LAB 9: ALPINE AND CONTINENTAL GLACIATION

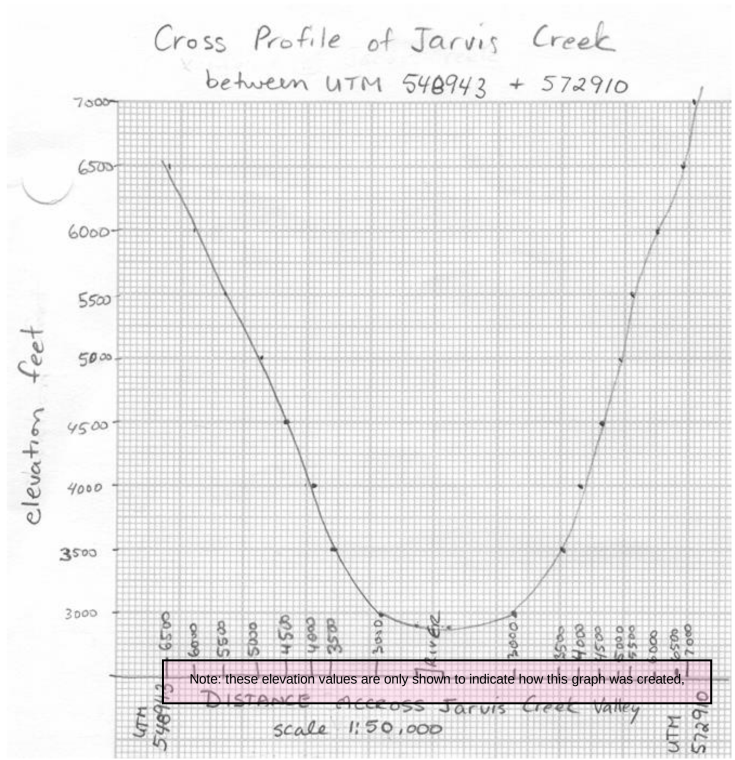
Total Marks: (50) **Use this grading scheme in your evaluations if you wish.**

SECTION A: MAPS & DIAGRAMS (25 marks)

1) **Alpine Glaciation: Ovington Creek** (NTS map 93 I/2 2nd edition) (12 marks)

   a) Use the graph (left) & name the type of cross sectional profile shown by Jarvis Creek. *U-shaped.*

   Why it might be shaped this way? (2)



U-shaped valleys are typical of glaciated valleys in bedrock. Here ice scours the base and sides of the valley to form straighter channels with steep walls and a curved base. At the base, the combined effects of weight and frictional drag are greatest. It is thought that warm glacial ice scours and removes more material. [In coastal areas, bedrock scoured glacial valleys are often hidden under the ocean as fjords.]

Note that the profile of U-shaped valleys differ from those of a classic river eroded valley (which tends to be V-shaped), and from those of a typical sediment filled meandering floodplain which tend to be more box shaped. However, there are always exceptions to these generalities.

   b) Downstream from this cross-section in a) is an unnamed glacier-fed creek that drains water from the glacier south of Nechamus Mountain. The creek's headwaters are just below the glacier at UTM 533946. Identify the feature(s) indicated by the various sized dots surrounding the creek? Briefly state what they indicate about this glacier? (2)

These features are moraines. (They are lateral moraines that formed along the now-melted glacier's sides.) See how they appear to converge at an end moraine that crosses the valley at lower elevations. The creek bisects the end moraine and eroded it. From a map, it is difficult to determine if the end moraine is a terminal or recessional moraine, as lower moraines may not be as visible or well documented on a map.

Having moraine material at lower elevations than the current glacier ice indicates that the glacier receded from an earlier, lower elevation position. Note that more U-shaped map contours in this area indicate that the valley was more likely eroded by ice between the moraines. [Notice how the contours appear more rounded and "U-shaped" at high elevations and become progressively more 'V-shaped' as the water approaches Jarvis Creek. The V-shapes are due to post glacial water erosion.]

