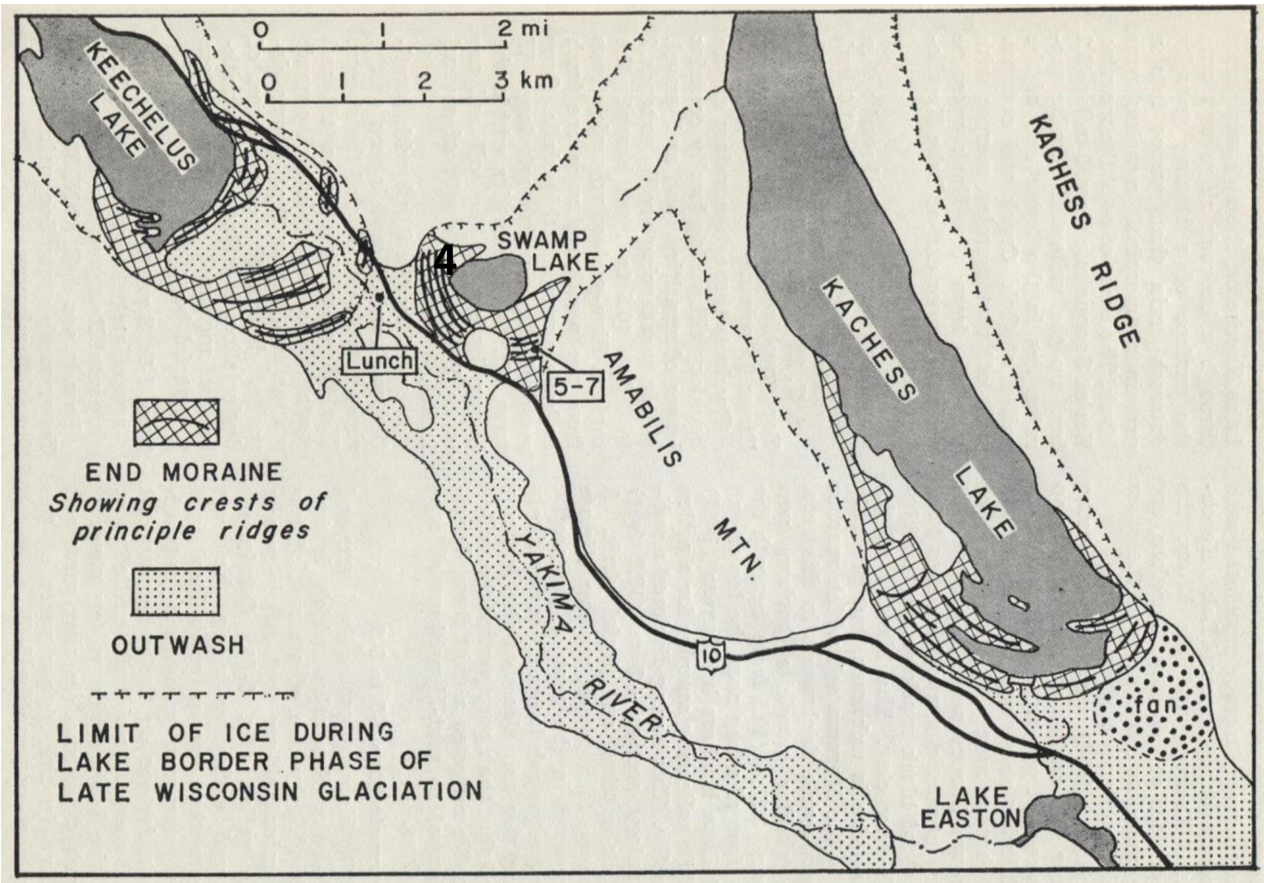


Figure 21. Late Pleistocene ice limit, moraines, and outwash in the vicinity of lakes Kachess and Keechelus. Bold number indicates field trip stop. Source: Porter (1965).

- **Tephra & Moraines**: A shallow pit atop this moraine exposes ~4 inches of forest duff overlying 1 to 2 inches of volcanic ash. The ash lies directly on glacial till. This tephra should represent the Mount St. Helens Yn (~3400 yr BP) and Wn (1480 A.D.) eruptions (Porter, 1981; Swanson and Porter, 1997) (Figure 22). Moraine crests are not great places for tephra preservation; therefore, it is not surprising that the older Mazama tephra is not here. Unfortunately for glacier studies, ~11,200 yr BP Glacier Peak tephra is not found in the vicinity of Snoqualmie Pass. (Figure 22).
- **Post-glacial landslides**: A large, post-glacial landslide from Amabilis Mountain has partially blocked the valley floor (Figures 11 & 20). Landslides are relatively common in deglaciated valleys because of oversteepened slopes and non-cohesive glacial drift.

