Answer Key for Lab 8 - Glacial Processes / Climate Change

1-1. A glacier is a mass of flowing ice at the Earth's surface with the ability to erode and transport sediment. The ice builds up as a result of total net annual snow fall. The snow is transformed to ice as it is compacted under it's own weight, partially melted, and recrystallized to form ice. As the ice reaches a critical thickness, it will begin to deform internally under it's own weight, and "squeeze" plastically under the influence of gravity. The ice mass will also have a tendency to slide along it's base, in a downslope direction. The net internal "squeezing" and basal sliding result in "flowing ice". The ice may then pick up sediment by plucking and abrasion of the earth's surface, and transport it downslope.

1-2. alpine (mountain) glacier - glacial ice locally restricted to mountain settings, usually at high elevation, and cold atmospheric temperatures.

continental glacier - a widespread glacier that covers 1000's of sq. miles. It is not restricted to high elevation areas, but is typical of high latitude (cold) regions.

	Alpine	Continental
Scale / Extent	Limited to mountains	Large continental scale
Ice Volume	Small comparatively	Very large, comparatively
Total Volume of Sediment	Small comparatively	Very large, comparatively
Mode of Occurrence	High elevation mtns.	High latitude regions

1-3. A. ground moraine, outwash, terminal moraine
B. terminal moraine, esker, kame
C. pro-glacial lakes, meltwater stream, deranged drainage
D. cirque, arete, col

1-4. Glacial climates (those conducive to glacial ice build-up) need to be cold and wet. The annual cold temperatures should hover around freezing, so that annual snow fall can accumulate and escape seasonal melting. Cold temperatures alone will not result in glacial build-up, abundant precipitation and snow fall is also required. So to get extensive glaciation of the central Cascades, it would require a shift to colder average annual temperatures, but maintaining the current precipitation levels. The Cascades have the precipitation levels, but colder annual temperatures are required for glaciation more extensive than present

Colder annual temperatures would result in a shift to more cold climate vegetation species. One hypothesis would be a vegetative shift to spruce / tundra conditions that are visible to the north in Canada. I would expect the vegetation to start looking like that of northern British Columbia, rather than northern California.

Part 2 - Lab Manual Exercises

1. The cobble shapes in Fig. 12.8 are the result of two different types of abrasion processes. In fluid stream flow, the cobble is tumbled, abraded and rounded during high-energy discharge conditions. The glacial cobble is carried by solid ice. The cobble is carried in ice and abraded by scraping and sliding along, rather than fluid tumbling like with the stream example.

LABORATORY THIRTEEN

Glacial Processes, Landforms, and Indicators of Climate Change

OBJECTIVES

A. Understand processes of mountain (alpine) glaciation and the landforms and water bodies they produce.

B. Understand processes of continental glaciation and the landforms and water bodies they produce.

C. Construct and analyze topographic profiles of glaciated valleys and infer ice thicknesses.

D. Analyze glacial features and calculate rates of glacial retreat (ablation) in Glacier National Park.

E. Evaluate the use of Nisqually Glacier as a global thermometer for measuring climate change.

STUDENT MATERIALS (Remind students to bring items you check below.)

_____ laboratory manual
_____ laboratory notebook
_____ pencil with eraser
_____ metric ruler (cut from GeoTools sheet 1)
_____ calculator (or provided by instructor)
_____ pocket stereoscope (or provided by instructor)

_____:

INSTRUCTOR MATERIALS (Check off items you will need or provide.)

_____: calculator (or obtained by students)
_____:

INSTRUCTOR NOTES AND REFERENCES

1. General information. Refer to Laboratory 13 on the Internet site at http://www.prenhall.com/agi for additional information and links related to all parts of this laboratory.

2. Reading Fine Print. Some printed words and numerals on maps are very small and difficult for some students to read. Plastic sheet magnifiers aid in map reading. They can be purchased in most bookstores for a few dollars (or less each). They also come in large sheet or credit card sizes.

