The IAFI Puget Lobe Chapter monthly newsreel:

<u>Introduction to the Milankovitch Theory, Ch 8, p. 1</u>

Last months meeting we discussed Hood Canal including the presence of a fault, bottom profile, and bathymetric features consisting of major crests/troughs at the north end, with “spires” on the bottom and some exposed on the surface. And a quick look at what isostatic depression looked like around Port Ludlow.

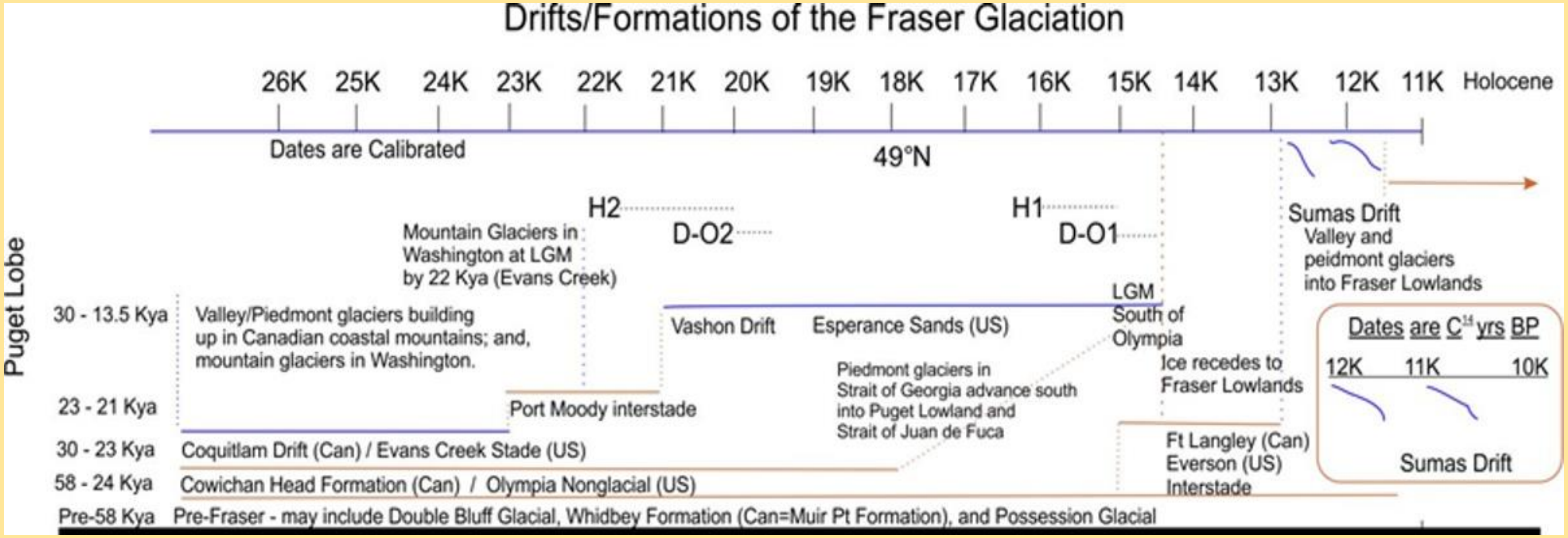
This month we will take a more detailed look at Ice Sheet generation, then quickly travel over to the coast and locate some alpine moraines near Quinault and their relationship to the Puget Lobe.

Finally, return to Continental Ice Sheets (CIS) and discuss whether the Puget Lobe was a piedmont glacier formed from of the Cordilleran Ice Sheet. And associated with that discussion, look at surging glaciers, mainly in British Columbia, and how and if our Frasier Puget Lobe could have surged.

Introduction to the Milankovitch Theory, Ch 8, p. 2

When looking at the timelines for the Frasier glaciation it was noticed that it took a while for the Puget lobe to manifest itself – a period of about 10ky from about 30Kya. However, notice mountain (alpine) glaciers were forming from 30Kya. And that by 22Kya alpine or mountain glaciers were at LGM in Washington.

And at the same time, mountain / valley glaciers were building in British Columbia. More in discussion on piedmont glaciers.



Introduction to the Milankovitch Theory, Ch 8, p. 3

In addition, the above chart gives the formation, life, and death of the Puget Lobe. In the left middle of the chart is shown an abbreviated discussion of alpine/mountain glaciers.

