

KEY

ES202 Lab 8 - Glacial Processes and Climate Change

Updated Feb. 2012 - AGI Lab Manual 10th Ed.

PART 1 - LAB MANUAL REVIEW QUESTIONS

Use your lab manual to answer the following questions / define the following terms.

1-1. Review Fig. 13.1 on p. 331 and read the text below. Define the following terms.

Glacier - **MASS OF FLOWING/MOVING ICE**

Zone of Accumulation - **POSITION ON GLACIER ABOVE SNOW LINE; ICE ACCUMULATION**

Zone of Ablation - **" " " BELOW SNOW LINE; ICE MELT**

"Drift" - **ALL GLACIAL SEDIMENT + DEPOSITS**

Ice Shelf - **GLACIAL ICE / FLOATING AT COAST**

Sea Ice - **MELTED OCEANIC WATER**

Ice Sheet - **CONTINENTAL GLACIER; LARGE MASS**

Mountain Glaciers - **ALPINE / MOUNTAIN ALTITUDE VALLEY GLACIER**

True or False: Antarctica and Greenland are covered by ice sheets.

True or False: Oregon is associated with extensive permafrost conditions.

1-2. Review Fig. 13.4-13.5 on p. 334-335; Define the following terms / answer the following questions:

Hanging Valley - **GLACIAL TRIBUTARY; ABOVE VALLEY FLOOR**

Horn - **TRIANGULAR-SHAPED PEAK, HEAD OF 3 CIRCLES**

Arete - **SHARP RIDGE SEPARATING GLACIAL VALLEYS**

Cirque - **BOWL-SHAPED DEPRESSION AT HEAD OF GLACIAL VALLEY**

True or False: mountain glaciation results in eroding flat-bottomed U-shaped troughs or valleys.

True or False: a tarn is also known as a cirque lake

1-3. Review Fig. 13.6-13.7 on p. 336-337. List, sketch and briefly define the following:

A) Three types of depositional features associated with alpine glaciers. -

**LATERAL MORAINES, TERMINAL MORAINES,
PROGLACIAL Deltas, OUTWASH**

B) Three types of depositional features associated with continental glaciers.

- ESKER RECISSION MORAINES
- KAME CROWN MORAINES
- END MORAINES OUTWASH

C) Three types of water bodies associated with continental glaciers.

- KETTLE LAKE OUMASH PLAIN/
- PROGLACIAL LAKE BRATION RIVER

1-2. Review Fig. 13.8-13.9 on p. 338 and read the text below. Draw a sketch and define the following terms.



Terminal Moraine

RIDGE OF TIL DEPOSITED BY MELT OUT AT TERMINUS OF GLACIER

Kettle

- LAKE / DEPRESSION LEFT BEHIND BY MELTING BLOCK OF ICE

Esker

- SINUOUS RIDGE OF SEDIMENT DEPOSITED BY SUBGLACIAL MOUNTAIN RIVER

Drumlin

- TEAL DROPSHAPED MOUND SCULPTED BY CONVENTIONAL GLACIER

True or False: continental ice sheets cover much larger areas than mountain glaciers.

True or False: continental glaciation results in disrupted drainage patterns, poorly drained areas and numerous lakes.

1-3. Compare the map on Figure 13.12 p. 341 to the continental ice block diagrams on p. 338 (Figure 13.8-13.9). Identify the glacial landforms shown on the map on Fig. 13.12, which type of glacial feature are they? Explain your answer.

1-4 Compare the map on Fig. 13.13 p. 342 to the continental ice block diagrams on p. 338 (Figure 13.8-13.9). Identify the glacial lake features shown on the map on Fig. 13.13, which type of glacial feature are they? Explain your answer.

1-5. Compare the map on Fig. 13.14 p. 343 to the mountain glacier block diagrams on Fig. 13.4, p. 334. Identify the glacial landforms for the following features:

Cerulean Lake (center-south of map)

Porcupine Ridge (east-center of map)

Boulder Peak (north-center of map)

PART 2. IN- LAB MATERIALS

Station 8-1.

- A. Compare the two cobbles labeled "A" and "B" on the counter. One deposit is associated with river processes, the other is associated with glaciations. Compare each sample to the description of "glacial striations" listed under erosional glacier features on Fig. 13.5, p. 335. Which cobble was likely transported by river water and which by ice. Describe your observations and reasons for your hypotheses.