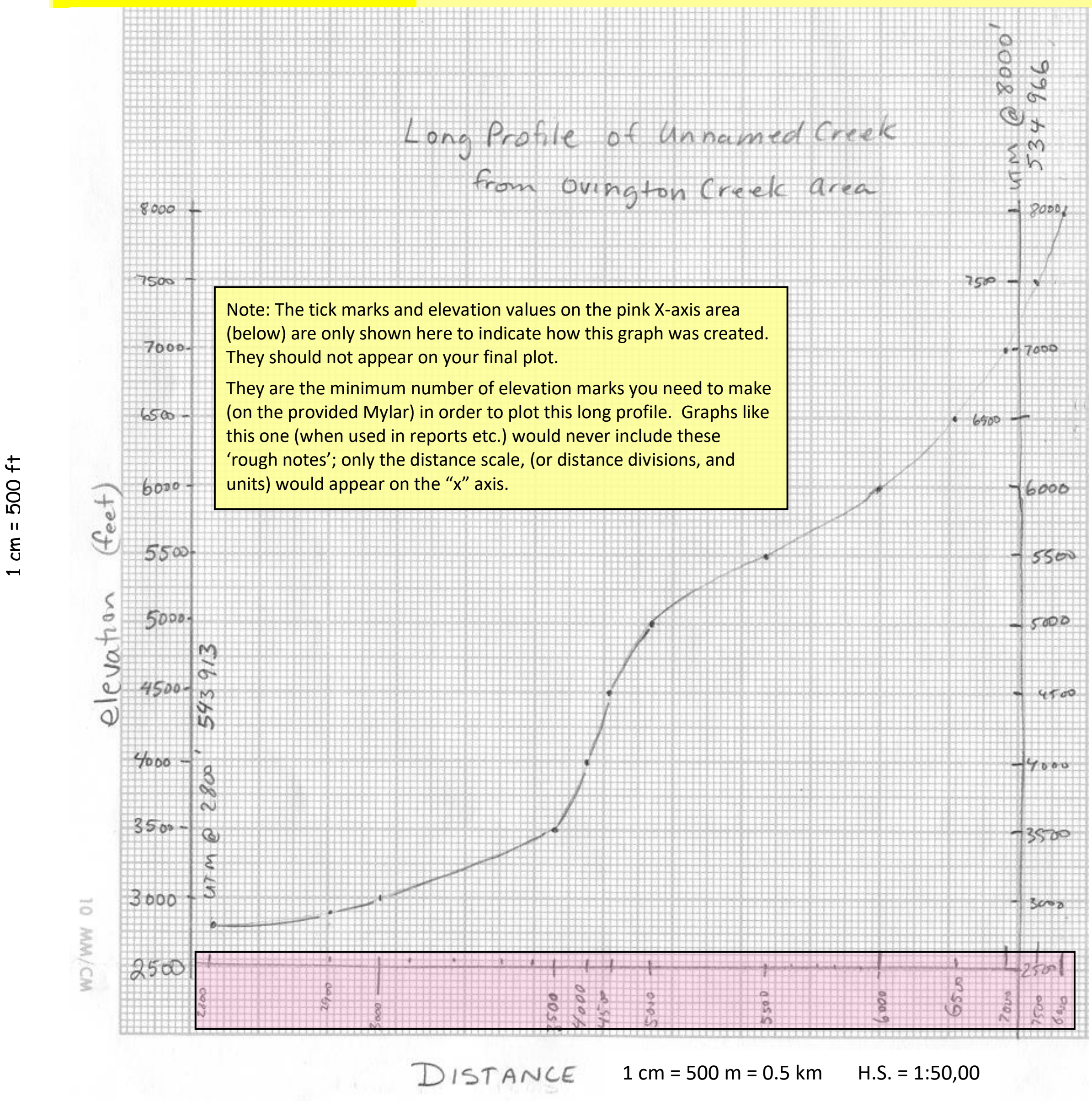
c) Long Profile Drawing (5)

Draw a long profile from the start of the cirque wall that encompasses the glacier at 8000 feet (UTM 534966) to the point where the creek joins Jarvis Creek at 2800 feet (UTM 543913). Start at the upper cirque wall so you can characterize the entire profile (both under the glacier and where the ice has melted). Use a vertical scale of 1: 15,240. Note this map's elevation is in feet. Consider why the ugly looking scale provided here might be a very good choice for this map – it has to do with converting elevation scales so you can graph them.