CISs develop as alpine or mountain glaciers over time and build ice domes. They first start as mountain/valley glaciers which grow and coalesce. In the case of the Cordilleran Ice sheet, once the dome grew beyond the confines of the British Columbia mountains it formed piedmont glaciers, such as the Malaspina Glacier has done in Alaska. The piedmont glaciers, in turn coalesced, and became part of the Puget and Juan de Fuca Lobes.

a. On the SW coast of BC beyond the influence of the Olympic Mountains the Cordilleran Ice sheet (fjord glaciers) terminated against/within the Pacific Ocean.

b. The Olympic Mountains and Cascades funneled the ice sheet into the Puget Lowland to create the Puget Lobe. This funneling caused the Puget Lobe to flow about 60 miles further south than the Okanogan Lobe and other easterly Cordilleran lobes.

c. Blue Mountain near Port Angeles is considered the bifurcation point between the Puget lobe and the Juan de Fuca Lobe.

<u>Introduction to the Milankovitch Theory, Ch 8, p. 4</u>

d. However, the west side of Mt Zion, a nunatak, was the last place ice flowed into the Puget Lobe (over Bon Jon Pass). To the west ice flow was into the Dungeness River valley, and other Olympic Mountain valleys that became part of the Juan de Fuca Lobe. We will visit the west side of Mt Zion and the Dungeness River Valley in Chapter 9.

Alpine/mountain glaciers had built up, reached LGM and then receded by the time the Cordilleran Ice Sheet domes had debouched sufficient ice to create the Puget Lobe and Juan de Fuca Lobe and advance into the Puget Lowlands.

Except for the buried sediment formations we saw in Chapter 7, for instance on the cross sections of Lilliwaup / Dewatto quadrangle, surficial features of the alpine moraines are non-existent in the western Puget Lowlands. Advancing glaciers are known to be unforgiving of anything in their path. But some surficial examples of alpine/mountain glacial moraines are found in the Forks and Quinault area.

The IAFI Puget Lobe Chapter monthly newsreel:

<u>Introduction to the Milankovitch Theory, Ch 8, p. 5</u>

Continental Ice Sheets have their own life and death. The Milankovitch theory explains the conditions for their beginnings. The associated feedback mechanisms, such as CO^2 and other gases, volcanic dust, etc., contribute to the long-term growth of ice sheets with subsequent termination very rapid.

Our Puget Lobe originated in British Columbia, as shown in the charts on the next slide.

The growth and decay of a CIS is graphically shown in the GSC* figure to the right. As an aside, look at the IAFI map (IAFI/Eastern Washington University, <u>Ice Age Floods in the Pacific Northwest</u>). It shows the CIS at LGM. Look at the Olympic Mountains, Cascades, and in the Flathead region of Montana. You will see an abundance of valley glaciers. In the Olympics, as are others, the glaciers are shown after alpine glacial recession.