A - ROUNDED RIVER COBBLE
B - STRIATED SUB-ANGULAR GLACIAL COBBLE

- B. Sample C - examine the melting glacial ice model, fresh from the freezer.

Is this a sample best termed "bedrock" or "regolith"? REGOLITH
Will the resulting deposit be well sorted or poorly sorted? POORLY SORTED
What is the range of grain size of the melt-out sediment from sample? CLAY-SAND-GRAVEL

Review the descriptions of depositional features on Fig. 13.4 (p. 297) of lab manual. Find the description for the deposit C that best fits your observations. Provide the name and explanation for it's origin here...

"DRIFT" MELTS-OUT TILL

Will the resulting deposit from the model be best termed "outwash" or "till" (see p. 331)

Station 8-2. Examine the Three Sisters, Oregon topographic map in the lab and answer the following questions.

- A. Do you see active glaciers on this quadrangle? If yes, where (list locations by Township and Range; note a review of the Township and Range Public Land Survey System in on p. 240 of the lab manual).

- YES
B. List the elevation range of the following features:

Prouty Glacier 8000-9500 ft

Carver Glacier 7500-8000 ft

Lost Glacier 7500-9000 ft

Diller Glacier 8000-9000 ft

Collier Glacier 7500-9000 ft

GLACIAL LOCATION

BETWEEN T.16S. AND
T.17S.
R.8E.

- C. Is there a relationship between glacier occurrence and elevation? What is the minimum elevation that you observe active glaciers?

YES, GLACIERS OCCUR ABOVE

7500 FT ELEVATION; ON AVERAGE
GREATER THAN 8000 FT

- 3-4. What is the meteorological explanation for your observations in 3-3 above? Why does that relationship exist?

HIGHER ELEVATION IN MOUNTAINS =
- HIGHER SNOW PACK COLDER CLIMATES AROUND
- > GLACIAL ICE

3-5. Why are there no glaciers on Mt. Washington? Do you see evidence for past glaciation? If so list. *Yes, steep, rugged, and -*
ELEVATION BELOW MODERN GLACIAL LIMIT. AVERAGE SUMMER
TEMP. TOO HOT TO SUPPORT MODERN GLACIATION
TEMP TOO LOW ON ELEVATION

Station 8-3 Plastic Block Models

Examine plastic "Block Model #6". Using your lab manual, p. 334 and p. 338, answer the following questions:

- A. Does this model represent an alpine or continental glaciated landscape?
- B. What is the name of feature "A", describe the process of how it forms during glaciation? *CIRQUE GLACIAL EROSION*
- C. What is the name of feature "B", describe the process of how it forms during glaciation? *ARETE*
- D. What is the name of feature "C", describe the process of how it forms during glaciation? *HORN*
- E. What is the name of feature "D", describe the process of how it forms during glaciation? *U-SHAPE VALLEY*

Examine plastic "Block Model #1". Answer the following questions:

- F. Describe the cross-sectional shape of the valley labeled "A", how does it compare to valley "D" in "Block Model #6". *V-Shape, Stream Valley; IN GLACIATION*
- G. Using the contour lines and law of "V's", which direction is the stream flowing in Valley "A" in block model #1. *Flow to Southeast*
- H. Compare the relief (landscape elevation change from lowest to highest points) between block models #6 and #1. Are they the same, different? Which one is greater or lesser in overall relief?
- I. Has the landscape in "Block Model #1" been glaciated? Why or why not, list your observations that support your answer.

Model 6 = High Relief; GLACIAL EROSION
Model 1 = Low Relief; FLUVIAL LANDSCAPE

Photo Station 8-4 (Crystal Set 1 Photos 6L/6R).

- A. If north is to the top of the photo, which direction is this glacier flowing? *EAST*
- B. What are the names of the linear cracks present near the snout of the glacier? Are the transverse or longitudinal with respect to glacial flow? *CREVASSES TRANSVERSE*
- C. Note the small glacier in the lower left of the photo. What is the name of the bowl-shaped depression that it is occupying? How does it form?
- CIRQUE GLACIAL
- HEADWALL / Ice Accumulation

Based on the discussion of process on Fig. 13.6, p. 336, is this a depositional or erosional feature?

