Glaciers and Glaciation
Lab 13
Integrated Earth Science: 3310

DR. GREGG WILKERSON

SOLUTIONS ARE IN RED

American Geosciences Institute ▪ National Association of Geoscience Teachers

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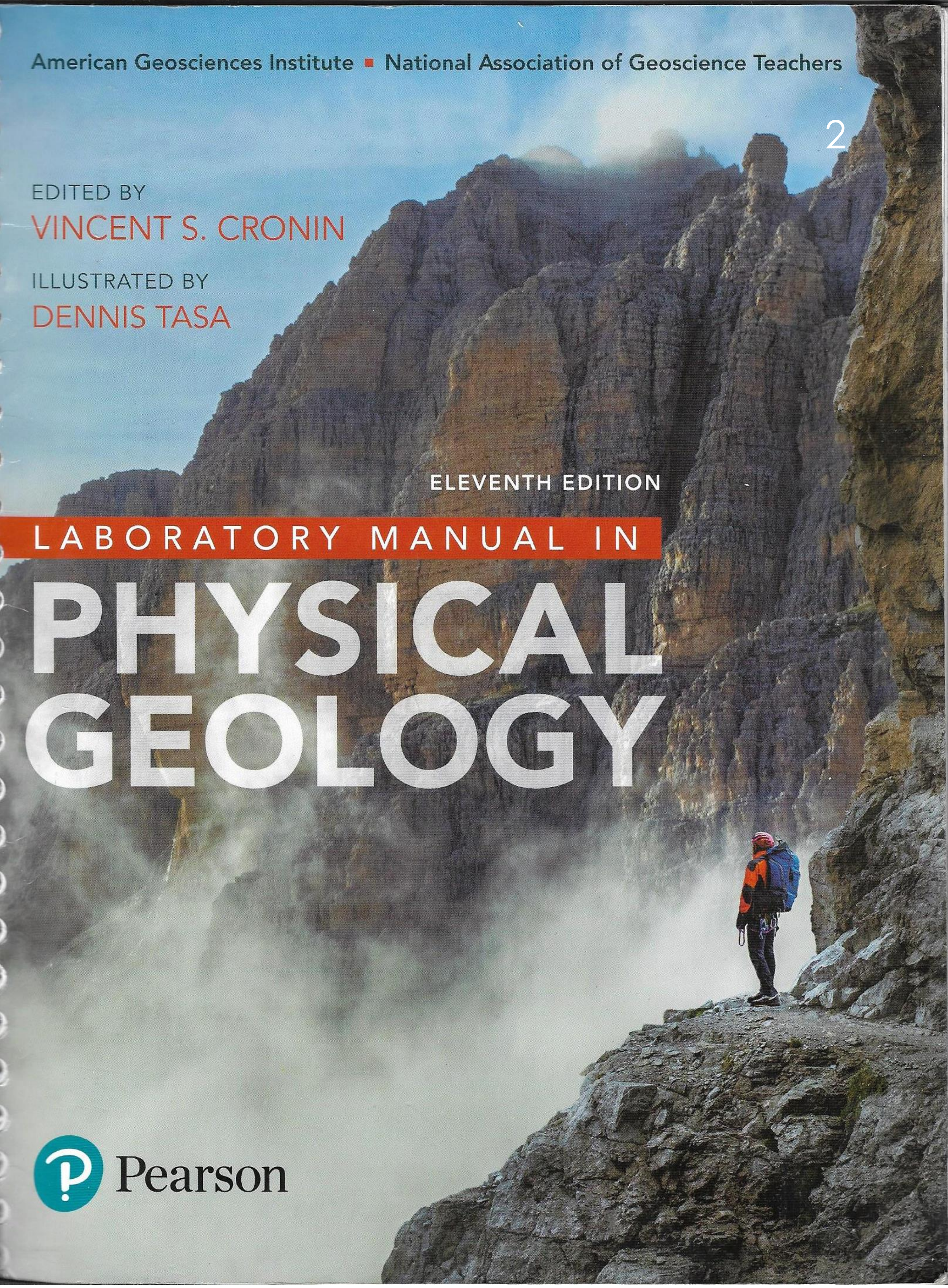
ELEVENTH EDITION

LABORATORY MANUAL IN PHYSICAL GEOLOGY



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LABORATORY 13

Pre-Lab Video 13

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Glaciers and the Dynamic Cryosphere

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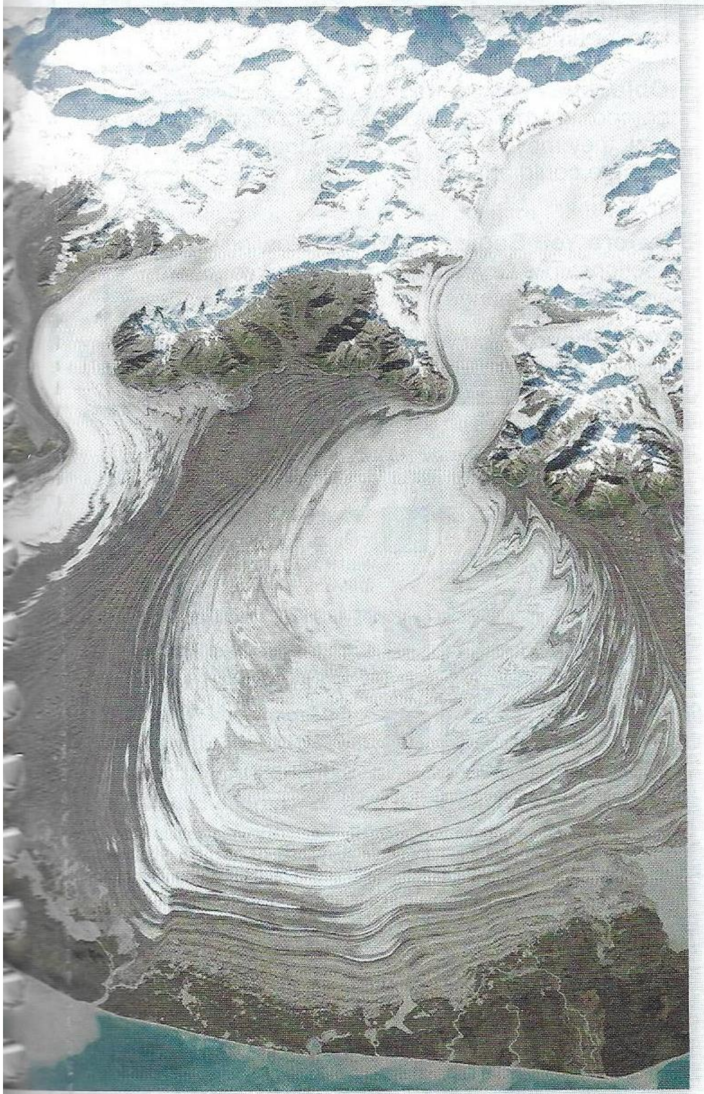

▲ Agassiz Glacier (left) and Malaspina Glacier (right) in Alaska are the largest of several glaciers in this NASA Landsat 8 image. Both begin as valley glaciers near the top of the image but then leave the mountains to flow across a flat coastal plain, becoming piedmont glaciers in which the ice forms a wild assortment of folds. The image center is near 60.05°N, 140.70°W.

BIG IDEAS

The cryosphere—made up of ice, snow, and frozen ground—is the part of the solid-Earth system that is at or below 0°C. It is both an important source of historical information about environmental change over the past ~800,000 years and a sensitive indicator of recent climate change resulting from human activities. Sea level varies by hundreds of meters between times when Earth is heavily glaciated compared with times when there is little or no persistent ice on the surface. During the past century, mountain glaciers in the Cascades, Sierra Nevada, Rocky Mountains, and elsewhere have receded measurably. An important effect of increased melting of continental glaciers, ice caps, and ice sheets is an increase in sea level that will endanger low-lying coastal communities worldwide.

FOCUS YOUR INQUIRY

Think About It What is the cryosphere, and how does the extent of sea ice vary over time?

ACTIVITY 13.1 The Cryosphere and Sea Ice (p. 348, 367)

Think About It How do mountain glaciers affect landscapes?

ACTIVITY 13.2 Mountain Glaciers and Glacial Landforms (p. 351, 369)

Think About It How might glaciers be affected by climate change?

ACTIVITY 13.3 Nisqually Glacier Response to Climate Change (p. 361, 371)

ACTIVITY 13.4 Glacier National Park Investigation (p. 361, 373)

Think About It How do continental glaciers affect landscapes?

ACTIVITY 13.5 Some Effects of Continental Glaciation (p. 363, 374)

Introduction

On February 14, 1990, the camera on the Voyager 1 spacecraft was directed back toward Earth, 6 billion km away, for one last photograph before the imaging system was shut down to save power. The resulting image has 640,000 pixels of which Earth occupied less than 1. Reflected light modified by water vapor, liquid water, and ice in the Earth environment provides the ultimate image of our world as the water planet—a pale blue dot in the vastness of space.

Our global environment is dominated by water, and as water transitions among its three phases (solid, liquid, gas), it is a sensitive indicator of temperature. The **cryosphere** is the part of Earth's interconnected systems that involves frozen water as well as rock that is persistently below the freezing point of water (**Fig. 13.1**). We monitor variations in the cryosphere with the same interest that a physician monitors a patient so that we can use our improved knowledge of environmental change to help society make good decisions about living sustainably within a global climate system.

It has become essential for us to understand better how Earth's climate has changed over time and how human activities affect climate. The cryosphere not only is affected by a changing climate but also provides us with a detailed historical record of climate change during most of the past million years through the study of ice cores. Ice near the bottom of a deep core collected from Dome C in Antarctica (75.01°S, 123.35°E) by the *European Project for Ice Coring in Antarctica* is more than 800,000 years old and contains a wealth of information about the last eight glacial cycles. Combined with other ice cores collected in Antarctica and Greenland, and information from marine sediment cores and continental glacial deposits, we are compiling a detailed picture of how Earth's cryosphere and climate have varied over time.

ACTIVITY 13.1

The Cryosphere and Sea Ice, (p. 367)

Think About It What is the cryosphere, and how does the extent of sea ice vary over time?

Objective Analyze global and regional components of the cryosphere and then infer how they may change and ways that such change could affect other parts of the Earth system.

Before You Begin Read the following sections: The Cryosphere and The Cryosphere and Climate Change.

Plan Ahead You will need a pencil, ruler, and a calculator.