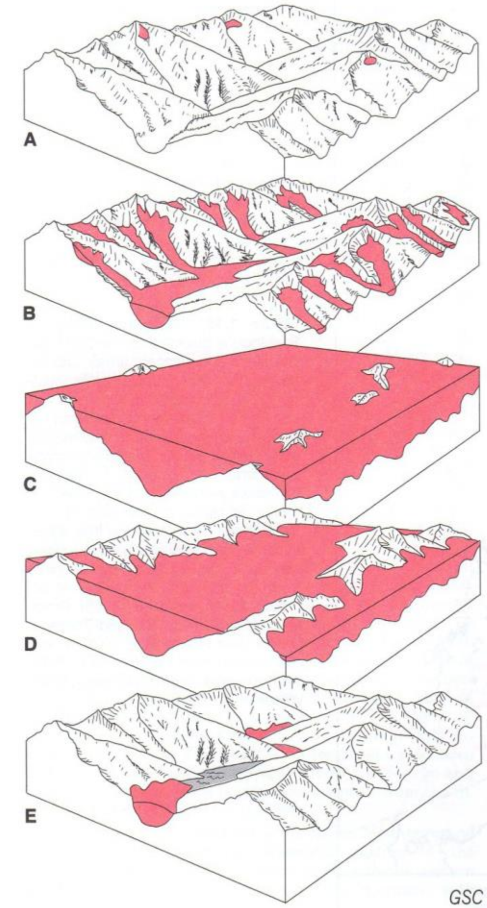


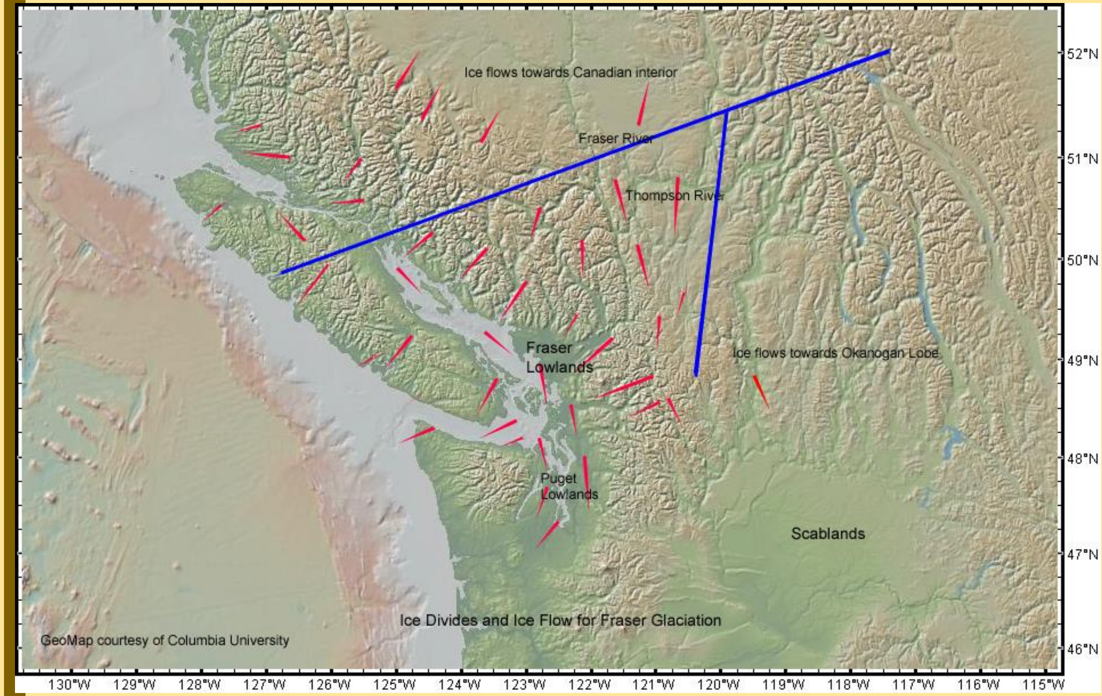
Figure 1.13. Growth and decay of the Cordilleran Ice Sheet. A. Mountain area at the beginning of a glaciation. B. Development of a network of valley glaciers. C. Coalescence of valley and piedmont lobes to form an ice sheet. D. Decay of ice sheet by downwasting; upland areas are deglaciated before adjacent valleys. E. Residual dead ice masses confined to valleys.

Clague, J.J.
1989: Relationship of Cordilleran and Laurentide glaciers; <u>in</u> Chapter 1 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.); Geological Survey of Canada, Geology of Canada, no. 1 (<u>also</u> Geological Society of America, The Geology of North America, v. K-1).

From: Ed, R.J. Fulton, Quaternary Geology of Canada and Greenland, 1989, Fig 1.13, p. 42

* GSC = Geological Survey of Canada

Introduction to the Milankovitch Theory, Ch 8, p. 6



These two graphics give you an idea of from where and how the Cordilleran Ice Sheet grew. Arrows are ice flow direction. Also see the upper left figure on page 10.

Ice flow arrows from: Ed, R.J. Fulton, Quaternary Geology of Canada and Greenland, 1989, Fig 4, p. 8, and Fig 1.12, p. 41

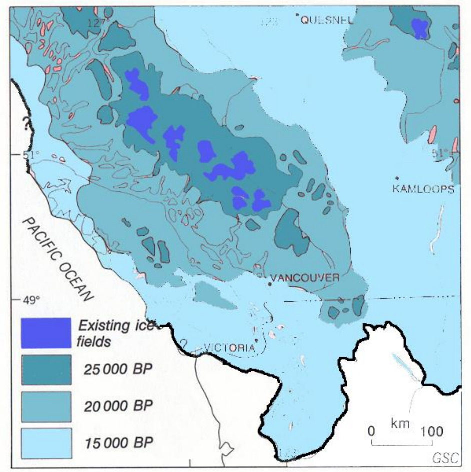


Figure 1.23. Growth of the Cordilleran Ice Sheet in southern British Columbia and northern Washington during the Fraser Glaciation (from Clague, 1981, Fig. 3). Approximate glacier margins at 25 ka, 20 ka, and 15 ka are depicted. Unglaciated areas within the confines of the ice sheet are not shown.