Mark distribution: *2.5 – title (0.5), axis labels & units (1 each axis)*
1 scale on elevation axis correct
1.5 – profile drawing (indicate start and end points and drawn correctly)

The profile's vertical scale (VS) is 1:15,240 and it, along with the graph paper used to plot the long profile, determines the graph's vertical axis. With 1 centimeter graph paper a VS of 1:15,240 means 1 cm of elevation on the graph is 15, 240 cm of real elevation on Earth (very hard to visualize or plot). This seemingly odd scale results when the map's elevation is in feet. By converting 15,240 cm to feet, the graph's VS becomes 1 cm = 500 feet. As done below, when plotting profiles from Canadian maps where the elevation is still in feet, it is clearest to keep the graph's elevations as feet but plot the distance (x-axis) in metric units as meters or kilometers.

$15{,}240\,cm \times \frac{1''}{2.54\,cm} \times \frac{1\,ft}{12''} = 500\ ft$ *so, the graph's elevation axis (y-axis) is: 1cm = 500 ft*



d) Determine the type of glaciated valley shown by your long profile (use Textbook & Supplementary Resources to assist)? Why is this type of long profile seen in glaciated valleys? (3)

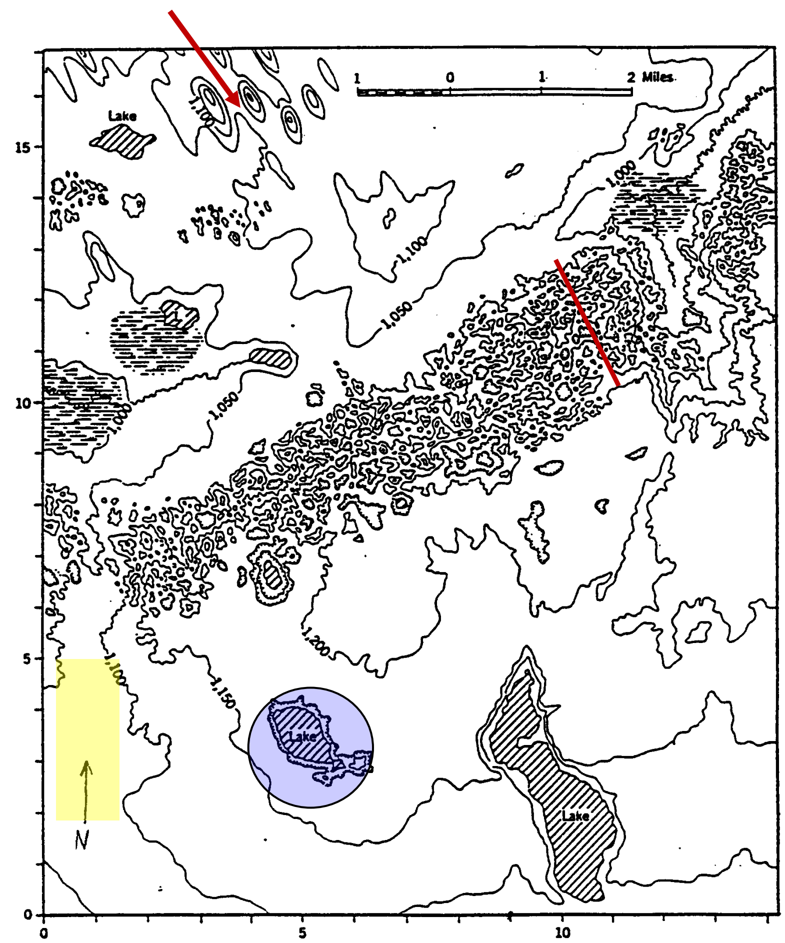
See Lab 9 Supplementary Resources: Landforms Produced by Alpine Glaciers; Paternoster Lakes, note the hanging troughs.

This is the long profile of a **hanging valley** (or hanging trough) (1)

Hanging troughs typically form in alpine glaciated environments where glacier troughs intersect at different elevations. When a glacier at a higher elevation joins the main valley (or trunk) glacier (which erodes at a lower level), the higher elevation glacier is no longer in contact with the valley bottom. Consequently the joining tributary glacier's trough hangs above the main valley's trough once the ice is gone. After glaciation hanging valleys often form spectacular waterfalls. (2).