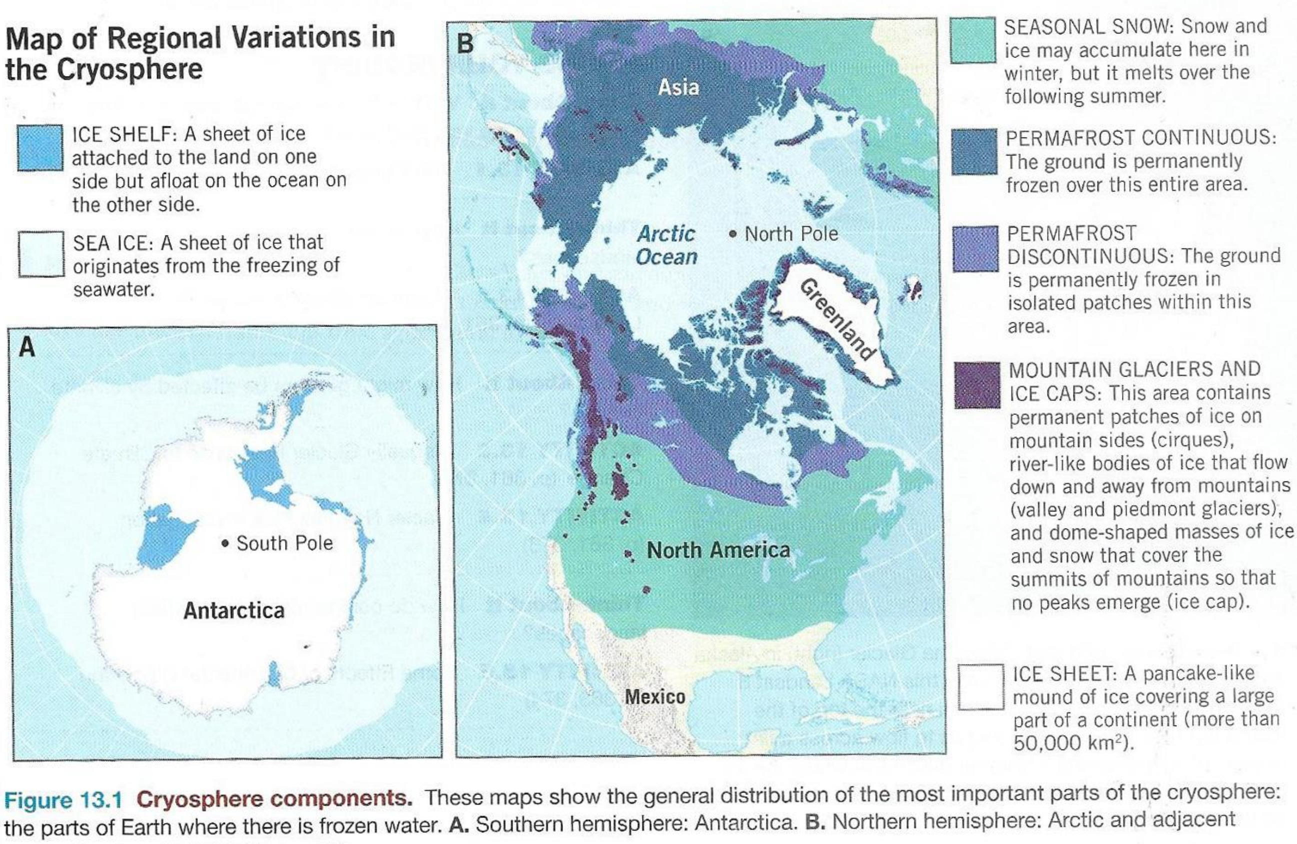

Figure 13.1 Cryosphere components. These maps show the general distribution of the most important parts of the cryosphere: the parts of Earth where there is frozen water. **A.** Southern hemisphere: Antarctica. **B.** Northern hemisphere: Arctic and adjacent areas. (Courtesy of UNEP/GRID-Arendal.)

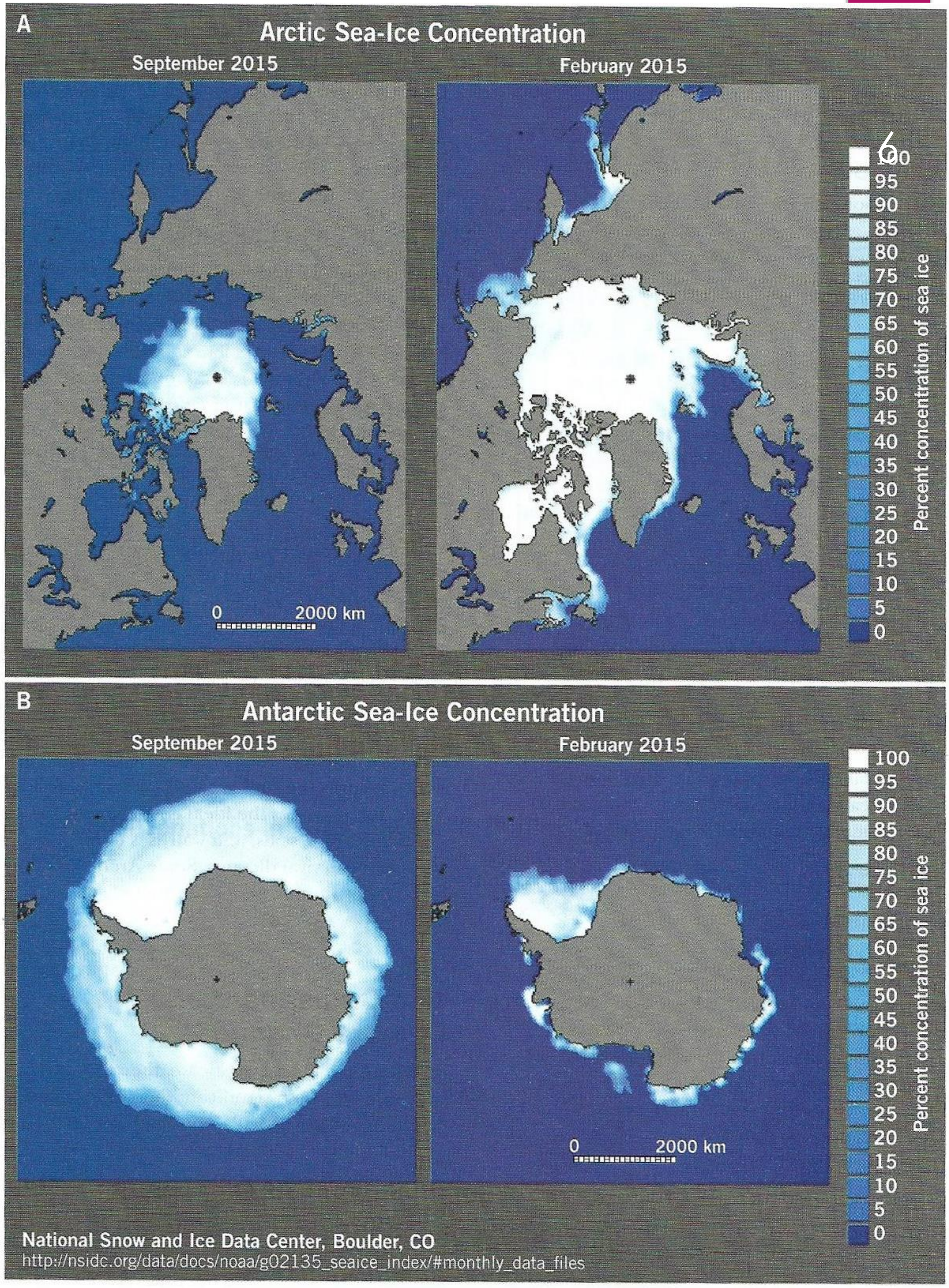

Figure 13.2 Sea ice at Earth's poles. These maps made by the National Snow and Ice Data Center use data from orbiting satellites that measure the concentration of sea ice. A 15% concentration for a given area means that 15% of the sea surface is covered in ice. **A.** Sea ice in the northern hemisphere, summer and winter 2015. **B.** Sea ice in the southern hemisphere, around Antarctica, winter and summer 2015.

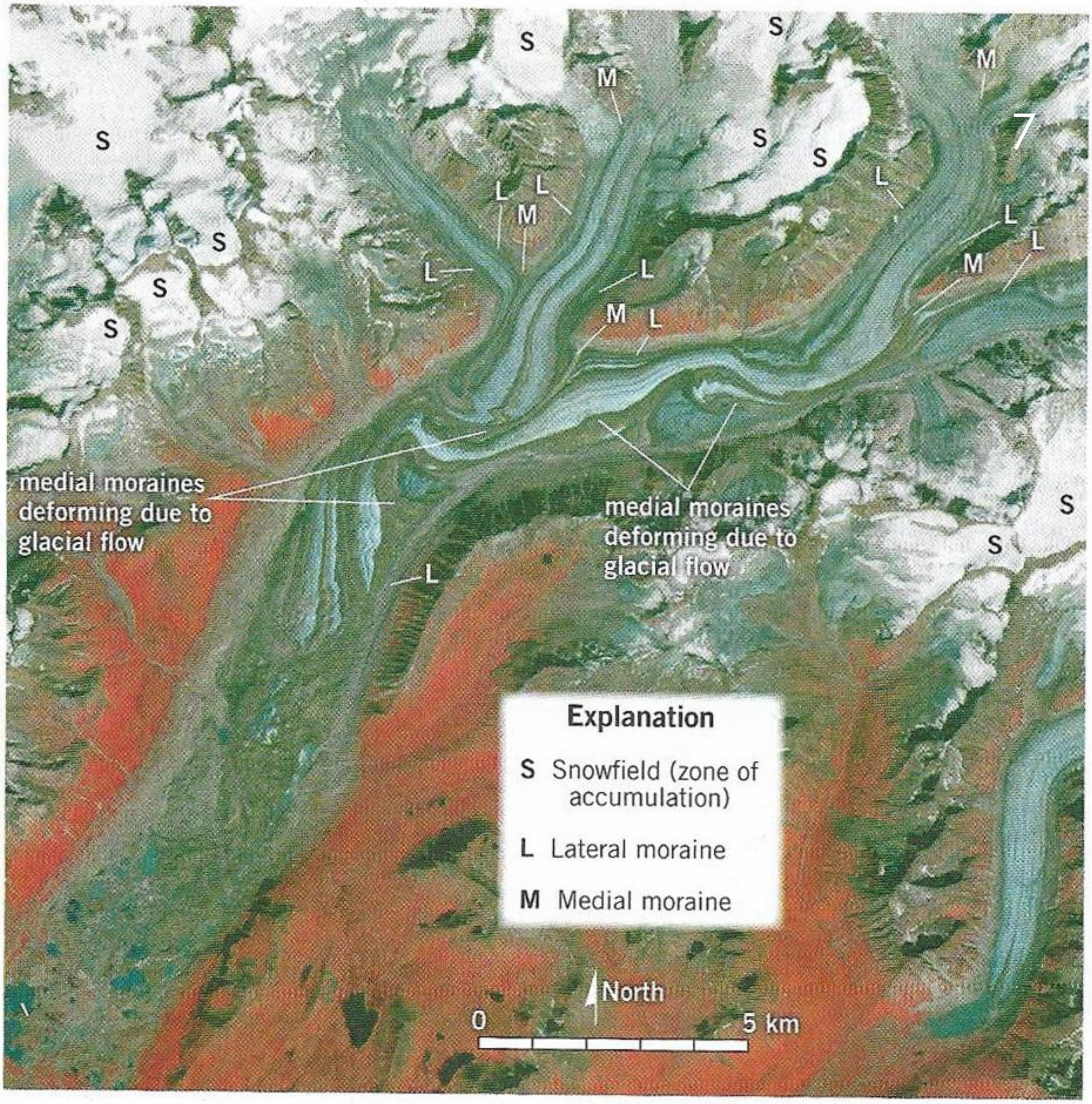

Figure 13.3 Mountain glaciers in Alaska. This is a false-color image of the area around the Susitna Glacier in the Alaska range. The red areas are covered in vegetation. White is snow, light blue-gray is ice, darker blue is water, and where rock and sediment cover the ice in moraines, the glacier appears brown. Some of the moraines are deformed by surging tributary glaciers. (The data for this image were collected by the ASTER instrument on NASA's Terra satellite and were processed by the NASA/METI/AIST/Japan Space Systems and United States/Japan ASTER Science Team.)