From: Ed, R.J. Fulton, Quaternary Geology Of Canada and Greenland, 1989, p.57

Introduction to the Milankovitch Theory, Ch 8, p. 7

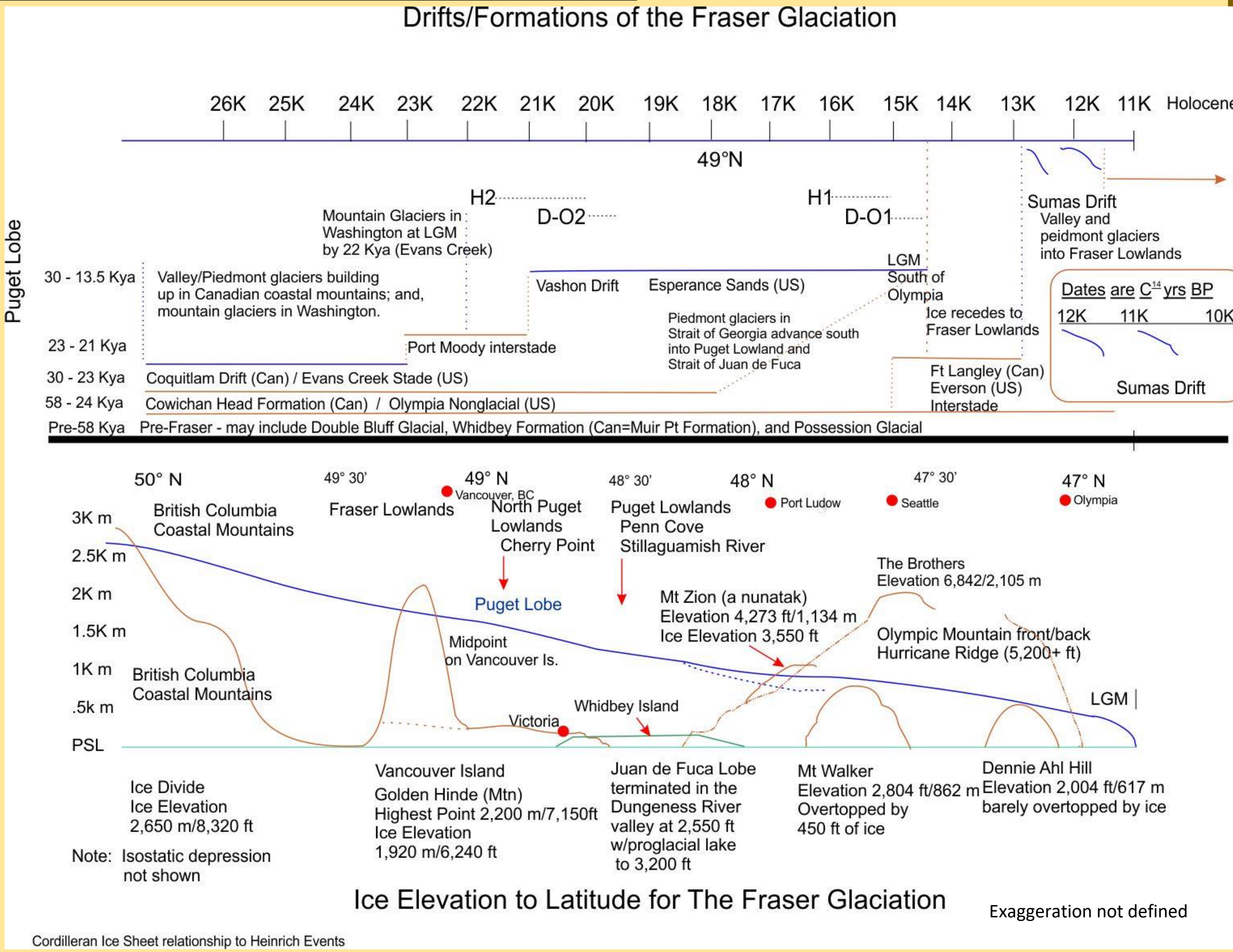
Note the activity in BC as the Cordilleran Ice Sheet (CIS) was developing.

a. This chart ignores previous events associated with the Puyallup Glacial event.

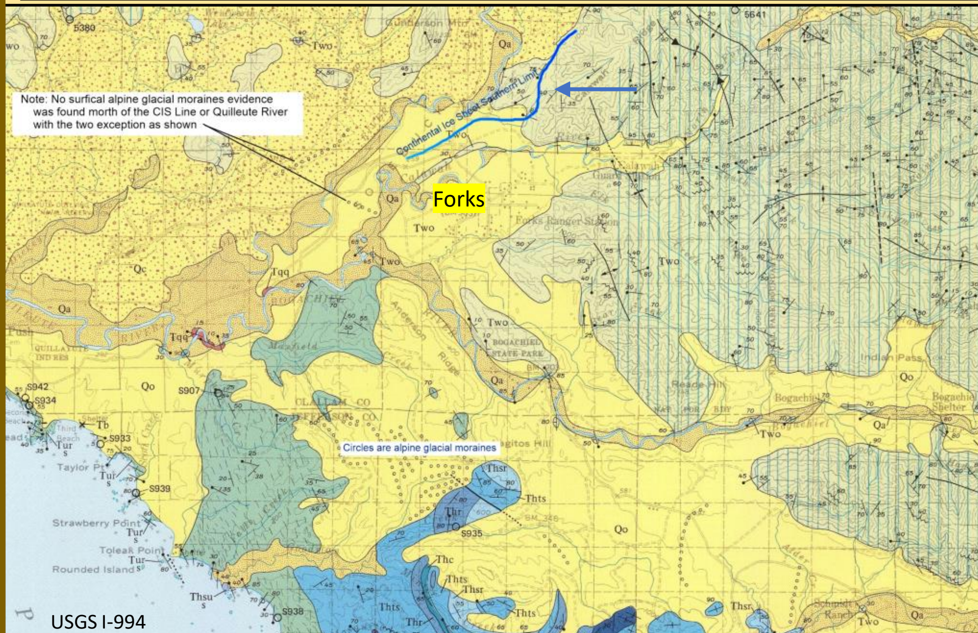
b. Notice the buildup of alpine glacial activity shown in the upper left.