ANSWERS TO QUESTIONS IN LABORATORY 13

Part 13A: Glacial Processes and Landforms

1. Stream cobbles are free to roll and tumble in the bed load of the stream, so they get rounded on all sides. Glacial cobbles are held firmly in ice and do not rotate as freely, so they develop flattened sides and deep groves (similar to the scoured and grooved bedrock surfaces that develop beneath glaciers).

2. The peaks are called **horns**. They are pyramidal peaks formed by headward erosion of several cirques converging on a central point (the tip of the peak).

3. This ridge is called an **arete** (or arête), a steep-sided ridge (knife-edge ridge) formed by headward erosion between two cirques.

4. This is a **hanging valley**, formed when the glacial trough of a tributary glacier did not erode down to the same level as the main valley glacier that it was merging into.

5. This is a **tarn**, a lake that fills the erosional basin of a cirque.

6. **-col:** the low point on a ridge separating any two tarns
-headwall: the uphill erosional surface at the head of any cirque
-valley train: sediments in the valleys of the Dolomite Creek and Siffleur River
-misfit stream: Dolomite Creek is too small to have eroded the valley in which it flows.
-paternoster lakes: the series of small lakes along the valley of Dolomite Creek
-marshes/swamps: formed in many poorly drained parts of the misfit valley

7. They are **medial and median moraines**, which form by transportation and accumulation of continuously supplied rocky materials eroded from the valley walls.

8. They are **transverse crevasses** that formed where the glacial ice descends over a break in slope, as indicated by the topographic contour lines on the ice surface.

9. This suggests that the shapes of the erosional features may become streamlined relative to the flow of the glaciers that formed them. In this case, the mountain ranges that separate valley glaciers became streamlined and narrower in the downglacier flow direction.

10. These hills are **drumlins, which are streamlined hills composed of till**. Their gentle slopes point downglacier (in the direction of ice flow).

11. The drumlins are elongated in a north-northeast to south-southwest direction, and their gentle slopes are generally on their south-southwest ends. This suggests that the ice flowed from north-northeast to south-southeast. A particularly good example is located north of the word "NATIONAL" in the southwest quadrant of the map.

12. Since drumlins form by accumulation of sediment that drops from melting ice without being transported by wind or water, the drumlin sediments are poorly sorted and not stratified.

13. This is an **esker**, which formed by deposition of sediments in a subglacial or interglacial stream. After the ice melted from the margins of what was once the subglacial stream, the sediments remained as long, sinuous hills that stand above the regional landscape.

Part 13B: Glaciation in Wisconsin

14. **-drumlins and ground moraine**—in the northwest quadrant of the map
-terminal or recessional moraine—in the southeast quadrant of the map
-marshes and swamps
-kettle holes (kettle lakes)

15. continental glaciation

16. The ice probably flowed from north to south (or north-northwest to south-southeast) over this region, based on the asymmetrical shapes of the drumlins and the location of the terminal/recessional moraines.

17. Some are **human-made lakes created by dams on rivers** (e.g., Cushman Pond). Some are **kettle lakes** that formed where chunks of glacial ice were isolated in deposits of ground moraine, whereupon they melted to form water-filled depressions (e.g., Rome Pond, Blue Springs Lake).

18. a terminal or recessional moraine with scattered kettle holes

19. This feature could be a **swale**, but students may regard it simply as a poorly drained area between two recessional moraines. It is possible that at some point in the past this marshy area was an ice-margin lake.