ICE REMAIN - MELT OUT ALL - MORANE
Provide a discussion of how it forms. Is it associated with alpine or continental glaciations?
CONTINENTAL GLACIAL

Station 8-7 Glacial Model 2

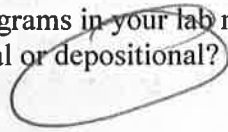
- A. The deposit located on the plastic tub was melted out of ice left in the freezer for a week. Describe the sorting and texture of this "melt-out" glacial deposit.

"TILL"

What is the general name for this type of material that is deposited by a glacier?

POREY SORTED GLACIAL DEPOSIT

- B. Using the block diagrams in your lab manual, identify the landform located at point A. How did it form? Is it erosional or depositional?



KETTLE LAKE; DEPOSITIONAL

- C. Using your lab manual, explain the nature of the drainage pattern located in the vicinity of point B. Why is this type of drainage indicative of glacial landscapes?

DERANGED DRAINAGE

POOR DRAINAGE INTEGRATION

- D. Identify the group of hilly landforms in the vicinity of point C. Are they erosional or depositional? How do they form? Based on their topographic configuration, determine the paleo-ice flow direction in this landscape (i.e. which direction was the continental glacier moving over the landscape).

DRUMMINS ↓↓↓ ICE FLOW SOUTH

Part 3 - Lab Manual Exercises.

The primary objective of this lab is to compare glacial features represented on topographic maps and air photo features to those represented on block diagrams and charts (Figures 13.1-13.9 in lab manual). Examine these figures and charts before answering the lab manual questions.

Complete Activity 13.2 p. 349-350.

Complete Activity 13.3 p. 351

Complete Activity 13.4 p. 352

- D. Note the waterfall emanating from the small glacier. What is the name of this type of tributary glacial valley?

Hanging Valley

- E. Does your observation suggest that the main valley ice was much thicker in the past? Cite your reasoning.

YES - SCORREN; Deep U-SHAPED VALLEY

- F. Note the fan-shaped deposit of sediment along the main glacier front. Where is this sediment coming from? What is this fan being deposited into? What is the name of this type of deposit (remember back to river systems)?

DELTA / LAKE-PROGLACIAL

Photo Station 8-5 (Crystal Set 1 Photos 8L/8R).

This photo set is from northern New England. The area was extensively glaciated by the Laurentide Ice Sheet, ~20,000 years ago.

- A. Note the "hummocky" topography in the northern 1/2 of the photo. Given the glacial history of the area, what are these deposits composed of? What is the name of this type of glacial deposit? Comment on the likely nature of sorting in these types of deposits.

EXTENSIVE PILES OF GLACIAL TILL
GROUND MORAINES, CONTINENTAL GLACIAL

- B. Note the numerous lakes inset into the glacial deposits. What are the names of these types of glacial lakes? How do they form?

- Kettle Lakes
- Buried Block of Ice / Melted Kettle

- C. Does it look like this land is being used for agricultural crop production? Explain why you think this is so.

NO; WOODLANDS - DRAINAGE DRAINAGE + HUMMOCKY TOP = NOT GOOD FOR AGRICULTURE

Station 8-6 Glacial Model 1

- A. Using the block diagrams of glacial landforms in your lab manual, was this portion of upstate New York subject to valley glaciation, continental glaciation or NO glaciation?

DRUMLIN FIELD

- B. Depending on your answer in A above, identify the landforms represented by the small hills in the vicinity of point D. How are these landforms created (hint: use your lab manual). Are they erosional or depositional landforms?

STREAMLINED GLACIAL DEPOSIT

- C. Examine plastic "Block Model #2" labeled with the call-out arrows next to the upstate New York map. Compare to Figure 13.9 on p. 338, identify the landform.

RECESSIONARY MORAINES

ICE RAN

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 its own weight, partially melted, and recrystallized to form ice. As the ice reaches a critical thickness, it will begin to deform internally under its own weight, and "squeeze" plastically under the influence of gravity. The ice mass will also have a tendency to slide along its 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.