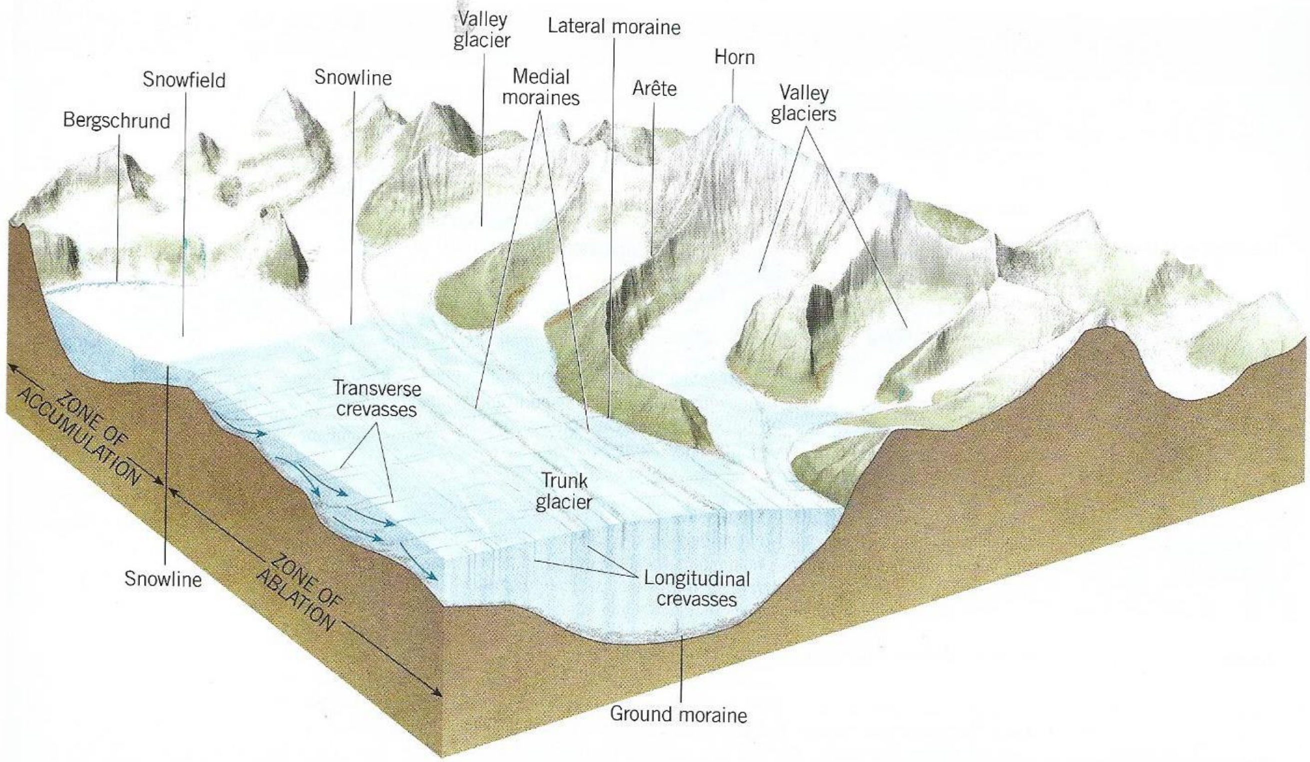

Figure 13.7 Typical features of an active mountain glacier system.

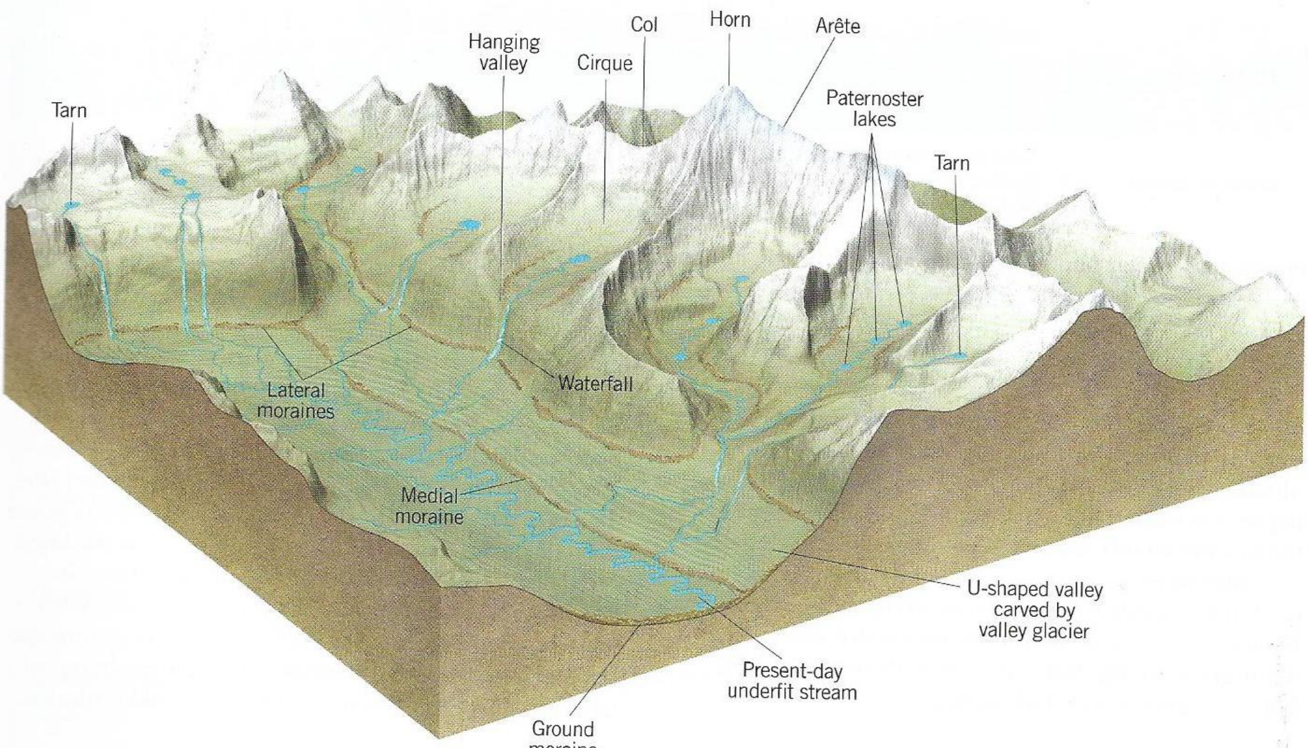

Figure 13.8 Typical erosional and depositional effects of mountain glaciation. Most of the terms used in this figure are defined in **Figs. 13.4–13.6.**

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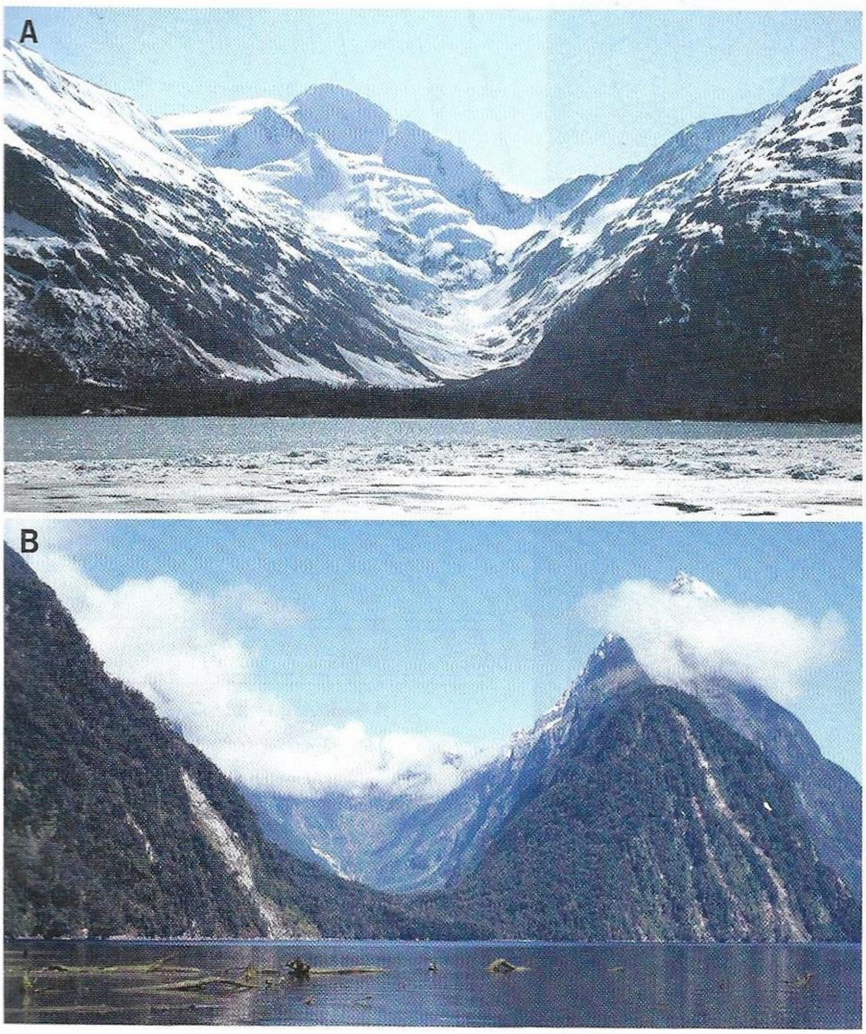


Figure 13.9 Typical U-shaped glacially modified valleys. Mountain glaciers usually follow valleys that were originally established by stream erosion. Subsequent glaciation widens and deepens the existing valley. **A.** Valley of the Byron Glacier, Alaska (60.754°N, 148.855°W). **B.** Tributary valley adjacent to Milford Sound, a glacially carved fiord in Fiordland National Park, South Island, New Zealand (44.659°S, 167.894°E).