Stop 4—Swamp Lake

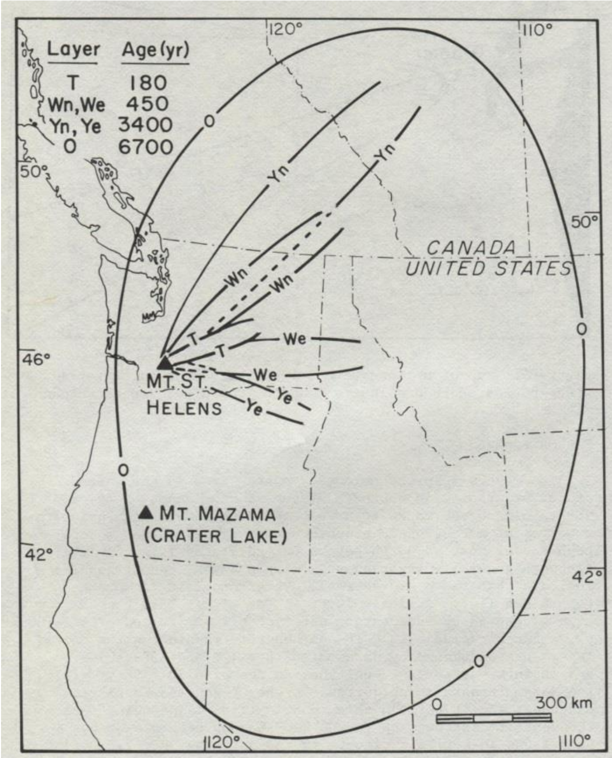


Figure 22. Distribution of widespread Holocene tephras from Mt. Mazama and Mt. St. Helens. Source: Porter (1981).

Swamp Lake to Snoqualmie Pass

- **Route**: From the pullout along the Kachess Lake Road, proceed northeast for another several hundred yards to U.S. Forest Service road 4832. Turn around here and return to I-90. Take I-90 westbound to Exit 53—East Summit. At the stop sign at the base of the exit, turn east (right) onto Yellowstone Trail Road, and park on the pavement (but outside the white lines).
- **Geology**: From the downstream end of Lake Keechelus to Gold Creek, we mainly see bedrock. Much of this is similar to that seen on the previous leg—i.e., sedimentary and volcanic rocks of the Naches Formation. In addition, volcanic rocks (including tuff) of the Ohanepecosh Formation outcrop along the route.
- **Glaciers & Lake Keechelus**: I-90 passes by a series of moraines near the downstream end of Lake Keechelus. The innermost of these Lakedale-Domerie moraines impounds Lake Keechelus. As at lakes Cle Elum and Kachess, Russell (1900) was the first to recognize that the Lake Keechelus basin was glaciated but did not see evidence that the three main glaciers of the Upper Yakima River Basin ever merged.
- **Landslide lakes**: Most of the lakes in the Cascade Range owe their origins to glaciation. This is true in this part of the Eastern Cascades as well. However, two significant exceptions exist in the Upper Yakima River Watershed. Lost Lake to our west (Figure 24) originated from a large landslide. Cooper Lake in the upper Cle Elum drainage (Figure 14) appears to be alluvial fan dammed.
- **Keechelus Glacier**: The Keechelus Glacier originated primarily in cirques along the Cascade Crest and on Rampart Ridge (Figure 24). Valley glaciers formed from cirques in the Upper South Fork Snoqualmie River, Commonwealth Creek, and Gold Creek drainages. These merged in the upper Keechelus Valley to form a large valley glacier that then coalesced with the Kachess and Cle Elum glaciers in Lookout Mountain and Kittitas times. The Lakedale Keechelus Glacier and Kachess Glacier merged at Swamp Lake Valley and below Lake Kachess to move downvalley east of Bullfrog. I-90 passes through a series of Lakedale-Hyak moraines above Gold Creek.