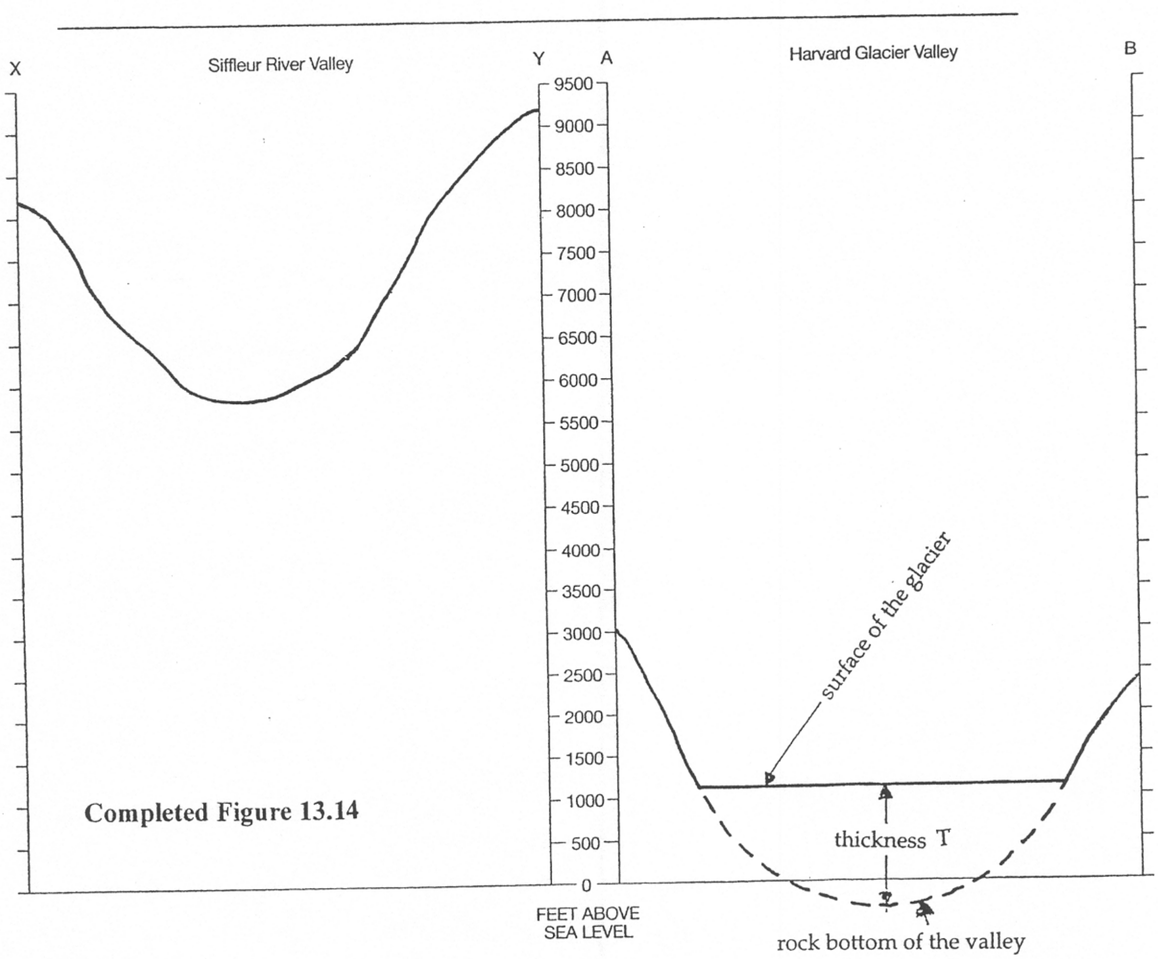
Part 13C: Comparing Topographic Profiles of Glaciated Valleys

20a. The horizontal fractional scale (**H**) of the Siffleur Valley map (Figure 13.9) is 1/48,000. On the topographic profile (Figure 13.14), one inch equals about 2200 feet, so one inch also equals 26,400 inches, and the vertical fractional scale (**V**) is 1/26,400. Using the method in Figure 9.18 for calculating the **vertical exaggeration for this Siffleur Valley profile:**

V/H = 1/26,400 ÷ 1/48,000 = 48,000 ÷ 26,400 = **1.82x**

20b. Refer to the completed profile (completed Figure13.14) below. Although the valley's vertical profile appears nearly twice (1.82x) as tall and steep as it actually is, the valley clearly has a U-shape, which is not normal for a river valley. River valleys typically develop V-shapes because it is the river at the base of the V that is cutting downward.