2) Map Interpretation: Moraine and Pitted Outwash Plain: (6 marks)

A recessional moraine belt composed of innumerable small hills and depressions runs across the following map from northeast to southwest. Southeast of the moraine is a sloping outwash plain containing kettle lakes (i.e. ice block formed). North of the moraine is a lower area with marshes and drumlins which was beneath the ice and has a cover of thin ground moraine (i.e. till). Answer the following questions briefly in point form. ***NOTE THIS MAP HAS BEEN RESCALED FROM THE LAB COPY***



a) Identify the map contour interval. (0.5)

contour interval = 50 feet (from map margin information)

b) Draw a line across the widest point of the moraine belt; determine and report its real width below (1)

See the red line. The moraine belt is 1.7 to 1.9 miles wide (measured width ~ 3 cm using the bar scale on the map)

c) Use drumlin orientation at map margin numbers 4.0, 16.0 (read as x, y coordinates) and the moraine belt to determine the direction the ice sheet moved <u>from</u> as an azimuth. Explain how you knew the correct direction. (2.5)

Azimuth ice moved from _330^0__ See red arrow. (0.5) __ *because:*

[Toward 150^0 is the wrong direction.]

We know the direction of ice motion because the steep side of drumlins first contacts the moving ice. This map shows that the ice came from the NW. Why?

Drumlins are formed as glaciers override the till that they have pushed in front of them as they move. At some point a glacier can run over the till debris at its leading edge and creates drumlins – the elongated spoon shaped hills which have a steeply sloped end and a shallow-sloped end. The steeply sloped end was in contact with the advancing ice. (2)

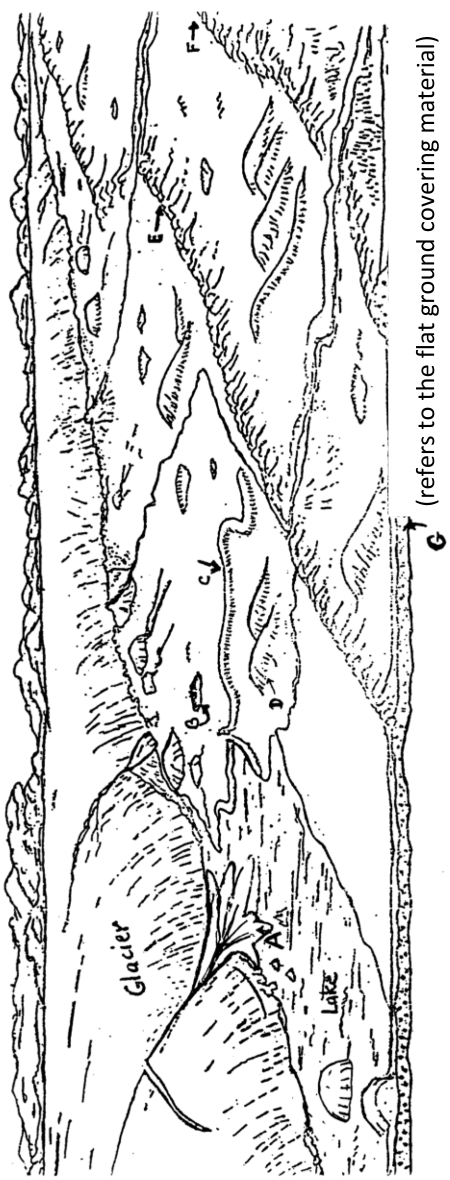
d) What map evidence indicates the ice advanced over the area now covered by the outwash plain? Briefly explain. (2)

The depressions and depressed lakes (some circled in purple). These are most likely kettle holes /kettle lakes as they are not connected by rivers/creeks. They occur in the outwash plain, south east of the recessional moraine, and signal that ice blocks were left behind in this area. Thus the glacier likely extended beyond the recessional moraine. During deglaciation, as the glacier disintegrated and melted, it left blocks of ice behind that occupied space. Massive amounts of water and sediment flow from the melting glacier. In the outwash plain sediment gets deposited around the blocks of ice as water levels drop. When the ice melts the reserved space becomes depressions or kettle holes that can fill with water and became kettle lakes. Kettle holes and lakes are typically associated with ice sheets, not alpine glaciers.