Swamp Lake to Snoqualmie Pass

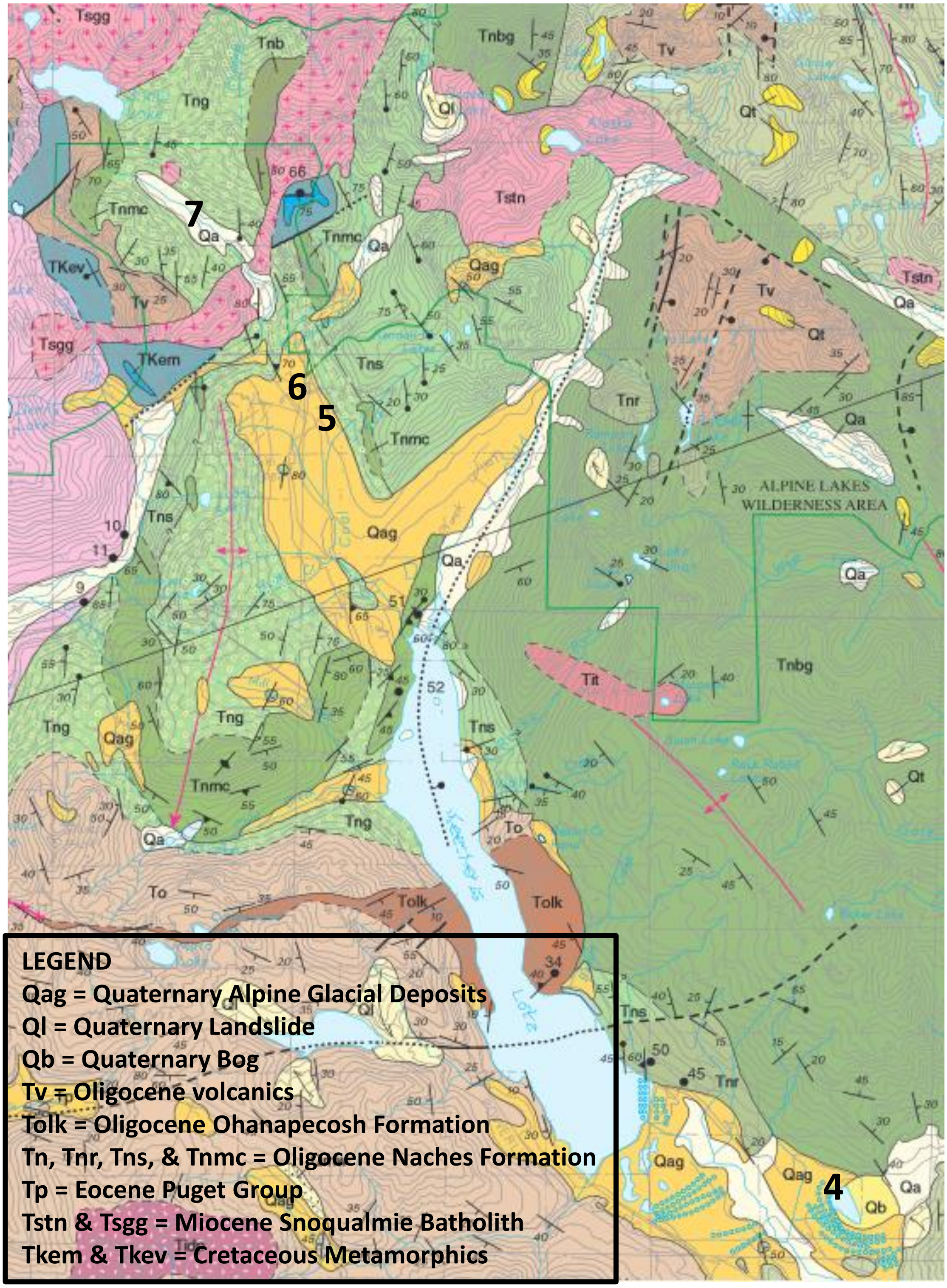


Figure 23. Geologic map of the Swamp Lake to Alpental areas. Numbers indicate field trip stops. Source: Tabor and others (2000).