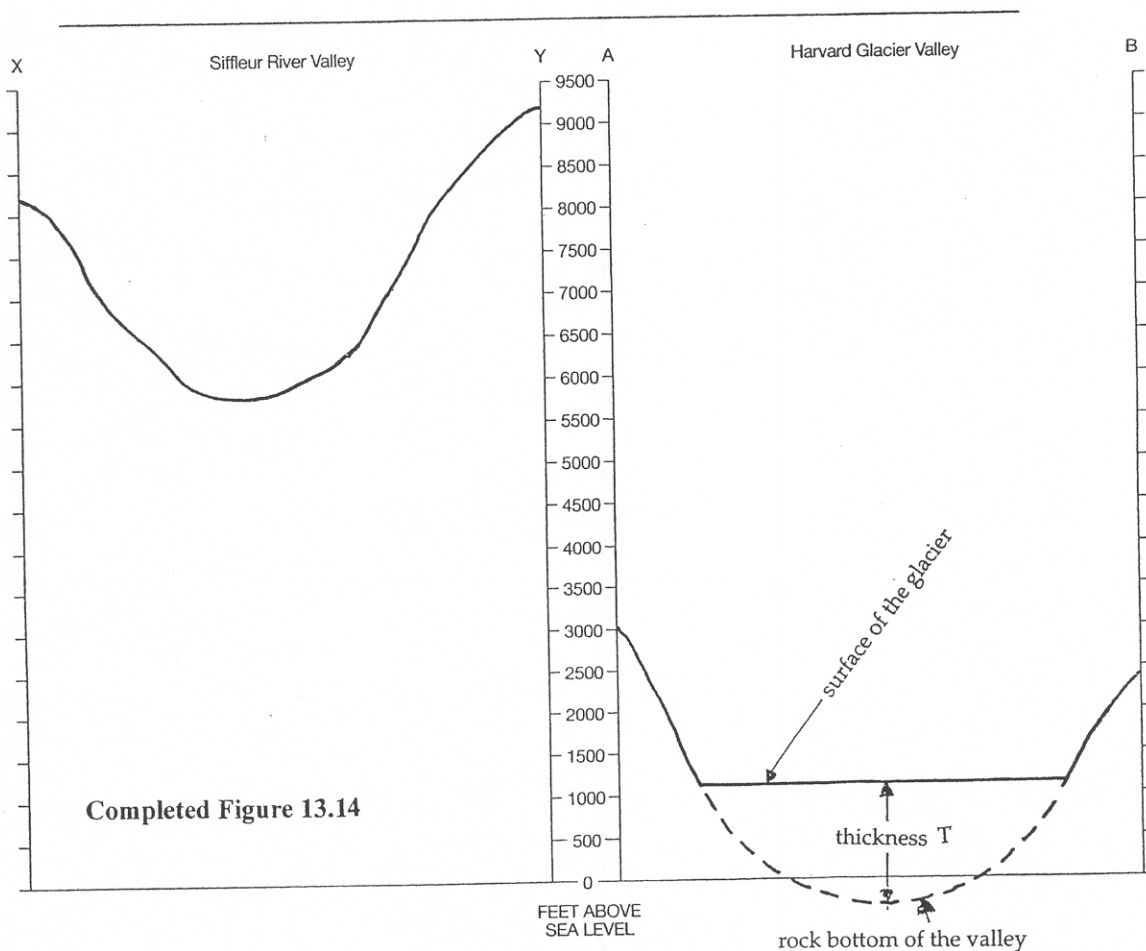
Part 13C: Comparing Topographic Profiles of Glaciated Valleys

- 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:

$$V/H = 1/26,400 \div 1/48,000 = 48,000 \div 26,400 = 1.82x$$

- 20b.** Refer to the completed profile (completed Figure 13.14) 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:**
- $$V/H = 1/26,400 \div 1/63,360 = 63,360 \div 26,400 = 2.40x$$
- 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: $4.06 \text{ km}^2 - 1.02 \text{ km}^2 = 3.04 \text{ km}^2$ so $3.04 \text{ km}^2 / 4.06 \text{ km}^2 \times 100 = 74.9\%$
- 27b. Vulture: $0.77 \text{ km}^2 - 0.21 \text{ km}^2 = 0.56 \text{ km}^2$ so $0.56 \text{ km}^2 / 0.77 \text{ km}^2 \times 100 = 72.7\%$
- 28a. Agassiz: $4.06 \text{ km}^2 - 1.02 \text{ km}^2 = 3.04 \text{ km}^2$ in 143 years,
so $3.04 \text{ km}^2 / 143 \text{ years} = 0.021 \text{ km}^2/\text{year}$
- 28b. Vulture: $0.77 \text{ km}^2 - 0.21 \text{ km}^2 = 0.56 \text{ km}^2$ in 143 years,
so $0.56 \text{ km}^2 / 143 \text{ years} = 0.004 \text{ km}^2/\text{year}$
- 29a. Agassiz: $1.02 \text{ km}^2 \div 0.021 \text{ km}^2 / \text{year} = 48.6 \text{ yr} + 1993 \text{ yr} = 2042$
- 29b. Vulture: $0.21 \text{ km}^2 \div 0.004 \text{ km}^2 / \text{year} = 52.5 \text{ yr} + 1993 \text{ yr} = 2046$