c. Also note the occurrence of Heinrich Events (H) and Dansgaard-Oeschger (D-O) events.

d. On the next slide we go the coast and look at Alpine moraines around Forks and Quinault.



Introduction to the Milankovitch Theory, Ch 8, p. 8



1. On the left, south of Forks, alpine glacial moraines are shown as circles. The blue line, showing the limit of the Fraser Glaciation, would destroy any alpine glacial moraines; consequently, except for the two possible exceptions, there are no alpine glacial moraines north of Forks. The Juan de Fuca Lobe prevailed. In addition, the Queets and Hoh Rivers show alpine glacial moraines.

2. On the Quinault graphic to the right, you can count approximately 7-8 crescent-shaped moraines. Realistically you can "age" date them by their position. The ones further inland are the youngest; otherwise, they would have been overridden or cut through by any glacial moraines in front of them. More about terminal moraines when we discuss surging glaciers.

The IAFI Puget Lobe Chapter monthly newsreel:

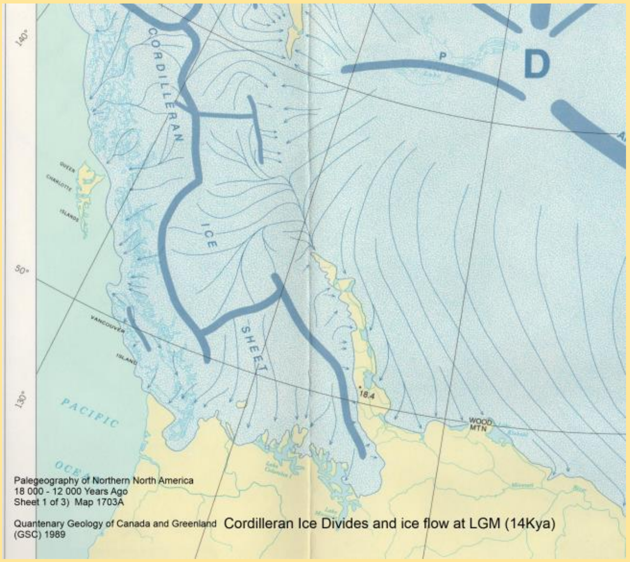
Introduction to the Milankovitch Theory, Ch 8, p. 9

The previous slide contained excerpts from USGS Miscellaneous Investigation Series Map I-994 which was published in 1978; the current geological map is DNR Open File Report 2004-4 which does not show moraines - just morainal deposits. And some morainal deposits follow or occur within enclosed contour lines in the same position that I-994 shows. More later after we transpose information between the two geological maps.

Is the Puget Lobe part of a piedmont / lobe of a CIS? It formed from the Cordilleran Ice sheet. The Cordilleran Ice Sheet was not constrained by topography, and was in excess of 50,000Km^2. These are two of the main features of a Continental Ice Sheet.

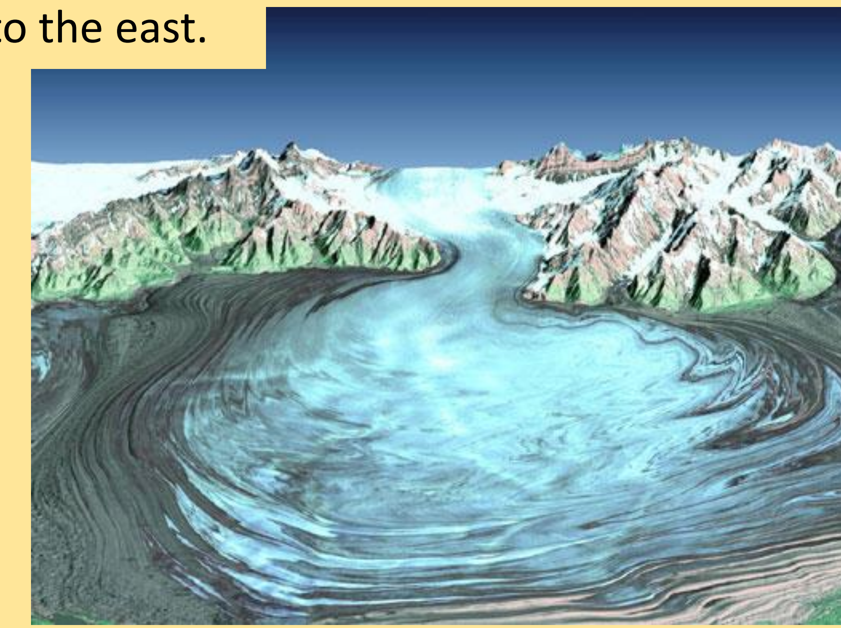
The Puget Lobe can thus be called a piedmont glacier or lobe. Or "Wherever, valley glaciers debouch on to lowland areas after travelling through bedrock troughs, they will form a piedmont glacier or lobes….are characterized by having large areas below the equilibrium line altitude." (Benn, 1998, p.19)