3) **Continental Glaciation:** Identify depositional glacial features shown by A through G in the space provided in the table. Use the drawing's cut through /underground (lowest part of the diagram). Ask if you aren't sure about what is being drawn. (7)

A	*Delta (specifically a kame delta because it is water washed sediment, and the delta formed in contact with the glacier ice)*
B	*Kettle hole, kettle depression or kettle lake*
C	*Esker*
D	*Drumlin*
E	*Recessional moraine*
F	*Terminal moraine or end moraine*
G	*Till or Ground moraine*

Depositional Features of Continental Glacier



<u>Section B:</u> Identifying Glacial Features from Air Photos (14 marks)
Answers are expected to be brief (this time you do not need to report photo evidence unless asked to explain your reasoning in the question). USE SUPPLIMENTRY RESOURCES & TEXTBOOKS AS AIDS.

1) **Plate 3-1: Valley glaciers, Cumberland Peninsula, Baffin Island NWT**
   a) Identify the type of glacier at A? Be specific. Notice the convex snout, typical of a warm ice glacier as the ice is more plastic. (1)

‘A’ is a **confluent valley glacier** (two glaciers join together).
(See Supplementary Resources, “Types of Glaciers” at the end of the lab).

   b) Identify the feature running through the number 9. How does it form? (2)

This is a **medial moraine** (also called an interlobate moraine) formed by the **confluence of lateral moraines** when the glaciers join together.
(See Supplementary Resources, “Landforms Produced by Alpine Glaciers” at the end of the lab).

   c) Identify the feature surrounding the proglacial lake at 7. How/why does it form? (2)

The feature surrounding the pro-glacial lake at 7 is a **terminal or end moraine. It formed when** melt water from the glacier gets trapped behind the moraine which acts like a dam with some seepage and a few water channels release some of the contained water. As the glacier melts back, the lake grows, until the dam fails, or the water source dries up.
(see Supplementary Resources, “Features at a Glacier’s Terminus” at the end of the lab).

   d) Using the photo margin numbers, identify the feature located at C.1, 4.1 (x, y coordinates). (1)

The feature is a **cirque**

2) Plates 3-5 and 3-8
   a) Identify the elongated features at 1 and 3 on Plate 3-5 (1)

The elongated features are “**streamlined features” of differing types. This term encompasses all types of drumlin-like features as they are thought to have formed through similar processes.**

[Use the Supplementary Resources, “Drumlins and Glacially Streamlined Features” diagram to identify specific types. Streamlined features are categorized by their shape, and composition. On Plate 3-5 #1 is a ‘crag and tail’ while #3 is a pair of drumlins where at least one is a ‘rock core drumlin’ (look closely at the western most drumlin to see what looks like rock inside the drumlin).]

   b) Identify the elongated features running across the photo on Plate 3-8 (1)

The Plate 3-8 features are drumlins and drumlinoids. (This area is well-known for its classic drumlin features and is called the Peterborough Drumlin Fields).

[Use the Supplementary Resources, “Drumlins and Glacially Streamlined Features” diagrams to identify. It really helps to see this photo stereographically, as the patchwork pattern of crops with plow lines moving horizontally across the drumlins make these features harder to see than on other photos. The provided NTS map showing the photo area shows the topography of these drumlins/ drumlinoids.]

a) What was the direction of ice movement on each photo (report as general compass directions)? How can you tell? (2) [*In your answer clearly specify ice movement directions – "the ice moved from _ and toward __" .*]

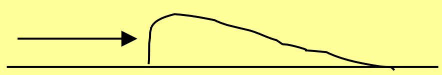
Note: when answering direction of movement questions, ensure answer clarity and explicitly state "from… and to…"in your answer

Photo 3-5: the direction of ice movement is **toward the south west from the north east.**

Photo 3-8: again, the direction of ice movement is **toward the south west from the north east** (more SSW and NNE in this photo).

Advancing ice is in contact with the steepest end of the drumlin as shown in the cross section below**.**

Direction of ice



2) Plates 3-24 and 3-25

a) Both these photos show variations of the same type of elongated feature. Identify the type of feature and indicate how you recognized it. (2)

Both photos show **Eskers.** Eskers are raised, linear, filled tunnel-like features that are created as sediment fills glacier melt-water channels. As these channels drain, glacial meltwater, laden with sediment, deposits in the tunnel. When the ice melts, an esker is left behind.

[Photo 3-24 shows two examples of a typical single esker surrounded by kettle lakes.]