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 area 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 melting 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, arêtes, 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 Glacier 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.

$$\text{Ablation Rate} = ((1.25 \text{ km})(1000 \text{ m/km})) / 6 \text{ decades} = \mathbf{208 \text{ m / decade}}$$

$$\text{Ablation Rate} = ((1.25 \text{ km})(1000 \text{ m/km})(1000 \text{ mm/m})) / 60 \text{ yr} = \mathbf{2.08 \times 10^4 \text{ mm /yr}}$$

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.

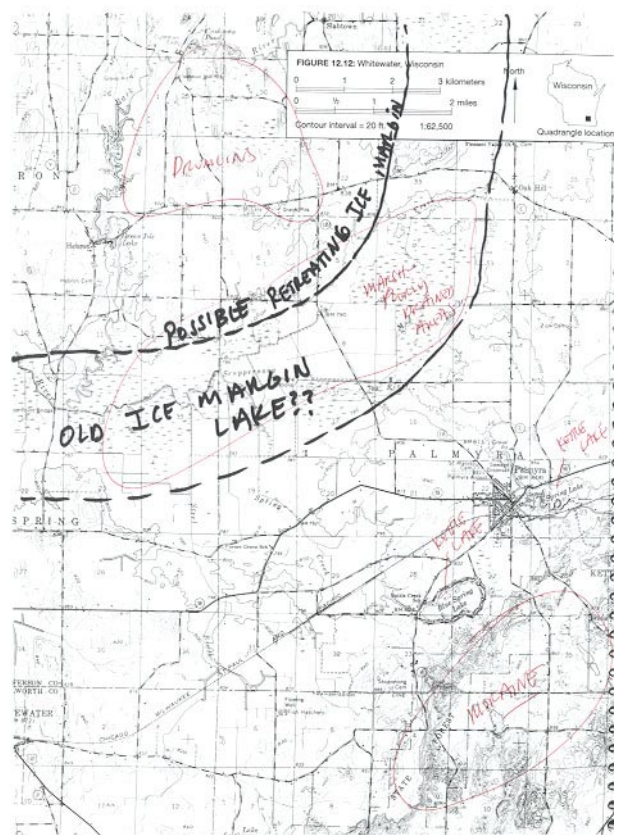
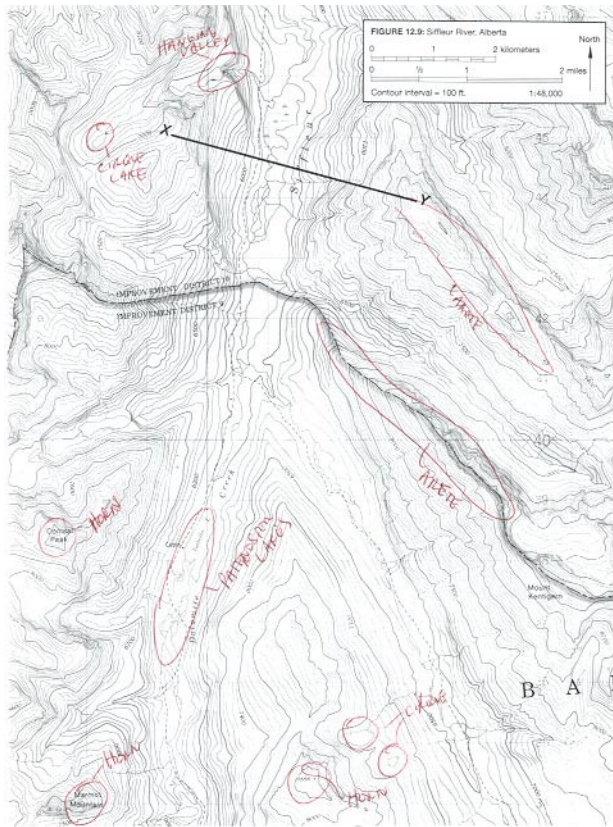
3-10. Hangining valleys suggest that the ice of the main tributary was much thicker in the past.