<u>Introduction to the Milankovitch Theory, Ch 8, p. 10</u>



Cordilleran Ice Divides and ice flow at LGM (14Kya)

1. To the left, Ice Divides of the Cordilleran Ice Sheet showing the ice flow lines at 14Kya or LGM. Note the ice divide (smaller blue line) on Vancouver Island and that the SE portions of the ice flow fed the westerly portions of the Juan de Fuca Lobe. Also note the Cascade Mountain's affect on the Okanogan Lobe compared to the lobes to the east.



2. The Malaspina Glacier is the example given for a piedmont glacier. It debouches from a valley glacier and "spreads out" to form an ice mass. In the case of the Puget Lobe, several ice flows coming from the Canadian ice divide coalesce into the Puget Lobe and are confined by the Olympics and Cascades.

The IAFI Puget Lobe Chapter monthly newsreel:

Introduction to the Milankovitch Theory, Ch 8, p. 11

Comparisons of Puget Lobe LGM to the Cordilleran ice lobes LGM. (miles from 49° North latitude or Canadian border)

Juan de Fuca Lobe	Puget Lobe	Okanogan Lobe	Columbia River Lobe	Coville River Sublobe	Purcell Trench Lobe	Flathead Lobe	East Flathead Lobe
10 mi South of the Olympic northern slope or Termination	146 mi	96 mi	74 mi	70mi	80 mi	74mi	94 mi

The point here is that the Olympics/Cascades funneled ice into the Puget Lobe; while the Cascades funneled ice into the Okanogan Lobe creating larger / longer lobes.

Taken from: (IAFI/Eastern Washington University, Ice Age Floods in the Pacific Northwest).

The IAFI Puget Lobe Chapter monthly newsreel:

Introduction to the Milankovitch Theory, Ch 8, p. 12

What is a surging glacier?

Glaciers advance, become stationary, and retreat in response to accumulation and ablation (melting). A simple way to look at this is: if snow accumulation and melting is in balance (accumulation = melting), the glacier may appear stationary, except it's still moving: growth = decay. $(U_{tx} = a_b/\tan a)$

a. if accumulation > ablation the glacier grows in mass and will follows the gradient / topography. Beyond the line of equilibrium there will growth. The terminus advances. $(U_{tx} > a_b/\tan a)$

b. if accumulation < ablation a glacier will retreat. The terminus retreats. $(U_{tx} < a_b/\tan a)$

Surging glacier follow the formula found above with some refinement. Benn (p.547) offers the best explanation; however, it's very abbreviated:

a. "Rapid sliding...and cavities at…the bed is conductive to high rates of abrasion and quarrying."

b. "Severe compressional deformation at…snouts…result(s) in extensive thrusting faulting and folding…elevates basal ice…." causing surges.

c. "…wastage during the quiescent period of the surge cycle…produces ice-cored moraines…which may be…incorporated…into the next surge."

Surging glaciers exhibit two characteristics: a. A *quiescent* phase where the snow reservoir builds up. And, b. the *surge* phase which involves a rapid advance of the snout down glacier. Then the process starts all over again. The cycle varies by location and over time.

Description and formula: Boulton (1989) found in Benn, 1998, p.242

Introduction to the Milankovitch Theory, Ch 8, p. 13

The periodicity for the *quiescent – surge* phases varies by geography. In the area that the Cordilleran Ice Sheet once occupied are several surging glaciers: Two of the most studied ones are Trapridge Glacier (rests on a bed of unfrozen deformable sediment) in the Yukon Territory and the Variegated Glacier (subpolar glacier?) in Alaska.

It is known that temperate and sub-polar glaciers can surge; however, polar glaciers, because of their cold base (frozen to their beds) don't surge. However, as we noticed in the description of the Heinrich Events, that cold based glaciers, such as the Laurentide, can and did exhibit surging characteristics due to ice elevation and geothermal heat.