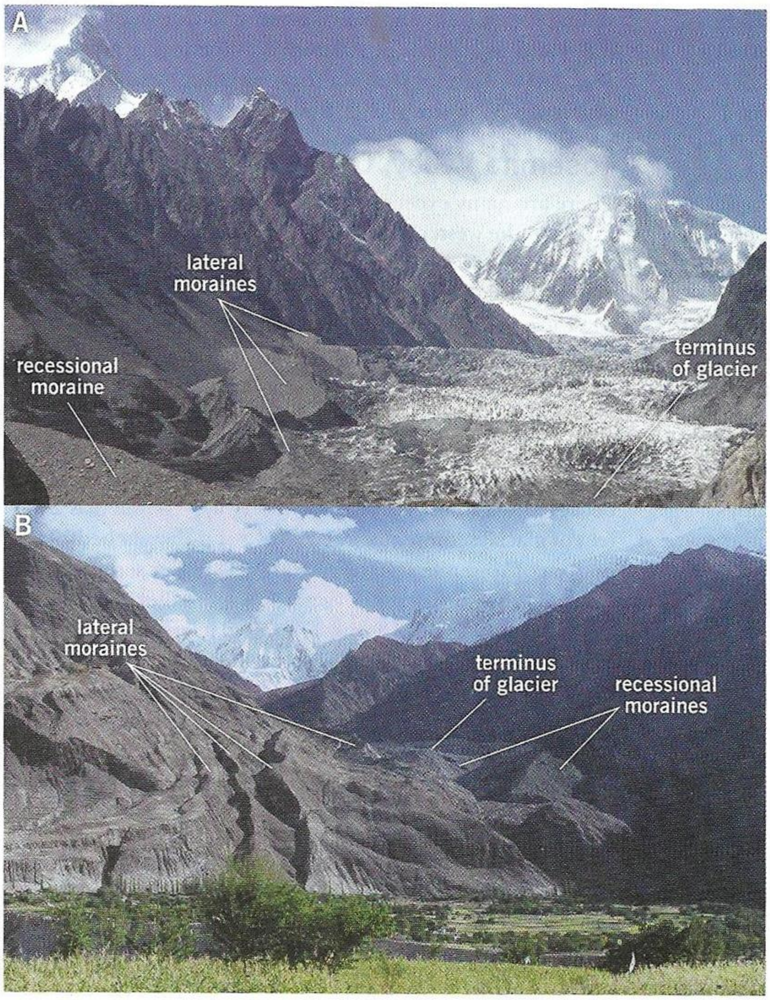


Figure 13.10 Moraine development by valley glaciers in the Karakoram-Himalaya Mountains. **A.** Lateral and recessional (end) moraines of Pasu Glacier (36.457°N, 74.870°E), which flows from a great ridge that contains Shispare (7611 m) in the upper left corner of the photo and Pasu (6478 m) in the right background. **B.** Moraines in the area were recently occupied by the Minapin Glacier that flows from the north side of Rakaposhi (7788 m). This view is from just north of the Hunza River (36.227°N, 74.548°E).

Figure 13.11 Glacial striations and polish. **A.** This rock was polished and scratched or striated as glacial ice from the Tuolumne ice field flowed over Pothole Dome (37.879°N, 119.393°W) on its way toward Yosemite Valley or the Hetch Hetchy Valley. The trends of several glacial striations are indicated with blue line segments. **B.** The inset photo shows another example of striated glacial polish, which is about 0.5 m across.

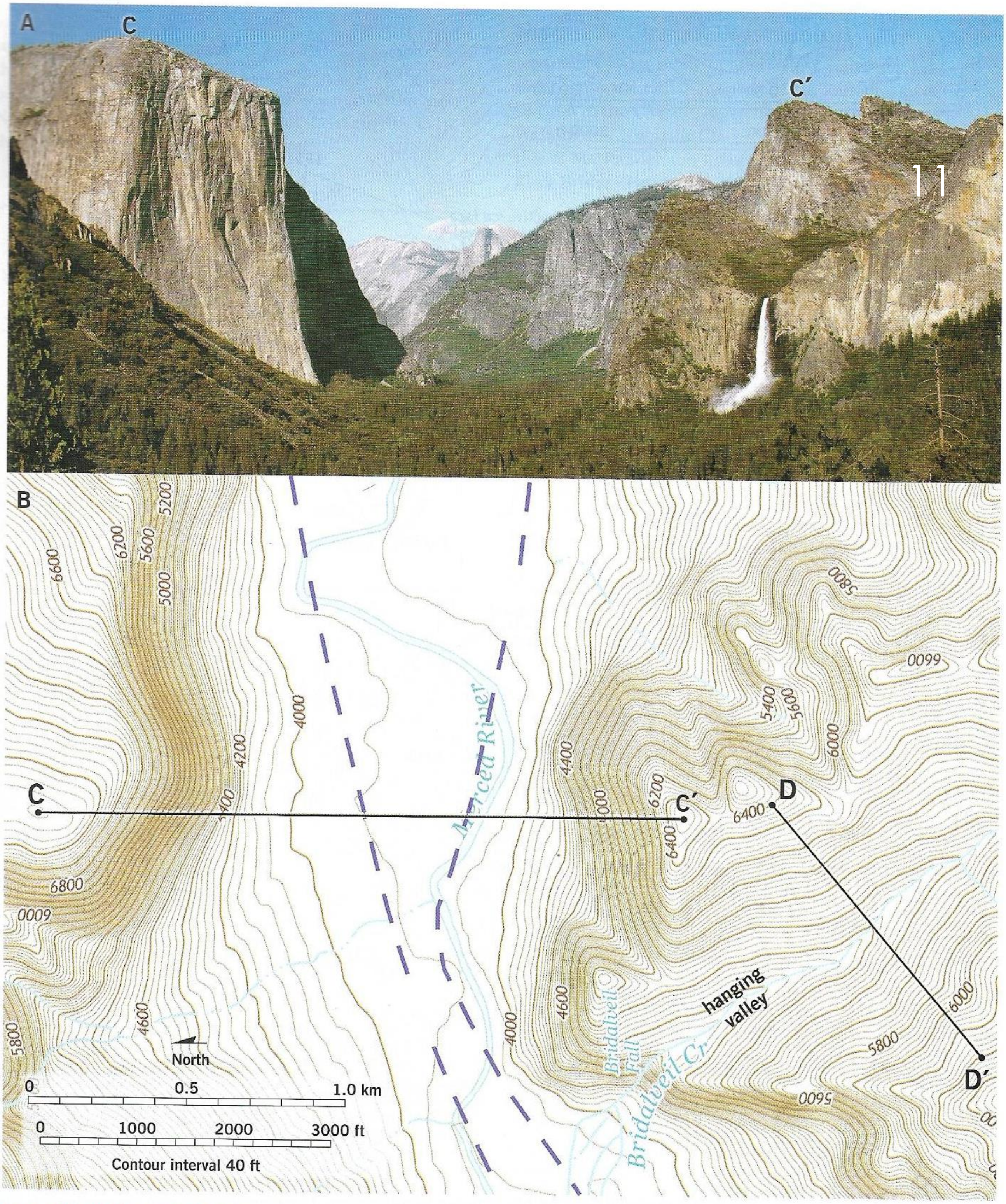


Figure 13.12 Yosemite Valley. **A.** View of glacially modified Yosemite Valley, looking east from Inspiration Point (37.7156°N, 119.6769°W). Points C and C′ are the endpoints of a profile constructed in Activity 13.2. Point C is on El Capitan, and C′ is on Middle Cathedral Rock. Bridal Veil Falls is to the right, and Half Dome is in the background at the center of the photo. **B.** Portion of the USGS 7.5-minute topographic quadrangle map of El Capitan, California. The purple dashed curve is a topographic contour on the top of the granitic basement below all of the glacial sediment in the valley based on geophysical investigations by Gutenberg, Buwalda, and Sharp in the mid-1950s. Sections C–C′ and D–D′ are used in Activity 13.2.

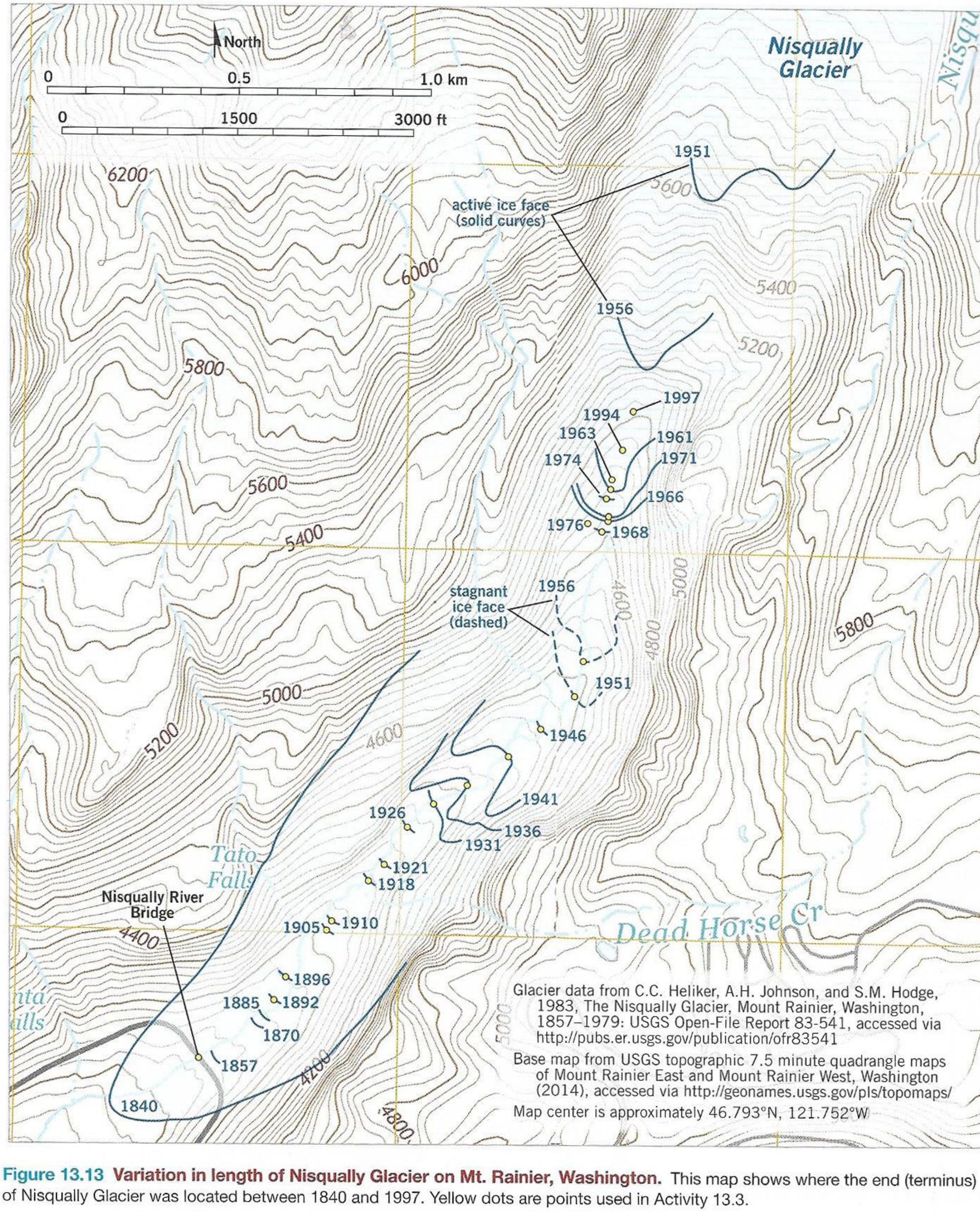


Figure 13.13 Variation in length of Nisqually Glacier on Mt. Rainier, Washington. This map shows where the end (terminus) of Nisqually Glacier was located between 1840 and 1997. Yellow dots are points used in Activity 13.3.

area—the Lyell and McClure Glaciers, which were first studied by John Muir around 1869–1872. Muir measured the rate of motion of McClure Glacier at about an inch per day, and nearly 150 years later, geoscientists from the National Park Service measured about the same rate even though the glacier is now much smaller.

Nisqually Glacier, Washington

Nisqually Glacier is one of many active valley glaciers that occupy the radial drainage of Mt. Rainier—an active volcano in the Cascade Range located near Seattle, Washington. Nisqually Glacier is located on the southern side of Mt. Rainier and flows south toward the Nisqually River Bridge (**Fig. 13.13**). The position of the glacier's

ACTIVITY 13.3

Nisqually Glacier Response to Climate Change, (p. 371)

Think About It How might glaciers be affected by climate change?

Objective Evaluate the use of Nisqually Glacier as an indicator of climate change.