Completed Figure 13.14



20c. U-shaped valleys are characteristic of glaciated valleys, so the Siffleur River Valley must have been cut by a valley glacier before the present river occupied the valley. The U-shape develops as a valley glacier scours all sides of a valley relatively equally (on both sides and in the floor of the valley).

21a. The horizontal fractional scale (**H**) of the Harvard Glacier map (Figure 13.10) is 1/63,360. On the topographic profile (Figure 13.14), one inch equals about 2200 feet, so one inch also equals 26,400 inches, and the vertical fractional scale (**V**) is 1/26,400. Using the method on lab manual page 153 for calculating the **vertical exaggeration for this Harvard Glacier profile:**

V/H = 1/26,400 ÷ 1/63,360 = 63,360 ÷ 26,400 = **2.40x**

21b. Refer to the completed and labeled topographic profile of Harvard Glacier on the preceding page (page 93).

21c. Refer to the completed and labeled topographic profile of Harvard Glacier on the preceding page (page 93).

22. **1200 – 1500 feet** (thickness T in the topographic profile on page 93)

Part 13D: Glacier National Park, Montana

23. cirques with cirque glaciers
aretes
finger lakes (like Quartz Lake)
U-shaped valleys (glacial troughs)
horns
cols

24.
a. The valley of Quartz lake was filled and scoured by a valley glacier.
b. As the valley glacier retreated (melted), it paused near the location of the Patrol Cabin where a recessional moraine was deposited (the piece of land on which the Patrol Cabin is now located).
c. The valley glacier then retreated up valley, so that only small cirque glaciers remain of it today.
d. Rain and melt water from snow and the cirque glaciers are trapped behind the recessional moraine to form Quartz Lake (a finger lake).

25. mountain glaciation

26a. There are more glaciers and lakes on, and west of, the Continental Divide than east of it.

26b. Moist air rising over the Rocky Mountains here must rise, cool, and condense to form rain and snow. As the air travels east of the Continental Divide it is drier, so there is less precipitation there.

27a. Agassiz: 4.06 km^2 – 1.02 km^2 = 3.04 km^2 so 3.04 km^2/4.06 km^2 × 100 = **74.9%**

27b. Vulture: 0.77 km^2 – 0.21 km^2 = 0.56 km^2 so 0.56 km^2/0.77 km^2 × 100 = **72.7%**

28a. Agassiz: 4.06 km^2 – 1.02 km^2 = 3.04 km^2 in 143 years,
so 3.04 km^2/143 years = **0.021 km^2/year**

28b. Vulture: 0.77 km^2 – 0.21 km^2 = 0.56 km^2 in 143 years,
so 0.56 km^2/143 years = **0.004 km^2/year**

29a. Agassiz: 1.02 km^2 ÷ 0.021 km^2 / year = 48.6 yr + 1993 yr = **2042**

29b. Vulture: 0.21 km^2 ÷ 0.004 km^2 / year = 52.5 yr + 1993 yr = **2046**

Part 13E: Nisqually Glacier—A Global Thermometer?

30. Some students will measure the distances from Nisqually River Bridge to the positions of the glacier's terminus (red dots) in a straight line, but some will measure along the stream. Thus, student values in the Nisqually Glacier Data Chart will vary somewhat from student to student. Be sure that students have recorded data to hundredths of kilometers.

31. Student data varies, so student graphs also vary somewhat in terms of numerical values. However, general trends in the student graphs will be the same, as follows:
   - The glacier generally retreated up the valley from 1850 to 1963.
   - The glacier advanced down the valley from 1963 to 1968.
   - The glacier retreated up the valley from 1968 to 1974.
   - The glacier advanced down the valley from 1974 to 1976.
   - The glacier has retreated up the valley since 1976.

32a. The long-term trend in averaged global land surface temperature, from 1880 to 2001, was warming from about 8° C to 9° C, or 47° F to 48° F.

32b. Students recognize two intervals of cooler-than-average temperatures (1880 to about 1935; 1963 to 1976) and two intervals of warmer-than-average temperatures (1935 to 1963, 1976 to now).