The surge is suggested by an increased basal water pressure which closes the internal water drainage system and prevents water from being discharged from the glacier. This water would act as a lubricant; hence, a surge until the water is expelled from the glacier resulting in a decrease in water pressure at the bed, and a realignment of the internal water system that expelled the water normally.

Introduction to the Milankovitch Theory, Ch 8, p. 14

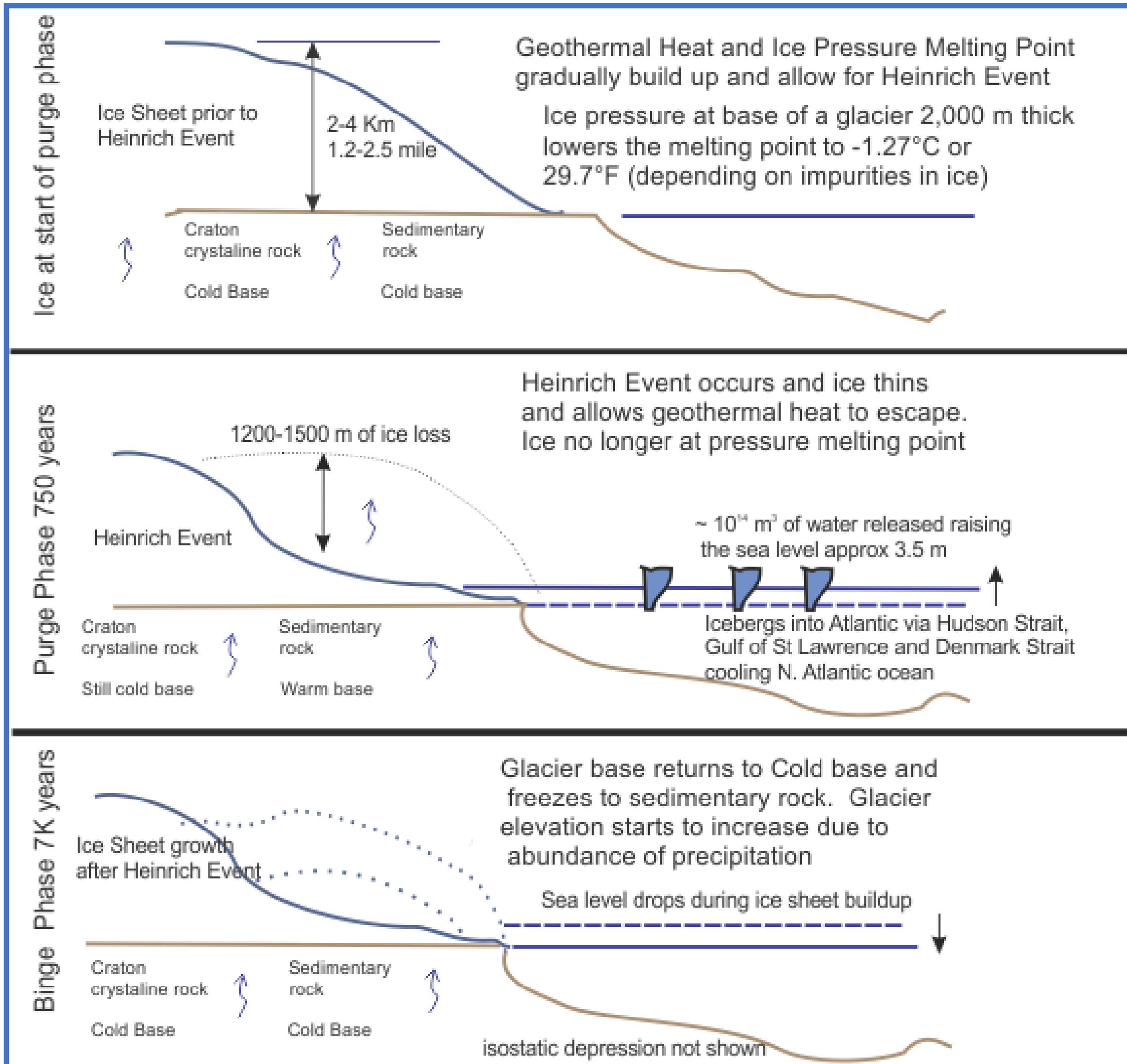
The previous slide presented a very quick review of surging glaciers. The question is: could the Puget Lobe also surged. It had a temperate base which was shown to have facilitated surging glaciers. And surging glaciers are not dependent upon climatic fluctuations; except, climate plays a role in <u>where</u> you find surging glaciers.