Before You Begin Read the following section: Nisqually Glacier, Washington. Refer to previous sections as needed.

Plan Ahead You will need a pencil, ruler, and a calculator.

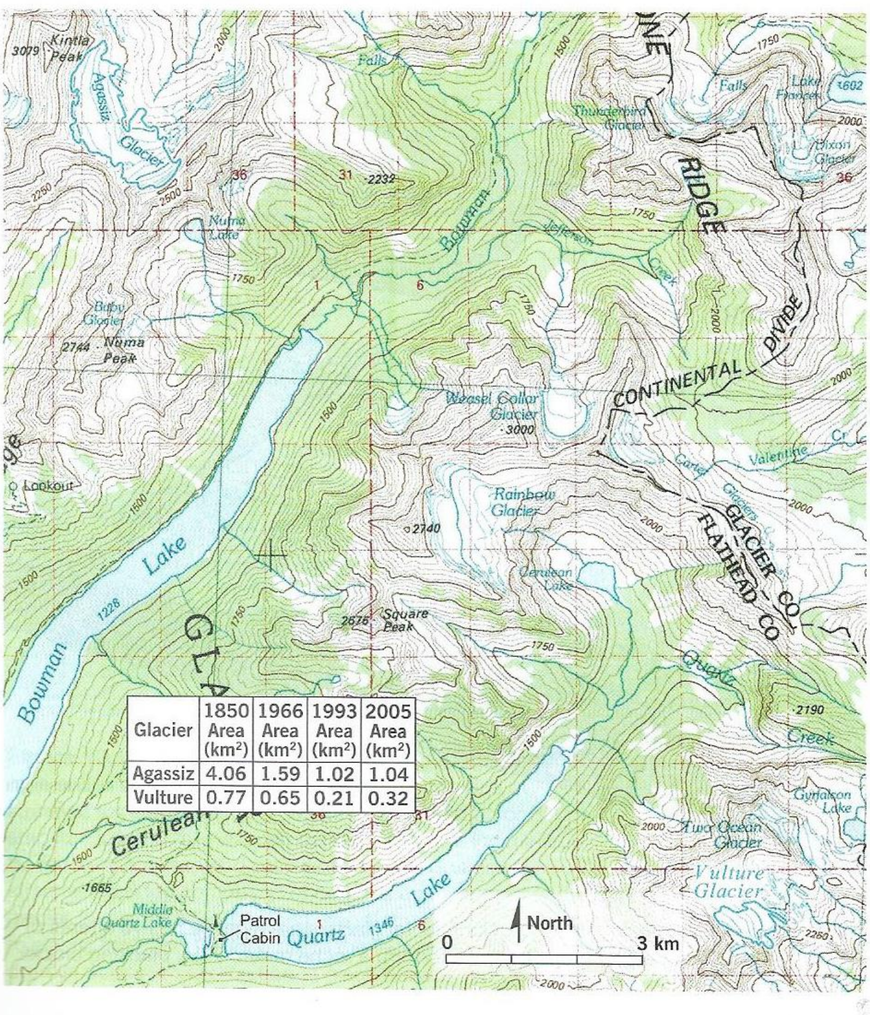
ACTIVITY 13.4

Glacier National Park Investigation, (p. 373)

Objective Analyze glacial features in Glacier National Park and infer how glaciers there might change in the future.

Before You Begin Read the following section: Glacier National Park, Montana. Refer to previous sections as needed.

Plan Ahead You will need a pencil, ruler, and a calculator.



Glacier	1850 Area (km²)	1966 Area (km²)	1993 Area (km²)	2005 Area (km²)
Agassiz	4.06	1.59	1.02	1.04
Vulture	0.77	0.65	0.21	0.32

Figure 13.14 Portion of Glacier National Park, Montana. This small map area includes nine named glaciers, including the Agassiz and Vulture Glaciers that are considered in Activity 13.4. Glacier data in the inset table are from the USGS and its research partners at Portland State University. The center of this map is 48.8845°N, 114.0921°W, and it is a portion of USGS topographic quadrangle map of the Whitefish Range (1981).

terminus or downflow end was first recorded in 1840, and it has been measured and mapped by many geologists since that time. The map in **Fig. 13.13** contains data published by the U.S. Geological Survey (USGS) in 1983 as well as more recent data acquired through aerial image analysis. Notice how the glacier has retreated with a couple of advances since 1840.

Glacier National Park, Montana

Glacier National Park is located on the northern edge of Montana across the border from Alberta and British Columbia, Canada. Many if not all of the erosional features formed by glaciation in the park developed during the Wisconsinan glaciation or a shorter cold period in the Holocene, known as the "little ice age" between ~1300 to 1850 AD. It has been estimated that there were approximately 150 small cirque glaciers in the park in 1850, but the USGS counts only 25 today that meet its criteria for an active glacier. Nine of those can be observed on the topographic map in **Fig. 13.14**. The USGS reports that a climate model intended to predict the rate of glacial retreat among the Glacier National Park's largest glaciers suggests that they might all vanish by the year 2030.

Continental Glaciation

During the Pleistocene glaciation, thick ice sheets covered most of Alaska and Canada, extending south into the continental United States. Continental ice sheets also formed in northern Europe and South America, and they persist to this day in Greenland and Antarctica. These continental glaciers produced a variety of characteristic landforms that are illustrated in **Figs. 13.15** and **13.16**.

Kames are low hills of stratified sand and gravel formed by one of several possible mechanisms (**Fig. 13.17A**). Some kames form when sediment-laden water flowed into a hole in stagnant ice. Other kames are remnants of meltwater deltas formed near the ice margin. **Drumlins** are composed of till and are interpreted to have been remolded under the pressure exerted by the weight of glacial ice on

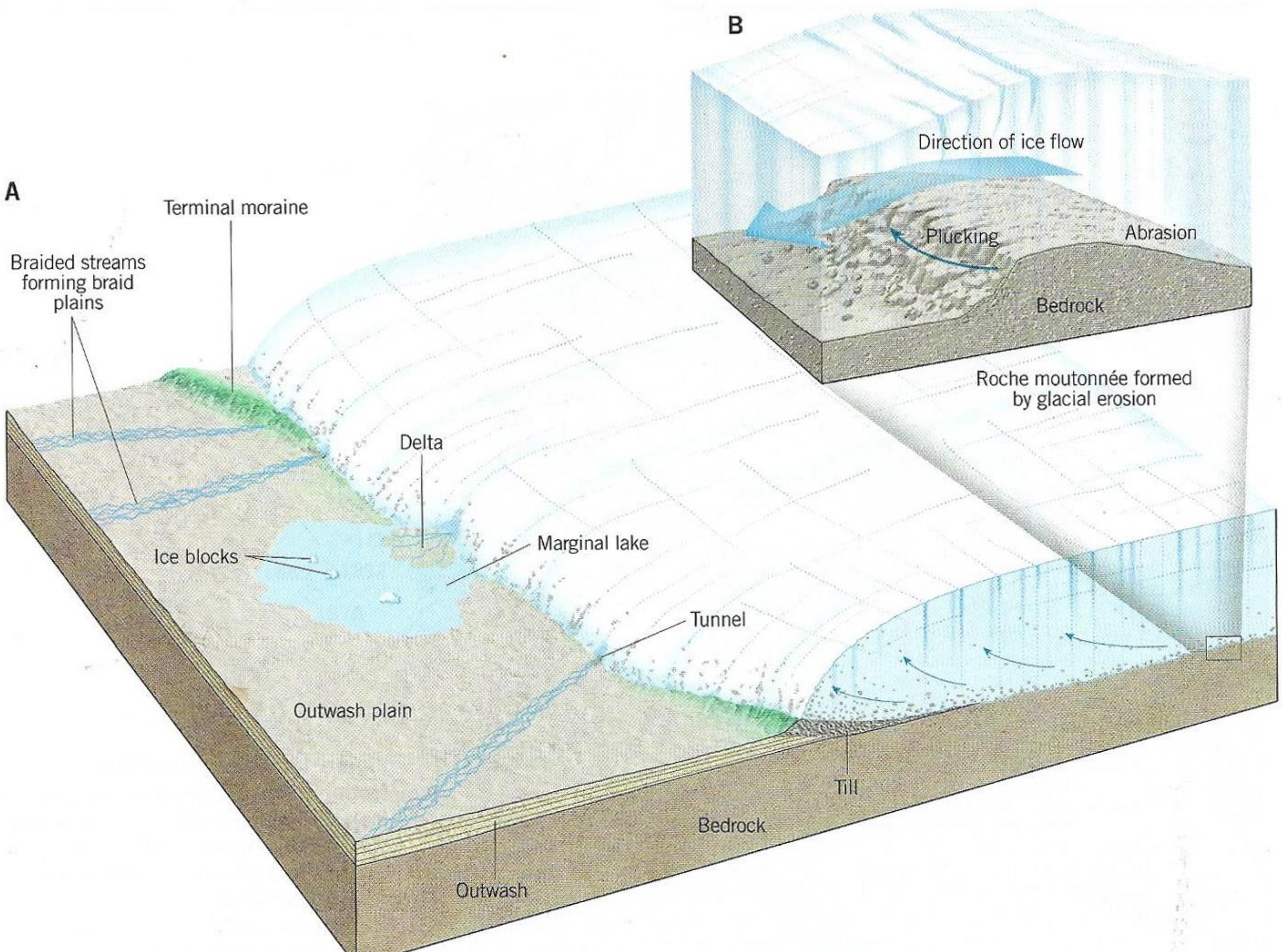


Figure 13.15 Typical features of an active continental glacier system. A. Continental glaciers are highly effective agents of erosion, sediment transport, and deposition. **B.** As the ice advances, it erodes bedrock to form a roche moutonnée, plucking blocks from the down-flow side.