Swamp Lake to Snoqualmie Pass

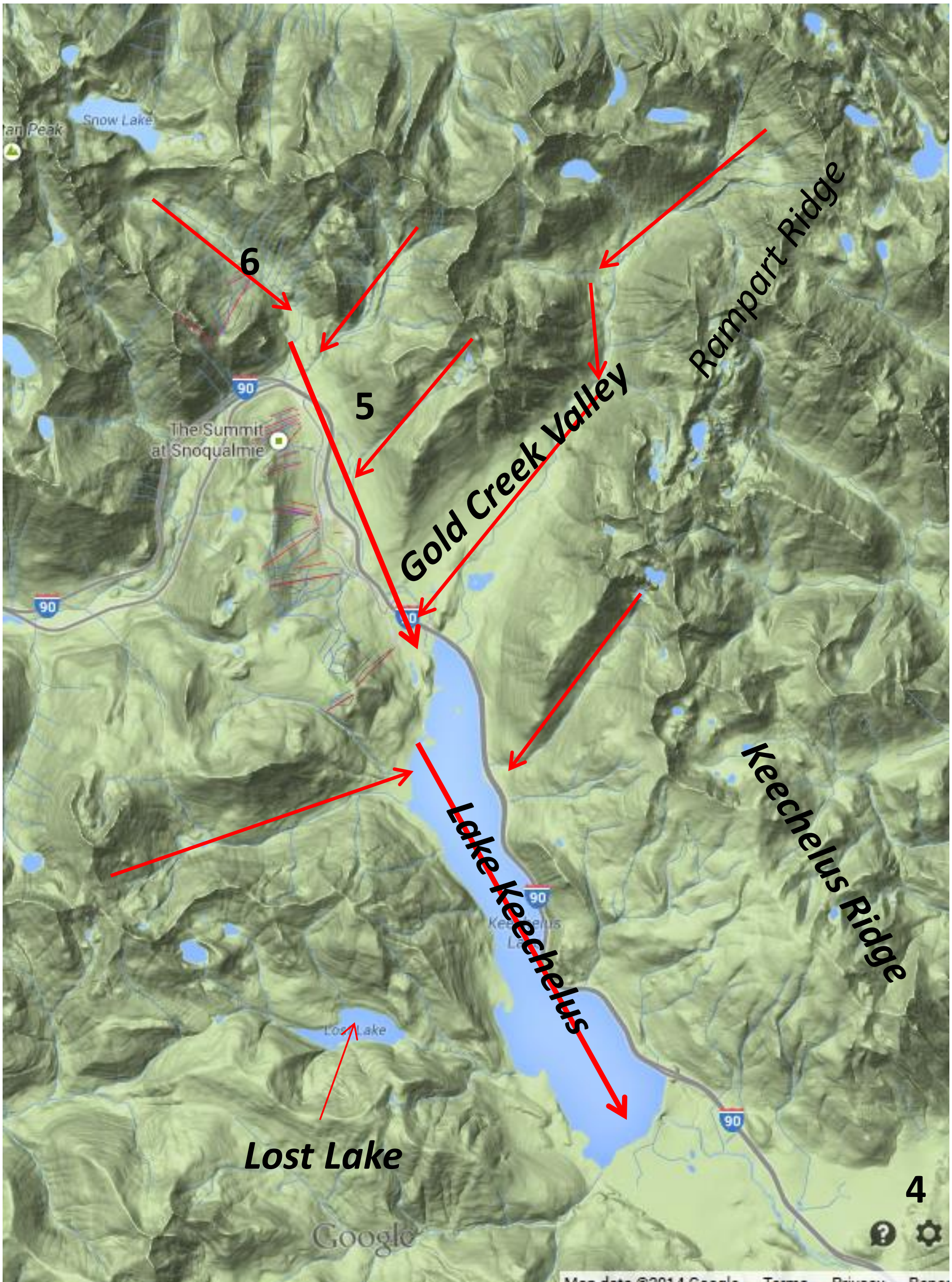


Figure 24. Sources of glacial ice in the Keechelus Watershed. Arrows indicate ice movement direction. Numbers indicate field trip stops. Source: Google Maps.

Stop 5—Snoqualmie Pass

- **Location**: We are located on Yellowstone Trail Road just east of Snoqualmie Pass and the Cascade Crest at ~2940 feet elevation. Average annual precipitation here is likely over 90 inches with much of that falling as snow.
- **Geology**: The geology here is dominated by volcanic and sedimentary rocks of the Naches Formation.
- **More Moraines**: This portion of Yellowstone Trail Road bisects two end moraines formed by a glacier moving from north to south (Figure 25). At this site, you see a topographic and stratigraphic cross-section of one of the moraines. Even when examining stereo airphotos, it is difficult to clearly identify the moraines in the area because of the dense forest cover, human modification of the surfaces, and the subdued nature of many of the moraines. These moraines are a complex of ridges separated by swales, many of which contain small ponds or wetlands. A pond is located in such a swale east of the second moraine and just south of the road. The outermost features suggest differential melting of a stagnant, debris-covered portion of the Lakedale--Hyak Glacier. Conversely, the innermost moraines are sharp-crested suggesting that part of the Hyak-age glacier was active and fluctuating in slightly upvalley of the stagnant ice terrain (Porter, 1976). Based on airphoto interpretation, I interpret our location on the upper end of the more subdued (eastward) moraines . These moraines formed before the very latest Pleistocene readvance of the Hyak-aged glacier. The very latest advances (Hyak I and II of Swanson an d Porter, 1997) are just west of our site (Figure 25).