[Photo 3-25 (Liard area) shows an esker complex, which is a more disorganized type of esker.]

b) These types of features are created by subglacial rivers moving meltwater and sediment under the ice. What causes this type of feature to form differently on these 2 photos? (2)

Both eskers and esker complexes have kettle lakes associated with them.

However, the eskers in Plate 3-24 are simpler, linear, have singular channels, and are topographically pronounced in comparison to the surrounding landscape.

The compound esker feature in Plate 3-25 has more complexity as there are multiple meltwater channels that look like inverted braided channel forms. Often channel gradients are shallower in these types of situations. Such eskers may result when many interlocking meltwater branches flow through or around stagnant ice. Esker complexes are often associated with deglaciation periods. Notice how the compound esker's shape mirrors the Liard River on Plate 3-25

Possible reasons for differences in these types of eskers:

- state of the glacier and climate when the esker was being formed (retreating quickly, or stagnating and disintegrating)
- slope of the land /ice under which these eskers formed (similar to how slope changes are associated with different channel forms in rivers).
- where the esker formed within the glacier (subsurface, surface, englacial (within the glacier, etc.)
- ask your instructor about other answers if you think they are reasonable

See over for Section C: Glacier Mass Balance Answers

SECTION C: GLACIER MASS BALANCE (11 marks)

Table 1: Elevation, area, and annual mass balance data for Sykora Glacier, BC. (Note: m.w.e. ice = meters water equivalent ice; and w.e. = water equivalent)

Elevation Band meters above sea level **(m.a.s.l.)**	**Glacier Area per Elevation Band ($\times 10^6$ m^2)**	**1982-83 Annual Mass Balance** (m.w.e. ice) **per Elevation Band**	**1982-83 Volume w.e. ice per Elevation Band ($\times 10^6$ m^3)**	**1984-85 Annual Mass Balance** (m.w.e. ice) **per Elevation Band**	**1984-85 Volume w.e. ice / Elevation Band ($\times 10^6$ m^3)**	**Percent Cumulative Glacier Area** from top to base **(%)**	**Cumulative Glacier Area** from top to base **($\times 10^6$ m^2)**
2800	0.0	------		-------		0.0	0.0
2700 - 2800	0.5	+2.50	*+1.25*	+1.00	*+0.5*	1.9	0.5
2600 - 2700	1.3	+2.50	*+3.25*	+0.50	*+0.65*	7.0	1.8
2500 - 2600	2.0	+2.50	*+5.00*	+0.23	*+0.46*	14.8	3.8
2400 - 2500	3.2	+1.62	*+5.184*	-0.50	*-1.6*	27.3	7.0
2300 - 2400	3.0	+1.41	*+4.23*	-0.65	*-1.95*	39.1	10.0
2200 - 2300	3.9	+0.78	*+3.042*	-1.20	*-4.68*	54.3	13.9
2100 - 2200	4.5	+0.50	*+2.25*	-1.80	*-8.1*	71.9	18.4
2000 - 2100	2.9	+0.25	*+0.725*	-2.07	*-6.003*	83.2	21.3
1900 - 2000	1.6	-1.06	*-1.696*	-2.67	*-4.272*	89.5	22.9
1800 - 1900	1.2	-1.91	*-2.292*	-3.11	*-3.732*	94.1	24.1
1700 - 1800	0.8	-3.04	*-2.432*	-3.98	*-3.184*	97.3	24.9
1600 - 1700	0.4	-3.45	*-1.38*	-4.79	*-1.916*	98.8	25.3
1500 - 1600	0.2	-3.50	*-0.70*	-4.99	*-0.998*	99.6	25.5
1400 - 1500	0.1	-3.53	*-0.353*	-5.00	*-0.5*	100.0	25.6
Net Mass Balance	------------	------------	*+16.078 → 16.08*	-------------	*-35.325 → -35.33*	-------------	-------------

1) Determine the volume of w.e. ice in m^3 that is lost or gained in each layer on an annual basis for both years. Record this data in the appropriate column. Show an example calculation below, clearly record your work and units. (3) *(answers must include units)*

See the columns (above) for the volume of water equivalent ice in each elevation band.