33. From 1880 to about 1963, Nisqually glacier generally retreated up the valley as averaged global land surface temperature increased. The sharp return to cooler-than-average temperatures in 1963 (blue) is marked by a sharp advance of the glacier (with one minor retreat that correlates to a warming in the early 1970s). The sharp return to warmer-than-average temperatures (red) in 1976 is marked by a sharp return to retreat of the glacier.

34. The long-term (century) trend of Nisqually glacier retreat up the valley correlates with the long-term warming trend in averaged global land surface temperature that has occurred since 1880.

Since about 1960, Nisqually glacier also shows a close correlation with the short-term (decades) cycles of cooling climate (glacial advance) and warming climate (glacial retreat).

Since the advances and retreats of Nisqually glacier seem to correlate with changes in averaged global land surface temperatures, Nisqually glacier is like a global thermometer.

Siffleur River, Alberta Map (this are has been glaciated in the past, but the ice has long since melted!)

2. Marmot Mt. and Conical Peak are examples of horns - triangular-shaped mountain peaks that result from glacial valley erosion on three sides.

3. The ridge is an example of an arete, or glacial valley divide. It results from alpine glacial erosion in two adjacent valleys.

4. This is an example of a small glaciated valley.

5. Cirque lake

6. See attached map for examples of features.

Anchorage, AK Quadrangle

7. The brown stripes represent medial moraine. The medial moraine represents glacial sediment that accumulates where two glacial tributaries merge.

8. These are transverse crevasses (or ice cracks) that form perpendicular to the direction of ice flow. These types of ice cracks result from flexure / bending of ice over a valley obstruction, resulting in ice fracture.

Peterborough Quadrangle, Ontario

10. The oblong hills are drumlins, they form by glacial sculpting / bull-dozer effect of till. The tail of the drumlin points in the direction of ice flow.

11. The gentle tail of the drumlins suggest that ice was flowing south-southwest here.

12. I would expect to find unsorted and unstratified till in a drumlin. They represent piles of sediment that were sculpted beneath glacial ice. The bull-dozer effect of the ice would not promote sorting, washing or stratification of the sediment.

13. The long sinuous ridge south the highway is likely an esker. An esker forms by deposition from subglacial meltwater rivers, beneath the ice.

14. Depending on what part of the glacier you mined the ice... ice near the base of the glacier contains abundant sediment. Ice near the top of a 2.5 mile thick glacier would be free of sediment, since it is not in contact with the earth's surface rocks. Otherwise, glacial ice is generally very clean water, since it is freshly distilled by evaporation of ocean water.

Whitewater, WI quadrangle

15. See attached map (drumlins, kettle lakes, marshes, poorly drained areas, ground moraine)

16. This is classic continental glaciation

17. The shape of the drumlins in the northwest corner of the map suggest that the ice flowed south-

southeast.

18. These are kettle lakes. They form by meting of isolated blocks of ice that were left behind as the glacier retreated.

19. The forested area represents hills made of ground moraine.

20. My hypothesis is that the marshy area represents the outline of the glacier margin as the ice was retreating. Around the ice front, lakes commonly form as the ice melts. The abundant meltwater and sediment in the lake would result in an arcuate, or curved area that outlines the glacial margin.

The following refers to the Mt. Rainier Quadrangle.

21. Alpine glaciers

22. Continental glaciation

23. Glacial valleys, cirques, arretes, cirque lakes

24. medial moraine, lateral moraine, terminal moraine

25. Evidence of glacial features extends well beyond the limit of the modern glacial extent. This suggests that the alpine glaciers were much greater in the past, presumably under a different climate regime compared to present.

26-28. See attached map. Vertical Exaggeration for the Siffleur map is x2, V.E. for Harvard map is x2.64

29. See attached Mt. Rainier Map and graph on Fig. 12.16.

By comparing pt. X on the 1924 and 1984 maps of Mt. Rainier, the Nisqually Glaicer has retreated 1.25 km up the valley between 1924 and 1984 (60 yrs of melting / retreat). Don't forget to plot your points on the graph in Fig. 12.16.