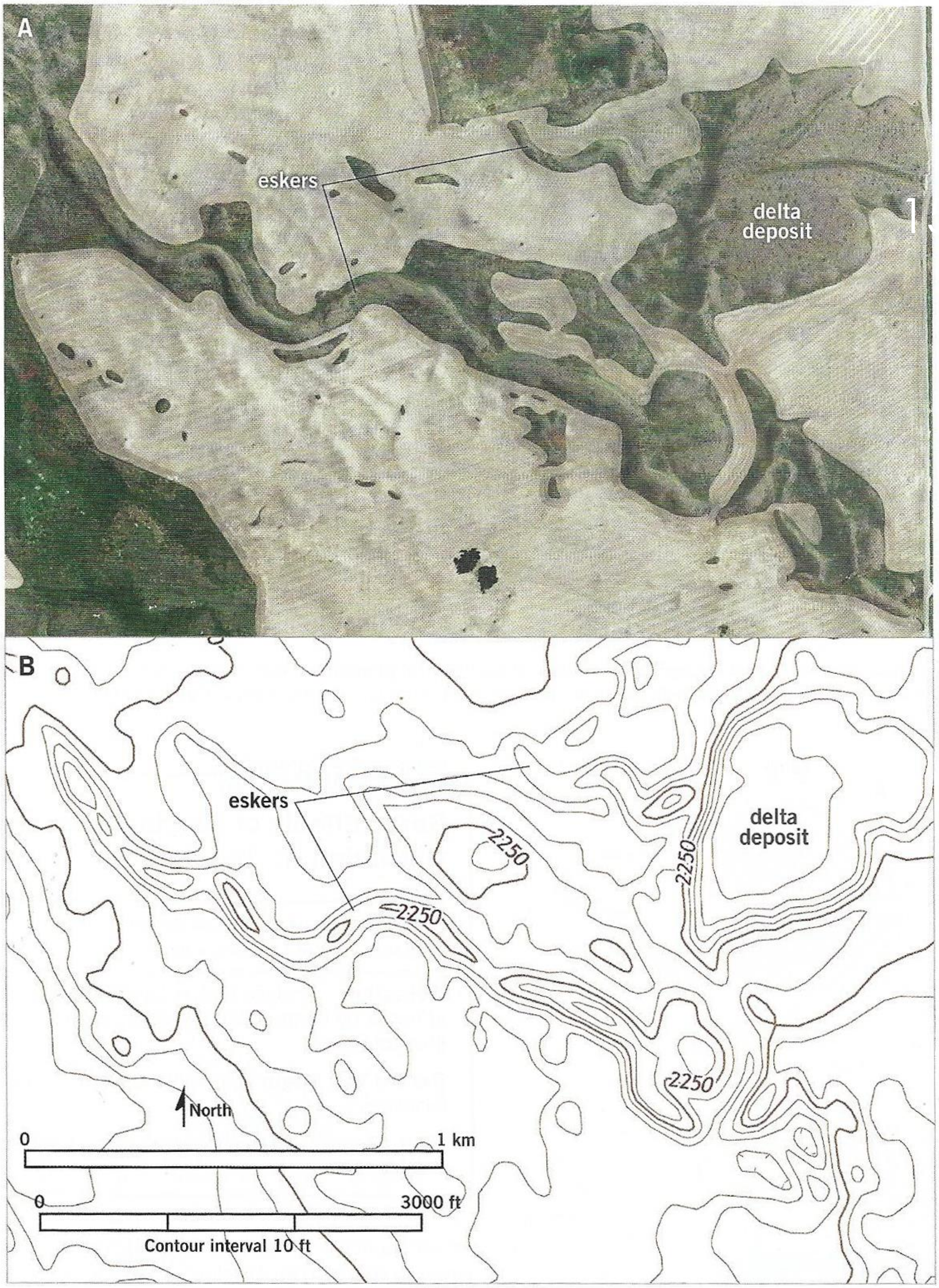


Figure 13.18 Eskers. Aerial photograph (**A**) and corresponding topographic map (**B**) of eskers near Sims Corner, Washington. Eskers are composed of sediment carried on, in, or below a glacier in a glacial stream. Eskers preserve the shape of the stream channel or ice tunnel and are deposited when the ice that contains them melts.

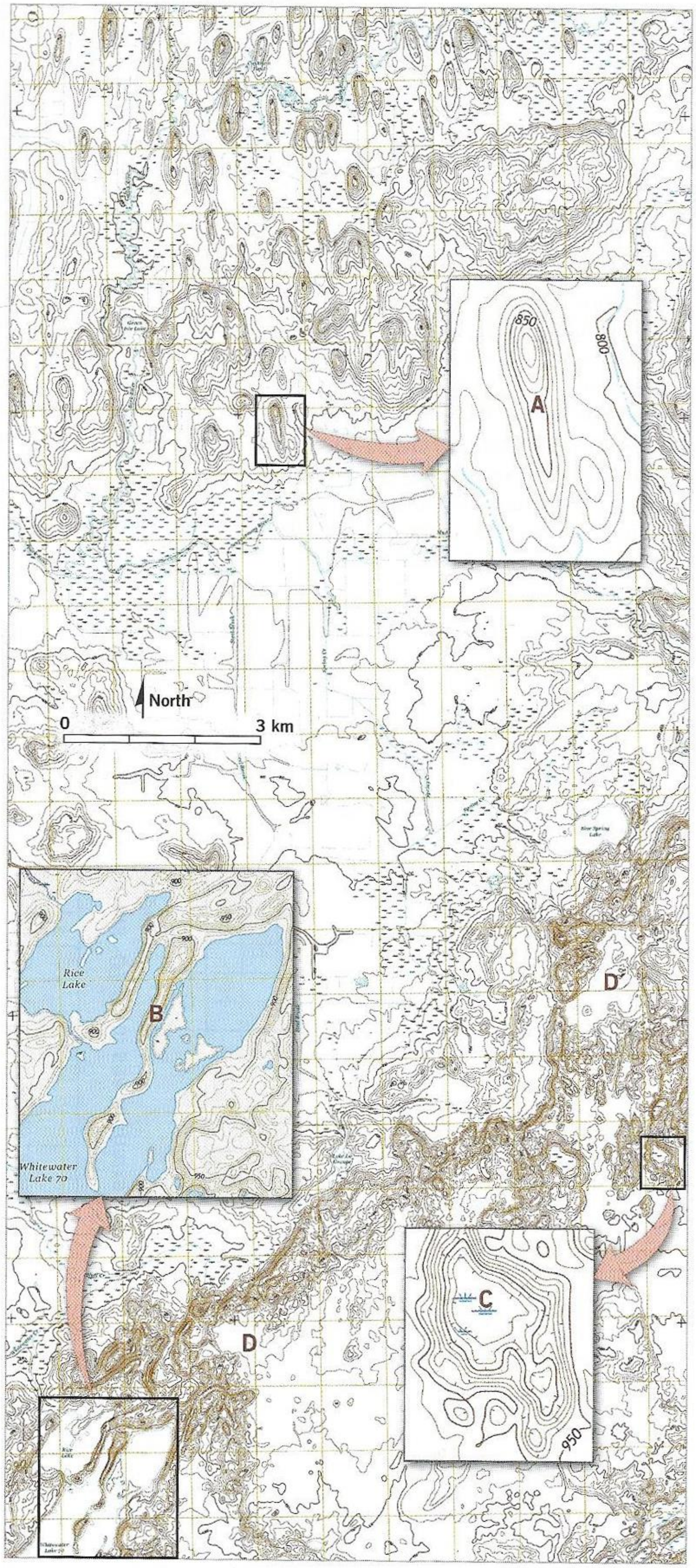


Figure 13.19 Continental glacier landforms near Whitewater, Wisconsin. Composite map processed to accentuate glacial landforms, derived from USGS 7.5-minute topographic maps of Rome, Palmyra, Little Prairie, and Whitewater, Wisconsin. The inset maps expand the areas indicated by the smaller black rectangles so that key features can be recognized in Activity 13.5.

Name: ______________________ Course/Section: ______________________ Date: ____________

A The cryosphere is composed of all parts of Earth where water is frozen, whether on the surface (snow, ice, sea ice) or below the surface (permafrost).

1. Notice that Mexico is a beige- to yellow-colored region with no snow or ice near the bottom of **Fig. 13.1B**. What is the order in which you would encounter different parts of the cryosphere if you traveled overland from Mexico to the North Pole?

2. While continental glaciation occurs only in Greenland and Antarctica today, mountain glaciers and ice caps occur in many places, including Canada, Russia, Alaska, the Rocky Mountains, the Andes, the Alps, and the Himalayas. Some mountain glaciers exist very close to the equator. How do you think it is possible for glaciers to exist at the equator?

B Scientists at the National Snow and Ice Data Center (NSIDC) have measured the extent of Arctic and Antarctic sea ice every month since at least 1978 using satellite data. A table of data from NSIDC for September in the Arctic and February in the Antarctic is provided in **Fig. A13.1.1**.

Summer Extent of Sea Ice

Year	September in Arctic, in millions of square km	February in Antarctic, in millions of square km
2015	4.68	3.77
2014	5.29	3.90
2013	5.35	3.91
2012	3.63	3.61
2011	4.63	2.52
2010	4.93	3.20
2009	5.39	2.98
2008	4.73	3.95
2007	4.32	2.95
2006	5.95	2.69
2005	5.59	2.99
2004	6.08	3.66
2003	6.18	3.92
2002	5.98	2.98
2001	6.78	3.81

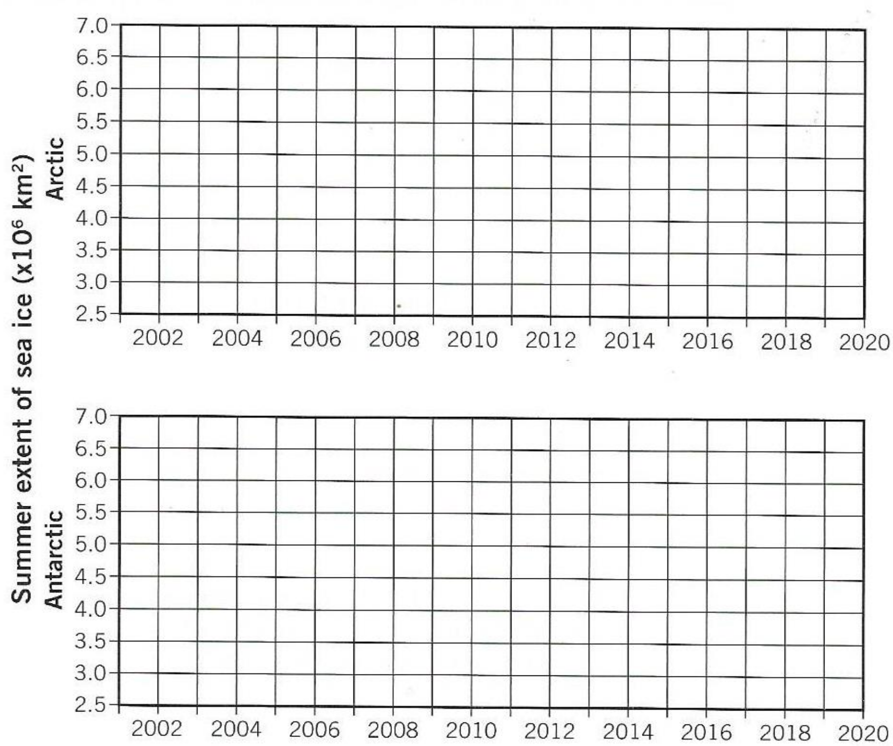


Figure A13.1.1

1. What was the average extent of Arctic sea ice in September from 2001 to 2015 in millions of km^2? Show your work.

2. Plot all of the data for the extent of Arctic sea ice from 2001 to 2015 on the graph labeled "Arctic" in **Fig. A13.1.1**, and then use a ruler to estimate a best-fit line through the points so that the number of points above the line is about the same as the number below the line.

P. 367, QA-1. Notice that Mexico is a beige-to yellow-colored region with no snow or ice near the bottom of Fig. 13.1B. What is the order in which you would encounter different parts of the cryosphere if you traveled overland from Mexico to the North Pole?