Example calculation for 1984-85, at the 2600 to 2700 m above sea level band:

Glacier Area x Annual Mass Balance (or change in glacier depth) **= Volume ice equivalent**

$(1.3 \times 10^6 \text{ m}^2) \times (0.5 \text{ m}) = 0.65 \times 10^6 \text{ m}^3$

2) Determine the glacier's net mass balance for each of the two years by summing the volume of water equivalent ice for the entire glacier. Record this value as the Net Mass Balance in the bottom of Table 1. This value represents the volume of water equivalent ice gained or lost by the entire glacier in that year.

   a) Comment on the state of the glacier and the prevailing climate during each of the two years. Your answer must show that you realize that climate consists of both precipitation and temperature and both are affected by season. (4)

The long term combination of precipitation and temperature make climate. Weather must be monitored over an entire year to monitor the growth or decline of a glacier. Determining a net mass balance over a "glacier year" (one summer melt & one winter accumulation season) detects climate impacts on glaciers. The combination of temperature and precipitation at particular times of the year or (seasonality) has the largest impacts on glaciers. High summer temperatures have the greatest effect on the amount of glacier melt, while winter precipitation as long as it is still snow has the largest impact on ice accumulation. Generally, winter temperatures at the elevations and latitudes where glaciers currently exist are still cold enough to produce snow.

In **1982/83 the Net Mass Balance is positive,** a 16.08×10^6 m^3 gain of w.e. ice as there was more accumulation than ablation (i.e. loss). An ice gain is attributable to climatic cooling and/or increased precipitation. Without climate data it is not possible to determine what the actual combination of temperature and precipitation occurred. Summer temperatures could be cooler causing less melt. Winter precipitation could be greater resulting in more accumulation. Or some combination of these two factors could have occurred. Sometimes greater precipitation can compensate for very warm summer temperatures and still result in a positive net mass balance when one wouldn't be expected if only temperatures are considered.

In **1984-85 years, there is a negative Net Mass Balance** of -35.33×10^6 m^3 (more ablation than accumulation) caused by high summer warming and less winter snow gains. Again, more detailed climate analysis is needed to understand the combination of climatic factors involved. However, as glacier melt has accelerated since the 1980's researchers have seen higher summer temperatures play a larger role in glacier losses than lack of winter accumulation.

3) Use the data in TABLE 1 to approximately determine the *equilibrium line altitude* (ELA) for each year. Recall that the ELA is the elevation where inputs equal outputs or the mass balance is zero.

   a) Record the ELA's elevation band for each year. (2)

ELA 1982-83 (positive net mass balance)**: Between 1900 & 2100 m**; but closer to the 2000 – 2100 m band**, by linear interpolation: just above 2000 or ~2031 m**

ELA 1984-85 (negative net mass balance)**: Between 2400 – 2600 m,** but closer to the 2500 – 2600 m band **by linear interpolation: just above 2500 m or ~2519 m**

To determine the precise altitude you must interpolate between the elevations.

   b) Comment on what happens to the ELA in years where the net mass balance is positive verses years where the net mass balance is negative. (2)

The equilibrium line altitude (ELA) occurs at lower elevations in years where the glacier net mass balance is positive. The ELA is at higher elevations when the net mass balance is negative.

Reasons: when positive net balances occur, (e.g. 1982-83) there are more w.e. ice gains than losses on the glacier (could be heavier winter accumulations than summer melting, or as indicated above commonly there is just less summer melting). Whatever the combination of climatic factors, the altitude where the equilibrium occurs (accumulation = ablation) is lower. For negative net balances, glacier losses dominate (usually increased summer losses) and the ELA is higher.

See the interesting extension activity below to help you visualize what is going on. (Other animations are in the Lab 9 Links (Lab website).

Extension Activity (optional but good learning tool):

Glacier Simulation (a glacier process game): https://phet.colorado.edu/en/simulations/glaciers