30. By comparing the curves in Fig. 12.16, the average global temperature increased from about -0.3 degrees C in 1924 to about +0.2 degrees C in 1984. It appears that the Earth has been warming on average. By comparison, the Nisqually glacier has melted and retreated ~1.25 km from 1924 to 1984. It seems that global warming is being reflected in the ice mass balance of Nisqually glacier.

31. The volume of ice in valley glaciers and the position of their ice fronts should reflect climate. An increase in ice volume and glacial advance is associated with cooling climate, while a decrease in ice volume and glacial retreat is associated with warming climate.

32. Rate of ablation for Nisqually Glacier, given 1.25 km of retreat between 1924 and 1984.

Ablation Rate = ((1.25 km)(1000 m/km)) / 6 decades = **208 m / decade**

Ablation Rate = ((1.25 km)(1000 m/km)(1000 mm/m)) / 60 yr = **2.08 x 10^4 mm /yr**

3-1. Yes I see active glaciers on this map, many of them are in T.17S., R.8E.

3-2. Glacial elevations

Prouty	8100-10,000 ft
Carver	7500-7000 ft
Lost	7000-9200 ft
Diller	7900-9000 ft
Collier	7500-9000 ft

3-3 Yes, the minimum elevation for glacier occurrence (as of the 1929 map) is 7000 - 7500 ft above sea level. I don't see any glaciers at elevations lower than this critical range.

3-4. The meteorological explanation is:

1) the Cascades receive abundant snow and precipitation (from Pacific Ocean weather systems)
2) the higher the elevation of land surface above sea level, the cooler the air temperature

3) it seems that the 7000-7500 ft elevation is the minimum necessary to keep average annual temperatures low enough to support year-round snow accumulation, freezing, and ice formation.

3-5. The elevation of Mt. Washington (at it's highest point) is 7802 ft above sea level. Given that the minimum elevation for glacial occurrence is ~7500 ft, it seems that Mt. Washington is not high enough to support the low average annual temperatures necessary for glacial ice formation (at least under the climate conditions up to 1929).

3-6. The glacier is flowing to the East.

3-7. Snout cracks = transverse crevasses (they are transverse (i.e. perpendicular) to flow).

3-8. The bowl-shaped depression = cirque, the small glacier = cirque glacier. The cirque forms from headward erosion by ice at the head of a glacial valley.

3-9. The waterfall is spilling over a hanging valley.

3-10. Hangining valleys suggest that the ice of the main tributary was much thicker in the past.

3-11. The sediment is being deposited by sub-glacial meltwater streams flowing out of the glacier snout. The sediment is derived from the glacial ice via rock erosion. The fan of sediment is being deposited into a proglacial lake. A sediment deposit in a standing body of water is referred to as a delta.

3-12. The hummocky topography is composed of ground moraine, or chaotic deposits of till (an unsorted form of glacial drift). These deposits are likely unsorted, as they were dumped directly from glacial ice.

3-13. These are kettle lakes. They form from melting of blocks of ice that were buried by glacial sediment.

3-14. No this hummocky topography is not being used for crop production. I don't see any well-defined fields or crops in the air photo. This land is too hummocky / chaotic for farm production. The soils are likely very stony as well.