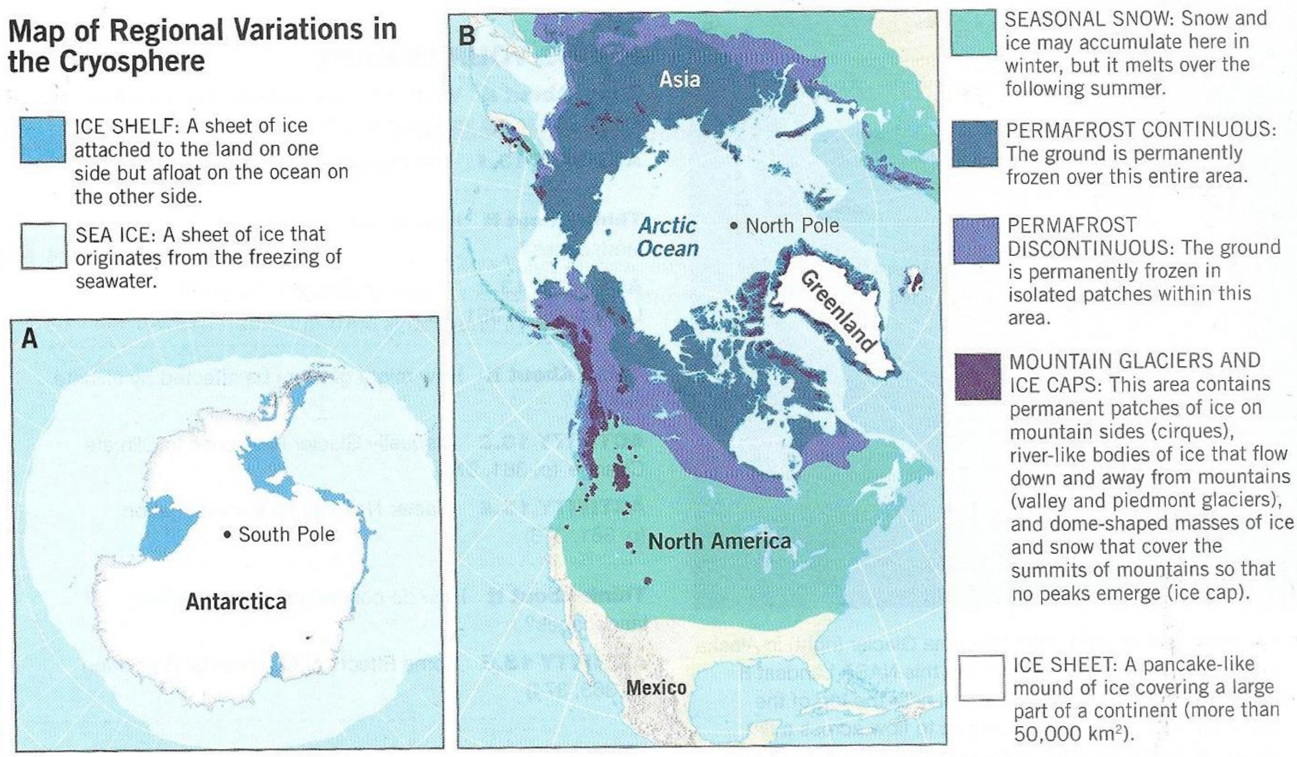


Figure 13.1 Cryosphere components. These maps show the general distribution of the most important parts of the cryosphere: the parts of Earth where there is frozen water. **A.** Southern hemisphere: Antarctica. **B.** Northern hemisphere: Arctic and adjacent areas. (Courtesy of UNEP/GRID-Arendal.)

P. 367, QA-1. Notice that Mexico is a beige-to yellow-colored region with no snow or ice near the bottom of Fig. 13.1B. What is the order in which you would encounter different parts of the cryosphere if you traveled overland from Mexico to the North Pole?
SOLUTION

- From Mexico to the North Pole you would encounter:
- Seasonal Snow with occasional areas of Mountain Glaciers
- Then
- Permafrost Discontinuous
- Then
- Permafrost Continuous

P. 367, QA-2: While continental glaciation occurs only in Greenland and Antarctica today, mountain glaciers and ice caps occur in many ,places, including Canada, Russia, Alaska, the Rocky Mountains, the Andes, the Alps, and the Himalayas . Some mountain glaciers exist very close to the equator. How do you think it is possible for glaciers to exist at the equator? SOLUTION

- If mountains at the equator are high enough, there will be mountain glaciers.

P. 367, QB: Scientists at the National Snow and Ice Data Center (NSIDC) have measured the extent of Arctic and Antarctic sea ice every month since at least 1978 using satellite data. A table of data from NSJDC for September in the Arctic and February in the Antarctic is provided in Fig. A13.1.1.

Summer Extent of Sea Ice

Year	September in Arctic, in millions of square km	February in Antarctic, in millions of square km
2015	4.68	3.77
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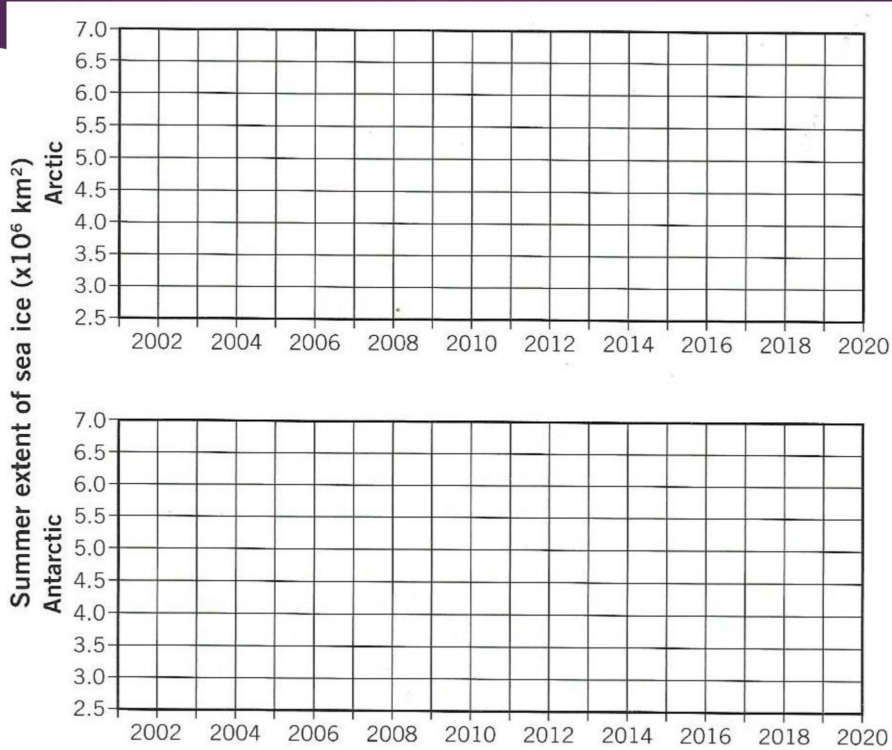
2010	4.93	3.20
2009	5.39	2.98
2008	4.73	3.95
2007	4.32	2.95
2006	5.95	2.69
2005	5.59	2.99
2004	6.08	3.66
2003	6.18	3.92
2002	5.98	2.98
2001	6.78	3.81

Figure A13.1.1

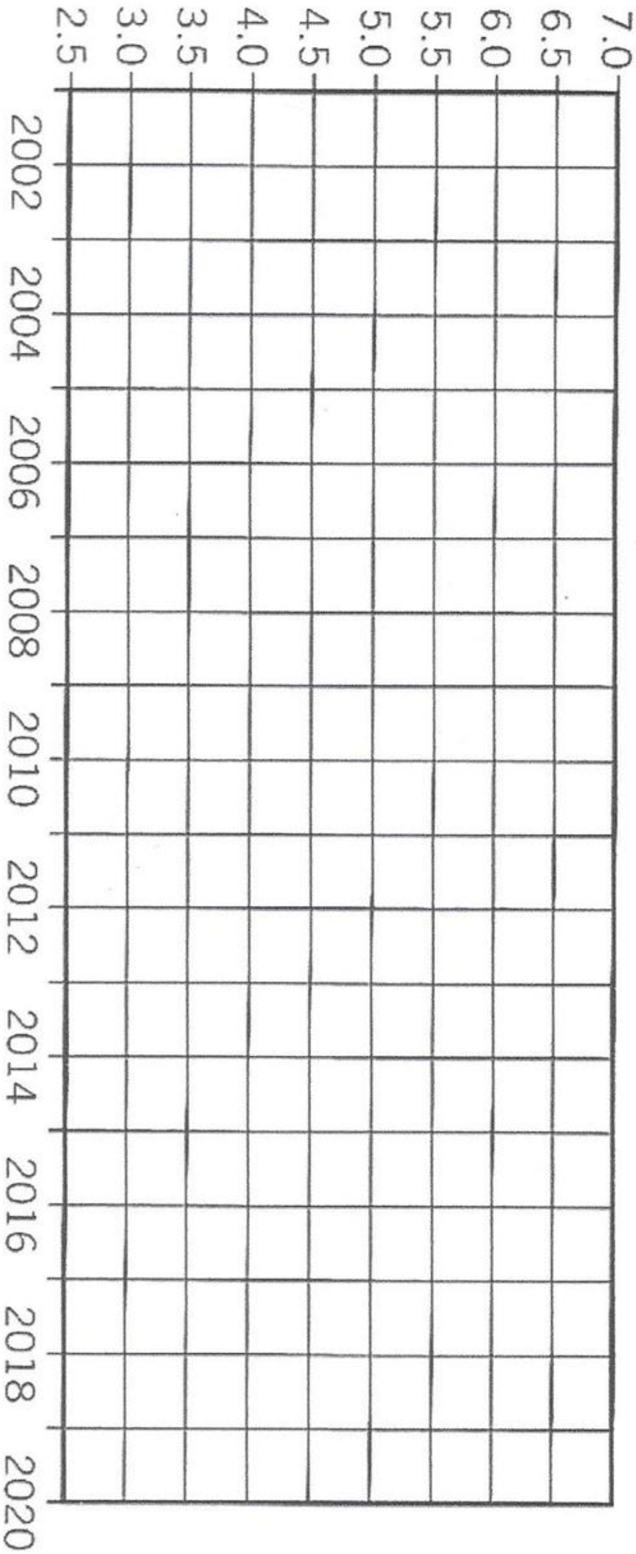
P. 367, QB-1: What was the average extent of Arctic sea ice in September from 2001 to 2015 in millions of square km ? Show your work.