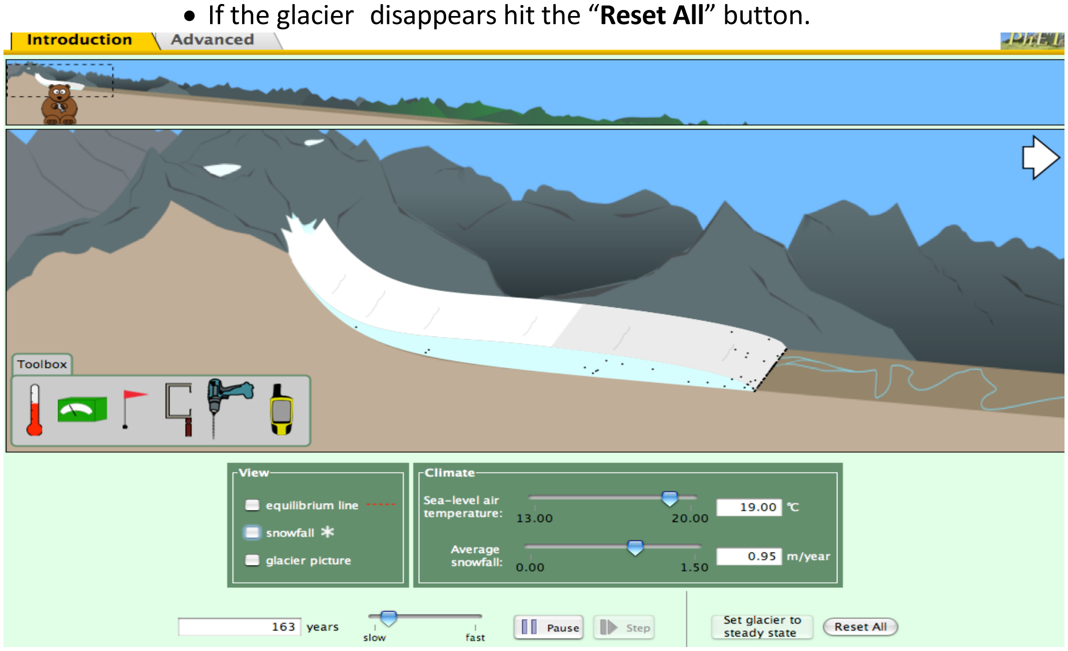
[Or go to https://phet.colorado.edu/new/simulations/ & search for "glaciers". Alternatively using a Google search for "glaciers phet" to find the link. You will have to download the application.]

Activity Objectives:

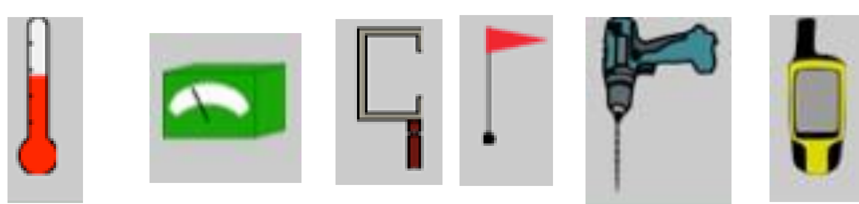
- Determine the factors that affect the motion of glaciers, and calculate the speed of glacier movement.
- Discover what a glacier budget means for the growth and destruction of a glacier, and describe the features it leaves behind.

Procedure:

1. Open the link above and run the "play" arrow button on the image.
2. * Turn off the snowfall effect. Play with simulation for 5 minutes.
   - Grab the bear and change viewpoints,
   - try to make the glacier grow/shrink.
   - If the glacier disappears hit the "**Reset All**" button.



3. In the toolbox are a variety of tools. Discover what each tool does or measures.



4. **Equilibrium line:** When you set the temperature and snowfall; and hit the STEADY STATE button, what happens to the glacier?

Making Predictions:

1. If the average annual snowfall increases (m/yr), what will happen to the glacier?
2. If the temperature changed, describe the two things that could change in the glacier.
3. If the temperature is decreased and the snowfall is increased,
   a. Will the equilibrium line move up the mountain or down the mountain?
   b. Will the changes in #3 cause the glacier to advance or retreat?
   c. What happens to the glacier's thickness and length if the climate changes as #3 describes?

Glacier Speed

Use the toolbox and you will determine the speed of a glacier, and what parts of a glacier move faster than others.

Drilling: Set to the temperature and snowfall to an amount that creates a decent sized glacier. Press the "STEADY STATE" button and Pause the motion of the glacier.

Drill several vertical holes through the glacier. What do you see?

a. What do you see (before the glacier moves again)?
b. Press play and allow the glacier to move, what happens to the drill holes as the glacier is moving?

Thanks to past lab TA Adam Hawkins for sharing this activity.