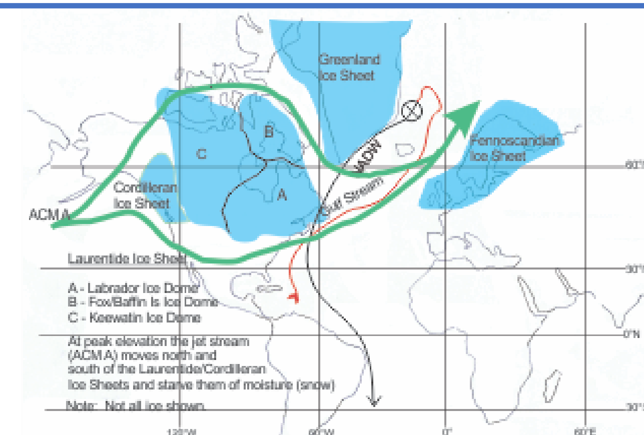
And studies of the Laurentide Ice sheet say “yes”. Especially, during termination or resulting from Heinrich events or DO events. And as shown on the next slide, ice sheet reconstruction of Heinrich events were complex. Siegert (p. 178) states “Eventually the basal temperatures reach the pressure melting value that initiates rapid basal motion (the purge phase)”. And modeling by Fisher et al. (1995) “using a time-dependent ice sheet model…concluded that the presence of subglacial water-saturated sediments would have had a fundamental control on the surface topography of the ice sheet.’ (Siegert, 2001, p. 180-181)

Looking at the three graphics on the next slide, to the left, you will see the binge-purge phases which can be loosely “applied” to our current surging glaciers on Trapridge and Variegated Mountain(s).

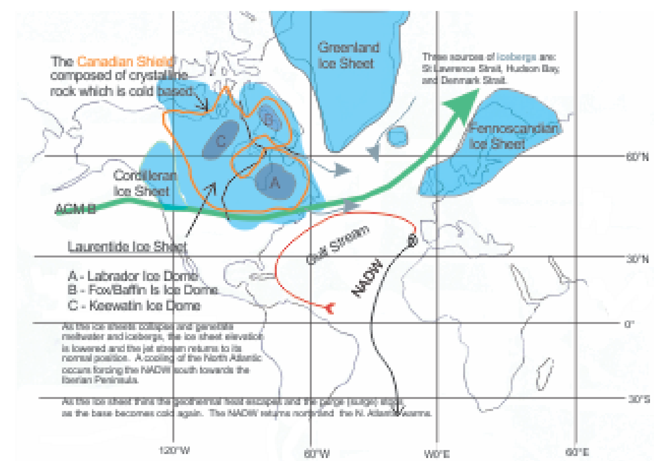
The IAFI Puget Lobe Chapter monthly newsreel:

Introduction to the Milankovitch Theory, Ch 8, p. 15





Laurentide Ice sheet Configuration prior to Heinrich Event



Laurentide Ice sheet Configuration during a Heinrich Event

Introduction to the Milankovitch Theory, Ch 8, p. 16

Some indicators that the Puget Lobe surged:

a. Bed was on sedimentary rock resulting in a “warm-bed” condition

b. Hummocky appearance at terminal location which is consistent with disintegrating lobe features of the Laurentide Ice Sheet.

(1) Some lobes on the southern part of the Laurentide Ice Sheet are reported to have “surged” during LGM or during deglaciation and are considered as surge events. (Siegert, p.167)

c. Heinrich Events occurred at 14.5 Ka (which resulted in a D-O event) and 21.5 Ka in the Laurentide Ice Sheet.

d. There was a report that near Denny Ahl Hill a “surge” event is evident.

These are preliminary findings and will be researched and expanded on over the summer hiatus and presented next fall or winter.

The IAFI Puget Lobe Chapter monthly newsreel:

<u>Introduction to the Milankovitch Theory, Ch 8, p. 17</u>

In May 2021 (Ch 9), the Newsreel continues with a look at an extrusion of Pillow basalt (Crescent Formation) on Mt Tyler above the Dungeness River, and a walk along Royal Creek to look for evidence of the proglacial lake that formed in the Dungeness River valley during the Puget Lobe. And if time allows, look at the sheer basalt cliffs on the west side of Mt Zion (northwest of Bon Jon Pass) that show the potential for glacial smoothing. Just a quick look, no rappelling gear involved.

In Sep 2021 (Ch10), the Newsreel will continue with a look at the Kame terrace on FS23 above Vance Creek, and then go beyond the High Steel Bridge over the S. Fork of the Skokomish River to look at the eskers* below Denny Ahl Hill (and one esker located on the side of Denny Ahl). And yes, we'll straddle the Frigid Creek Fault for some excitement.

* The esker shown on our web page is from that area and is used by the FS/landowners as a "borrow pit". That's why the vertical end.