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.



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.
- What is the vertical exaggeration of this topographic profile?
 - Is this a normal profile for a river valley? Why?
 - 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.

- What is the vertical exaggeration of this topographic profile?
 - Label the part of the profile that is the top surface of the glacier.
 - 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.

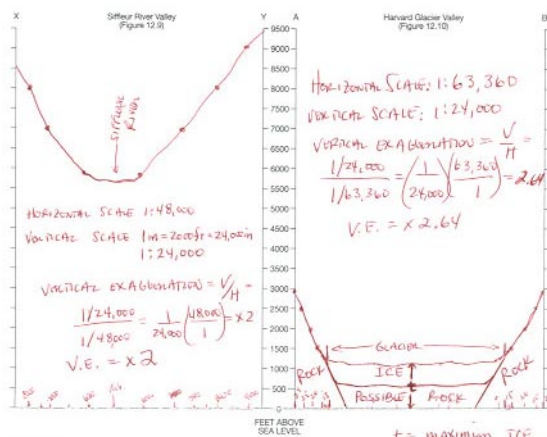
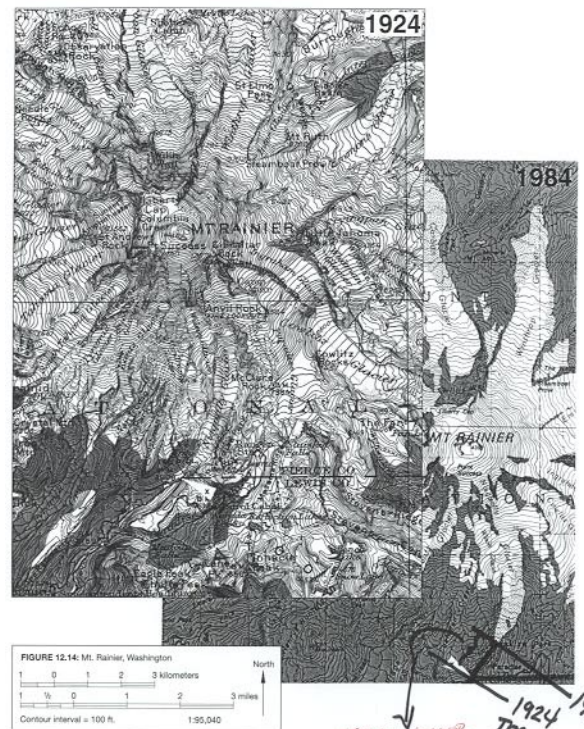


FIGURE 12.15 Graphs for completing topographic profiles of glaciated valleys.



1924
 1984
 VISUALLY GLACIER
 REPLEATED 1.25 km
 between 1924 & 1984

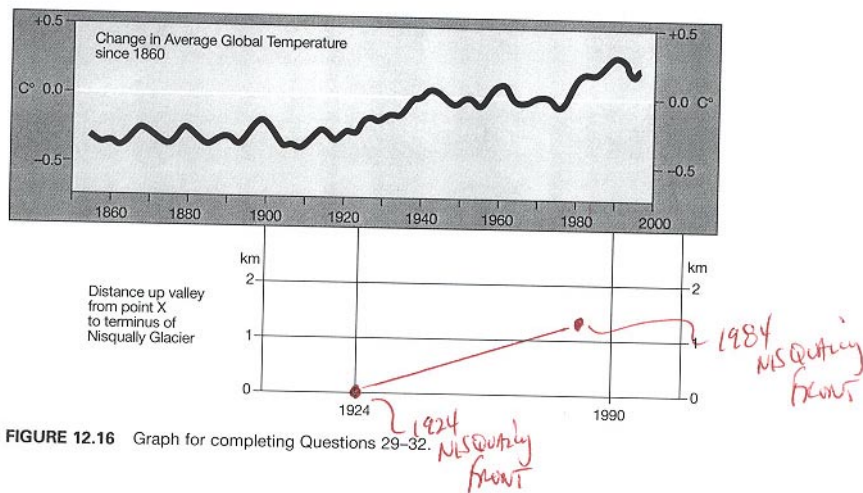


FIGURE 12.16 Graph for completing Questions 29–32.