- **Dating Hyak Moraines**: Near the Washington DOT Traveler's Rest (our next stop), Porter (1969) and Swanson and Porter (1997) used a combination of tephrochronology, radiocarbon, and ^{36}Cl dating to determine the age of the Hyak glaciation. Hyak moraines are overlain by 6850 yr BP Mazama tephra, 3400 yr BP Mt. St. Helens Yn tephra, and Mt. St. Helens 1480 AD tephra (Figure 26). A large bog once occupied the area west and north of the Traveler's Rest. Wood found at the base of the bog and atop glacial till was radiocarbon dated at ~11,050 14C yr BP (Figure 27). This indicates that the Hyak glaciation occurred at least 11,000 yr BP. ^{36}Cl dates indicate that outer Hyak I moraines formed ~13,500 yr BP while inner Hyak II moraines developed ~12,200 yr BP (Swanson and Porter, 1997). The Hyak is the youngest of the late Pleistocene glacial deposits identified by Porter (1976) in the Upper Yakima River Watershed. By Hyak time, the large valley glaciers were gone and most glaciers were confined to cirques (above ~2800 feet elevation) and valleys adjacent to the cirques. Outwash deposits from the Hyak glacier slope from the Hyak area to the upstream end of Lake Keechelus. formed by a glacier flowing from north to south.
- **The Glacial Story**: We are located at the crest of the Cascades where a cirque should be located that fed the Upper Yakima River Glacier. However, this not the case here. The glaciers that passed through Snoqualmie Pass originated in the Commonwealth Creek basin and in the headwaters of the South Fork Snoqualmie River (e.g., Source Lake & Alpental) (Figures 24 & 28). These glaciers coalesced just west of Snoqualmie Pass to form one glacier that then split sending lobes down the South Fork Snoqualmie River Valley and the Upper Yakima River Valley. This is a good reminder that glaciers often ignore drainage divides!
- **Origins of Mountain Passes**: Most mountain passes in alpine glaciated terrain are cols which form when two cirques headwardly retreat. Where the cirques meet, a low spot (col) forms. This is true with other mountain passes in Washington (e.g., Chinook, Cayuse, Stevens, and Washington). As described above, Snoqualmie Pass doesn't fit this pattern.