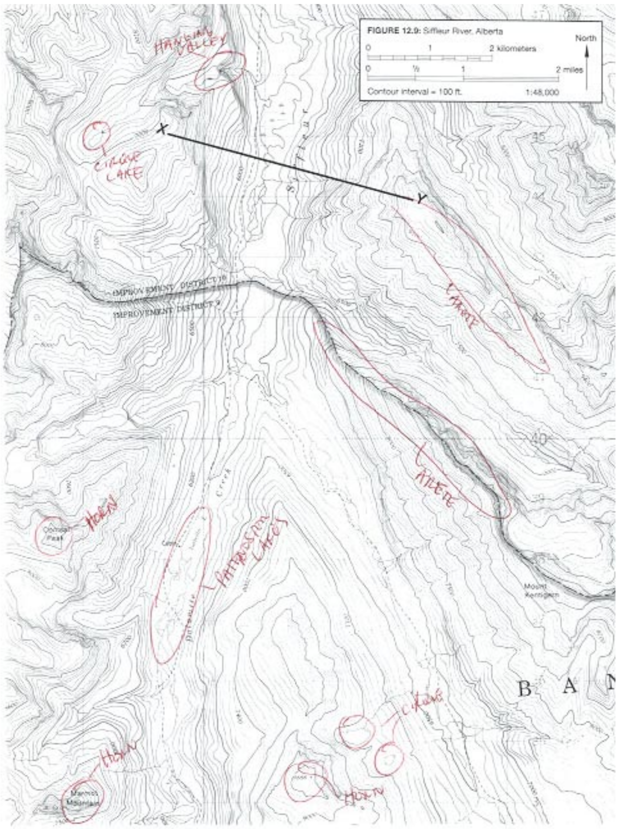


FIGURE 12.9: Siffleur River, Alberta

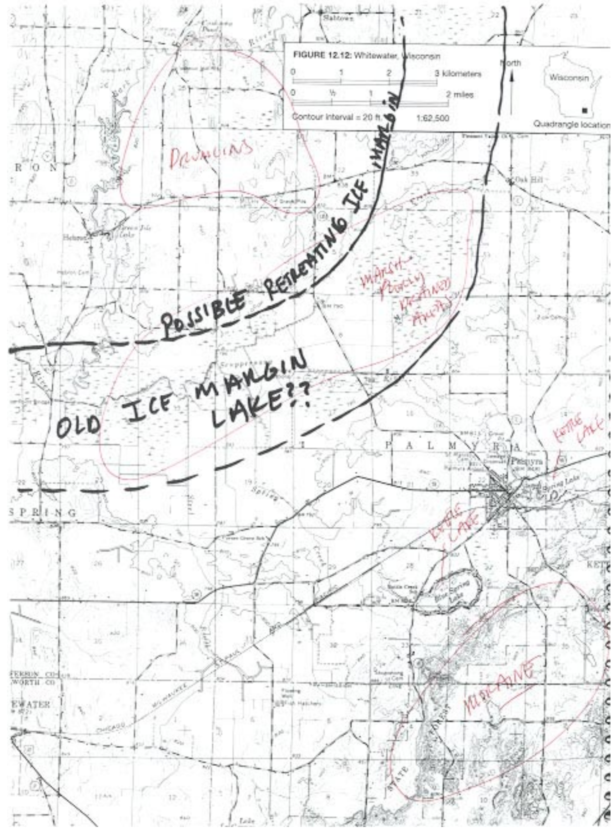


FIGURE 12.12: Whitewater, Wisconsin

PART 3: COMPARING TOPOGRAPHIC PROFILES OF GLACIATED VALLEYS

Questions

26. Complete the topographic profile on the left-hand side of Figure 12.15 for line **X–Y**, *across the Siffleur River Valley.* Refer to Figure 8.16 on page 153 (Topographic Profile Construction), if needed.

    a. What is the vertical exaggeration of this topographic profile?

    b. Is this a normal profile for a river valley? Why?

    c. Why does the Siffleur River Valley have this shape?

27. On the right-hand side of Figure 12.15, complete the topographic profile for line **A–B** *across the Harvard Glacier.* Refer to Figure 8.16 (Topographic Profile Construction), if needed.

    a. What is the vertical exaggeration of this topographic profile?

    b. Label the part of the profile that is the top surface of the glacier.

    c. Draw in a dashed line where you think the rock bottom of the valley is located under the Harvard Glacier.

28. Based on your work in Questions 26 and 27, what is the maximum thickness of Harvard Glacier at line **A–B**? Explain your reasoning.