Stop 5—Snoqualmie Pass

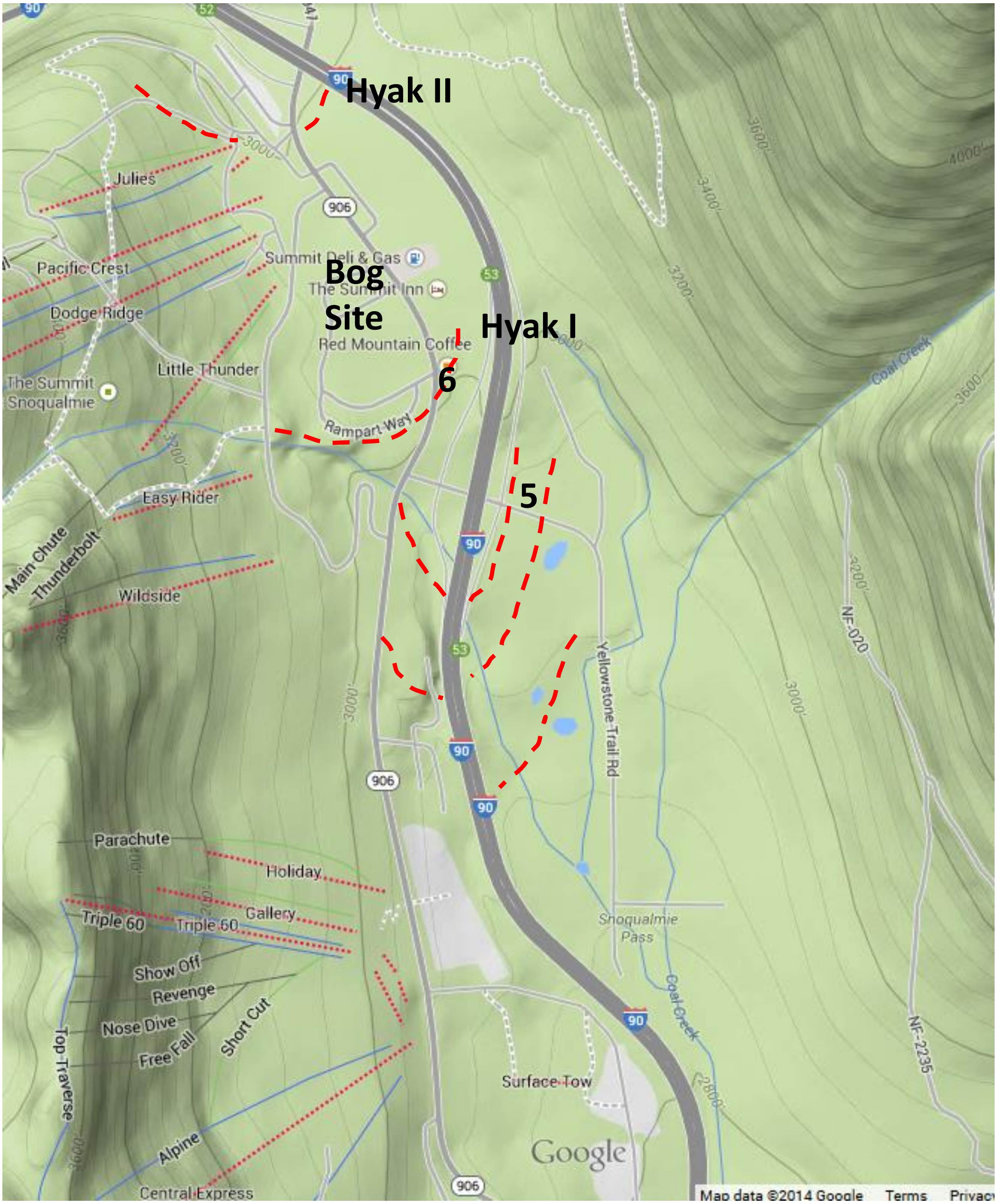


Figure 25. End moraines (red dashed lines) at and in the vicinity of Stops 5 and 6. Field stops shown with bold numbers. Source: Google Maps.

Stop 5—Snoqualmie Pass

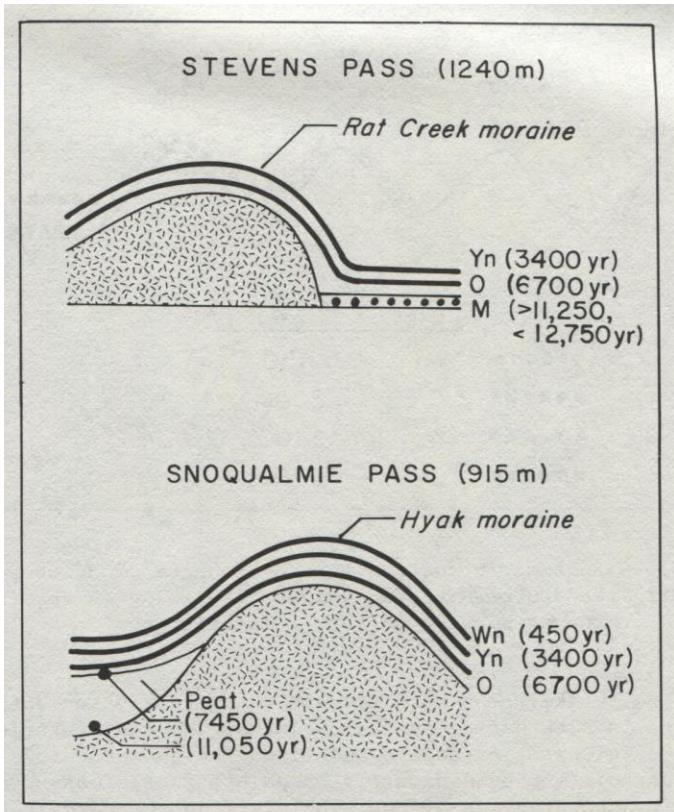


Figure 26. Cross section through Late Pleistocene end moraines at Stevens Pass and Snoqualmie Pass showing relationship of tephra layers. Symbol legend: M = Glacier Peak, O = Mazama, and Yn and Wn = Mt. St. Helens. Source: Porter (1981, p. 147).

Figure 27. Exposure in remnant bog west of Traveler's Rest, Snoqualmie Pass. Source: Author.

Stop 5—Snoqualmie Pass

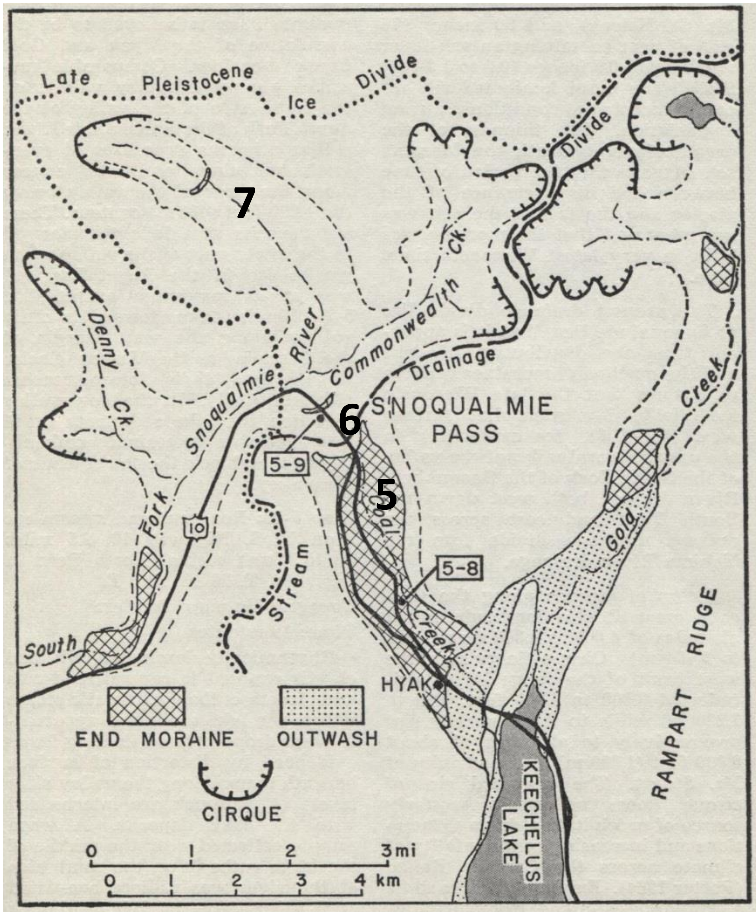


Figure 28. Major cirques, ice divides, end moraines, and outwash in the vicinity of Snoqualmie Pass. Numbers indicate field trip stops. Source: Porter (1965, p. 45).

Stop 6—Washington DOT Travelers Rest

- **Route:** From our stop on Yellowstone Trail Road, turn around and drive under I-90 to WA 906. Turn north (right) and proceed to Washington DOT Travelers Rest. This is our restroom stop.
- **Hyak I Moraines**: Note the Hyak I moraines across WA 906 and to the southwest. This moraine is now the site of many homes because of its view of the surrounding mountains.
- **Route to Stop 7**: From the WA DOT Travelers Rest, continue north on WA 906 through the Snoqualmie Summit area and under I-90. Go past the westbound on-ramp and turn north (right) onto Alpental Road (the sign says "To Snow Lake Trailhead". Follow this road to the large parking lot at the Snow Lake Trailhead. This is Stop 7.

Stop 7--Alpental

- **Location**: We are located at the large parking lot at the end of the Alpental Road.
- **Geology**: The geology of the area is diverse ranging from sedimentary to igneous to metamorphic rocks (Figure 23). New to our trip are the granites, granodiorites, and tonalites of the Snoqualmie Batholith, and the marble of Cave Ridge.
- **Glacier sources**: We are again located in a glacial trough characterized by very steep (often "over-steepened") valley walls and a relatively broad, low gradient valley floor. However, this trough, occupied by the headwaters of the South Fork Snoqualmie River, is much narrower than others we have been in today. This likely reflects our position in the watershed—i.e., we are very near the source area for the Upper Yakima River glacier. This trough was shaped by a valley glacier that originated from one of the numerous cirques on the surrounding valley walls (Figure 29). In the northern hemisphere, most cirques face north because such an aspect has limited sunlight. Sunlight (and associated warmer temperatures) melt snow preventing the formation of glacial ice. The generally north-facing position of the Alpental Ski Area also reflects this reality—i.e., snowfall remains longer on north-facing slopes. Source Lake, the "source" of the South Fork Snoqualmie River, is a tarn lying in a cirque. You can see that most of the Commonwealth Basin cirques are generally south facing. This is possible when ridges to the south shade such cirques. It can also work if cirques form at higher elevations than their north-facing counterparts.
- **Cirques and Snowlines**: Cirque floor elevations in the vicinity of Snoqualmie Pass are 4000 to 4800 feet. As a comparison, cirque floors near Mt. Stuart are approximately 6000 feet (Porter, 1965). Regional snowline during the late Pleistocene was ~2950 feet below present-day snowline as a result of colder conditions (Porter, 1977; Porter and others, 1983). Snowline rose to east reflecting decreasing precipitation to east.
- **Holocene glaciation and the Cirques**: If we had the time and the energy, we would hike to some of the cirques in the area. There, and even somewhat downvalley of the cirques, we would find steep, sharp-crested moraines, often with little vegetation cover. These represent readvances of Holocene (i.e., the past ~11,500 years) glaciers. Small glacial advances occurred in the Washington Cascades in the early, middle, and late Holocene (Burke and Birkeland, 1983). Middle and late Holocene glacial advances are often referred to as Neoglacial. Neoglacial advances occurring in the past ~500 years are called Little Ice Age features.
- **Today's Glaciers**: Present-day glaciers in the Upper Yakima River Watershed are confined to higher elevations and often, north-facing aspects along the Cascade Crest. Porter (1976) identified 14 small glaciers in the Upper Yakima River Watershed as of 1976. These glaciers are limited to Chickamin Peak, Lemah Mountain, Chimney Rock, Overcoat Peak, and Mount Daniel.

Summary

- Large Pleistocene glaciers formed in the Upper Yakima River Watershed despite being on the lee side of the moderately low elevation Cascade Range.
- Glaciers mostly originated in north-facing cirques. Cirque floor elevations rise from west to east reflecting the continentality of the watershed.
- Cirque glaciers grew to occupy valleys and become valley glaciers.
- Three major, Pleistocene glaciations occurred in the Upper Yakima River Watershed. The older glaciations were the most extensive.
- Evidence for these glaciations include moraines, outwash terraces, erratics, cirques, glacially sculpted bedrock, and abandoned drainages.