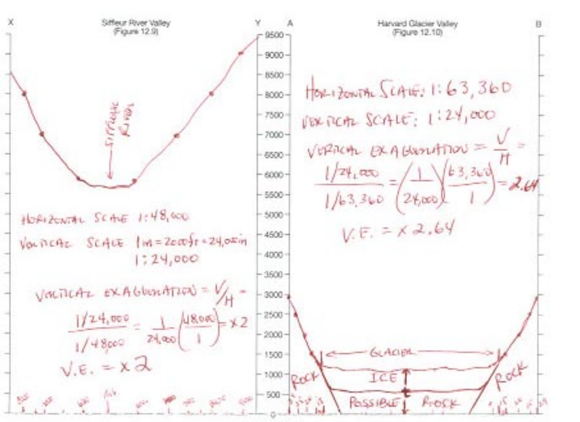


FIGURE 12.15 Graphs for completing topographic profiles of glaciated valleys.

t = maximum ICE THICKNESS = 1200ft POSSIBLE

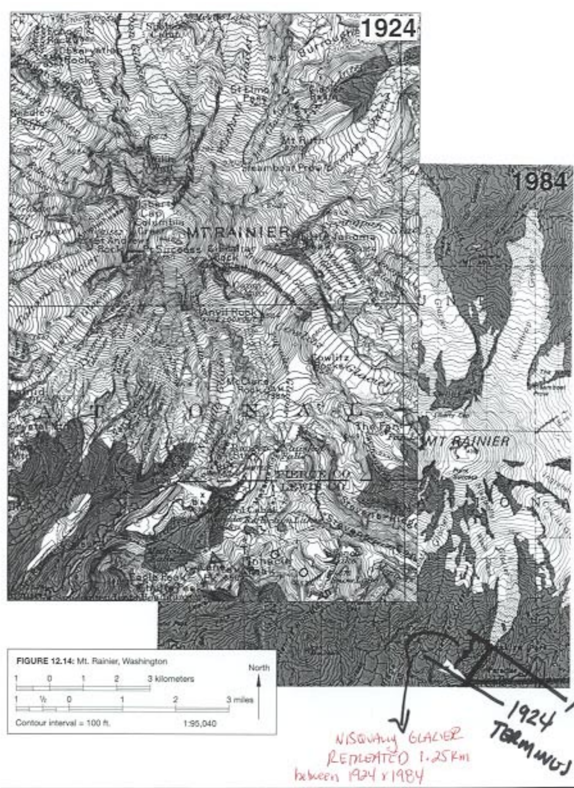


FIGURE 12.14: Mt. Rainier, Washington

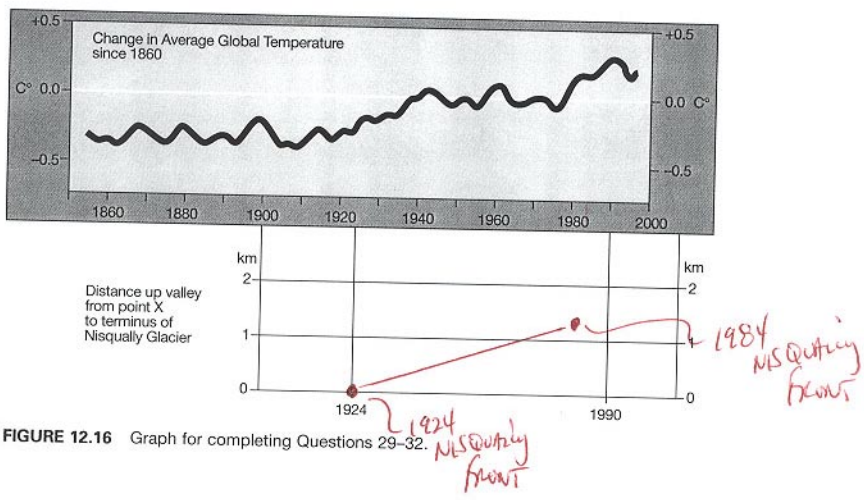


FIGURE 12.16 Graph for completing Questions 29–32.