Stop 7--Alpental

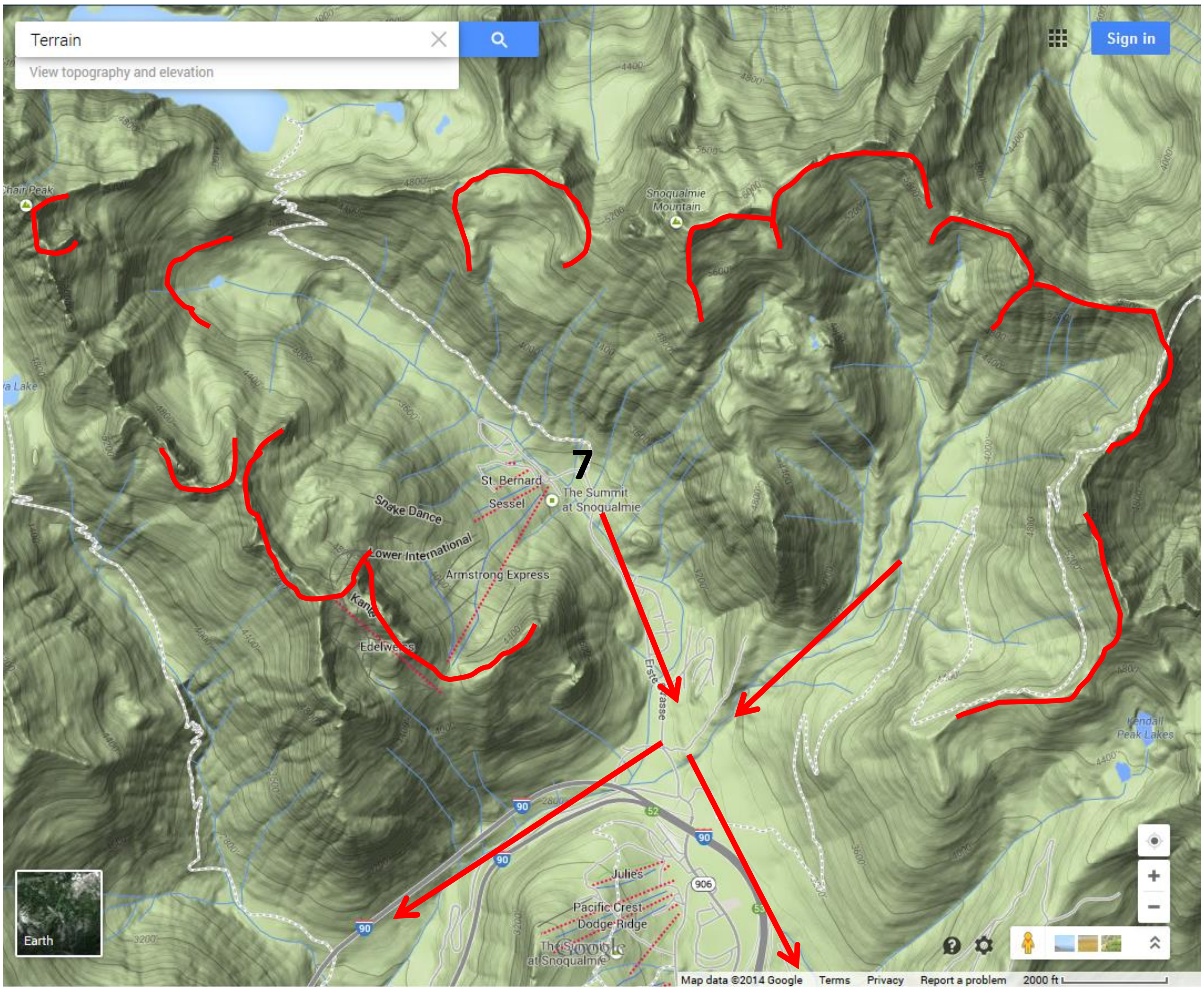


Figure 29. Alpental area at the westernmost headwaters of the Upper Yakima River Watershed glacier. Red outlined amphitheater shapes represent cirques. Arrows indicate direction of ice movement according to Porter (1976).

Summary (continued)

- Glaciations are differentiated by weathering rinds, loess thickness, relative positions, depth of soil weathering, ^{14}C, and ^{36}Cl.
- Pre-existing geological structures guided the paths of the valley glaciers in the watershed.
- Small glaciers occupied Upper Yakima River Watershed cirques at various times in the Holocene.
- Today's Upper Yakima River Watershed glaciers are limited to higher elevations and primarily north-facing aspects along the Cascade Crest.
- Glaciation has impacted many aspects of our lives in the Upper Yakima River Watershed.

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