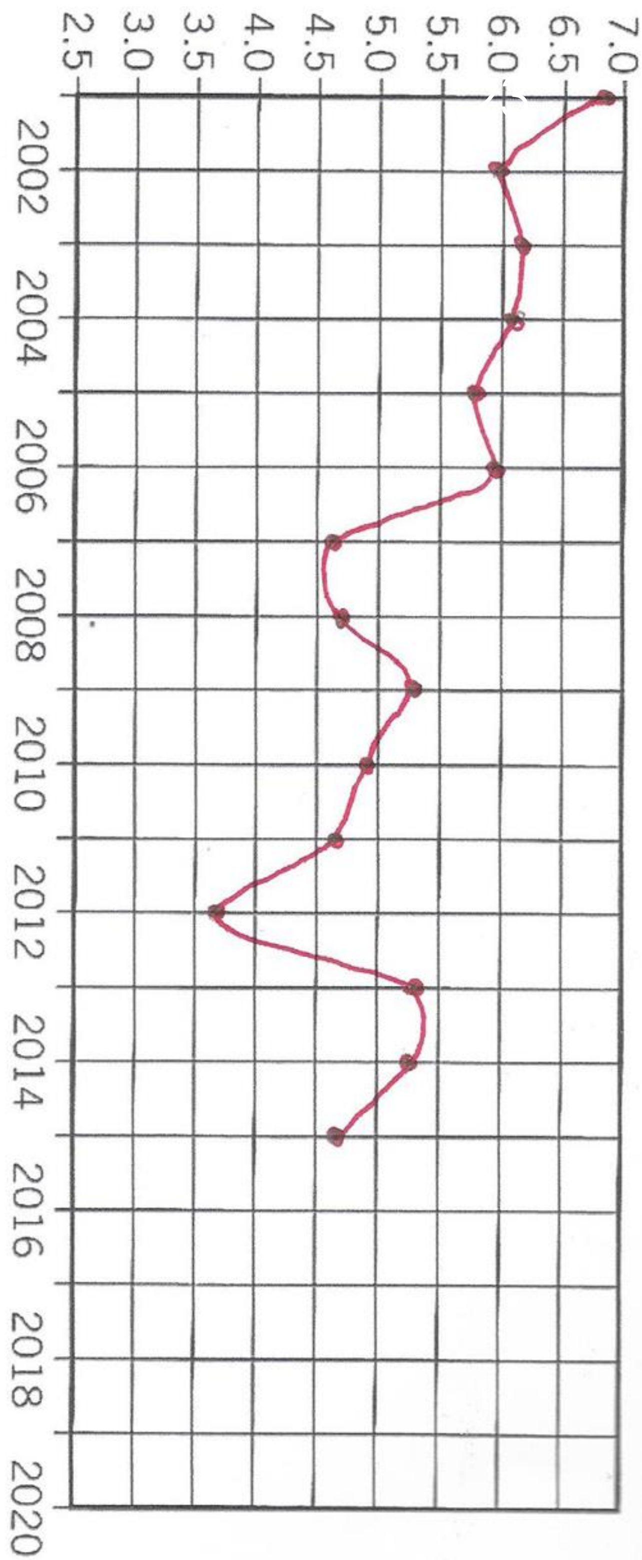
- Step 1: Plat the data from the table on the graphs

Summer extent of sea ice ($\times 10^6$ km^2)

Antarctic



Arctic



P. 367, QB-1: What was the average extent of Arctic sea ice in September from 2001 to 2015 in millions of square km ? Show your work. SOLUTION STEP 2

- Step 2. Calculate the average for years 2001 to 2015. Average = 5.30 million square km

	Average Sumer Sea Ice		
	Artic, September		
	Year	Millions square km	
	2015	4.68	
	2014	5.29	
	2013	5.35	
	2012	3.63	
	2011	4.63	
	2010	4.93	
	2009	5.39	
	2008	4.73	
	2007	4.32	
	2006	5.95	
	2005	5.59	
	2004	6.08	
	2003	6.18	
	2002	5.98	
	2001	6.78	
	Total	79.51	
	Average	5.30	

P. 367, QB-2: Plot all of the data for the extent of Arctic sea ice from 2001 to 2015 on the graph labeled "Arctic" in Fig. A13.1.1, and then use a ruler to estimate a best-fit line through the points so that the number of points above the line is about the same as the number below the line. SOLUTION STEP 1

- Step 1. Plot the points from the table

Summer Extent of Sea Ice		
Year	September in Arctic, in millions of square km	February in Antarctic, in millions of square km
2015	4.68	3.77
2014	5.29	3.90
2013	5.35	3.91
2012	3.63	3.61
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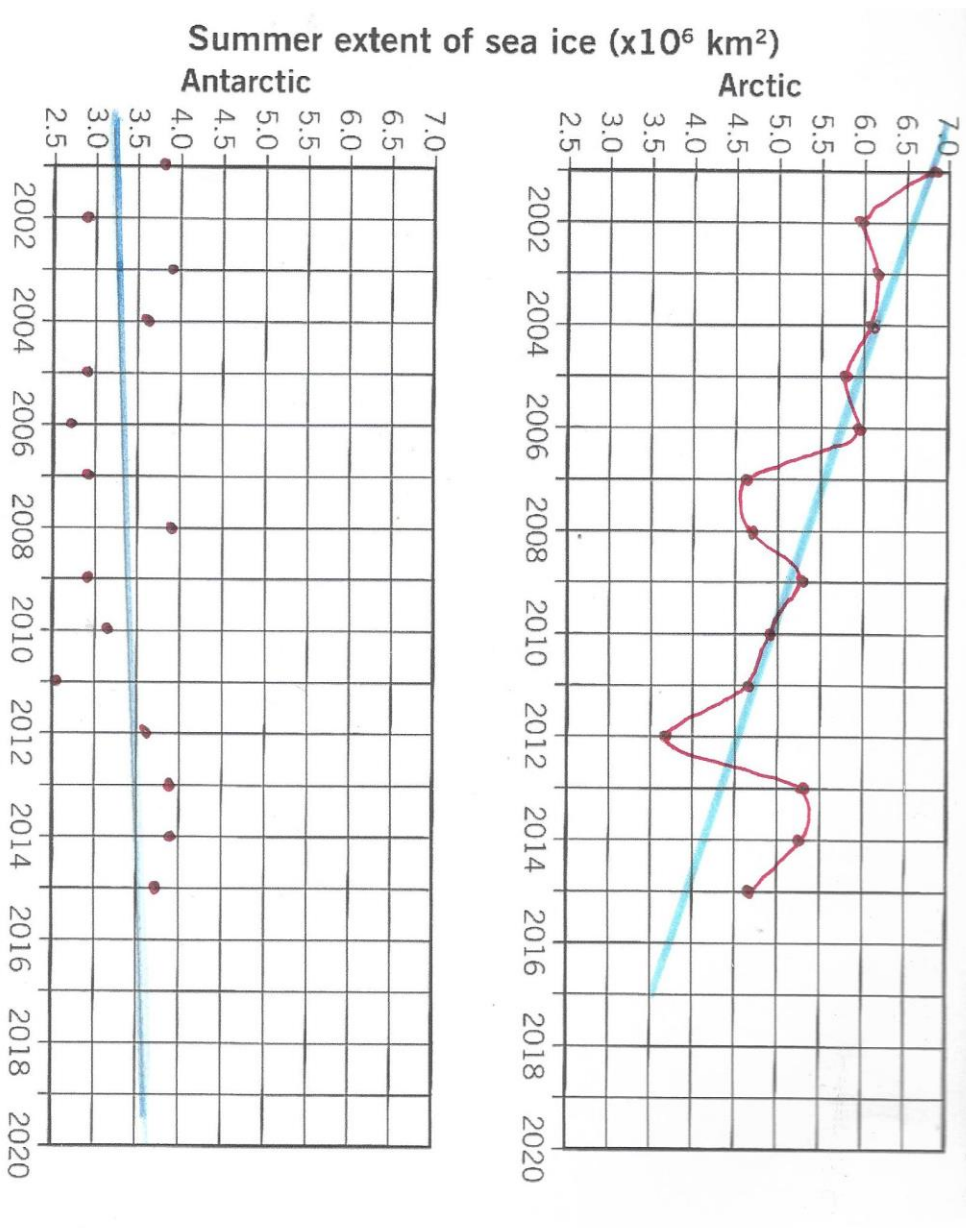
2006	5.95	2.69
2005	5.59	2.99
2004	6.08	3.66
2003	6.18	3.92
2002	5.98	2.98
2001	6.78	3.81

Figure A13.1.1

P. 367, QB-2: Plot all of the data for the extent of Arctic sea ice from 2001 to 2015 on the graph labeled "Arctic" in Fig. A13.1.1, and then use a ruler to estimate a best-fit line through the points so that the number of points above the line is about the same as the number below the line. SOLUTION STEP 2

- Step 2. Draw a line showing trend in data



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3. Based on your plot and calculations in part 2, would you say that the amount of Arctic sea ice as measured in September of each year is decreasing, increasing, or staying about the same? Explain.

4. What do you predict the extent of Arctic sea ice will be in 2020?

5. What was the average annual extent of Antarctic sea ice from 2001 to 2015 in millions of km^2? Show your work.

6. Plot all of the data for the extent of Antarctic sea ice from 2001 to 2015 on the graph labeled Antarctic in **Fig. A13.1.1**, and then use a ruler to estimate a best-fit line through the points.

7. What do you predict the extent of Antarctic sea ice will be in 2020?

8. Based on your work in response to parts B2 and B5–B7, would you say that the annual amount of Antarctic sea ice as measured in February of each year is decreasing, increasing, or staying about the same? Explain.

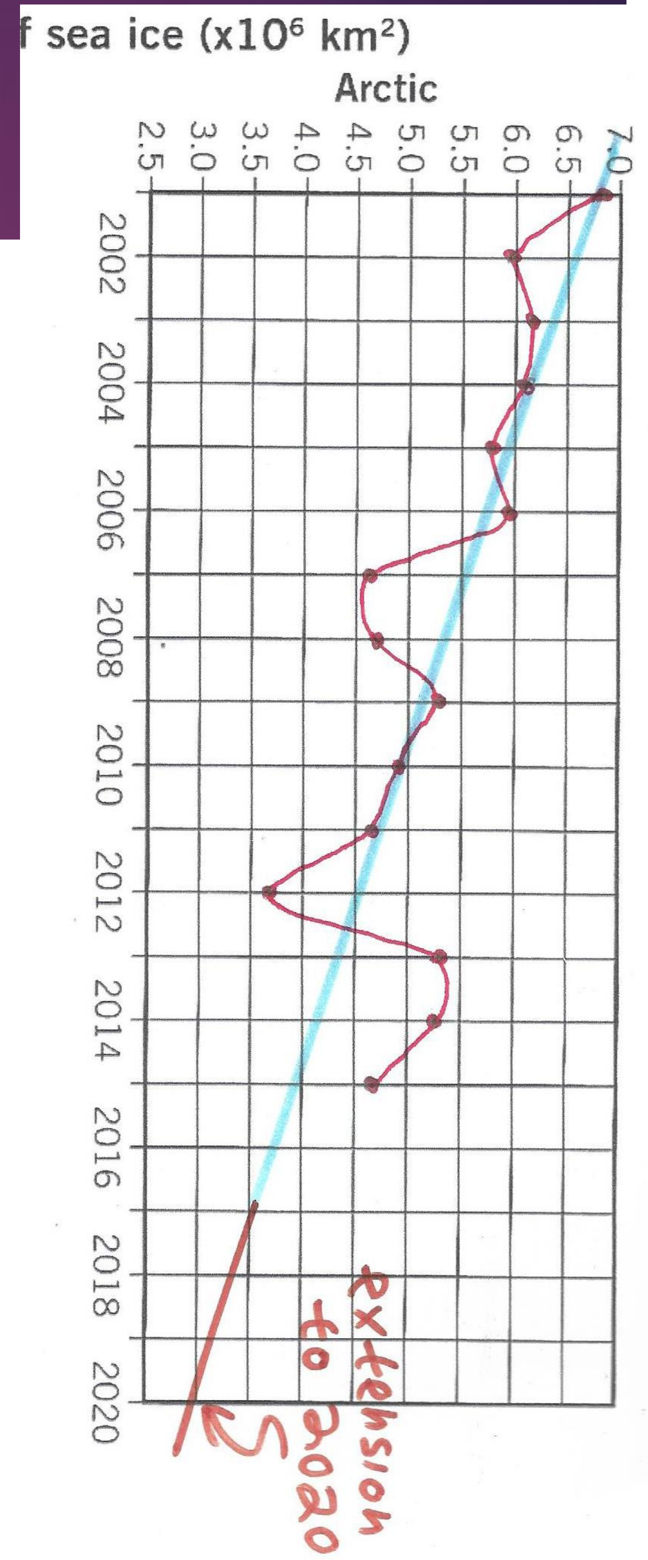
C REFLECT & DISCUSS How do the changes in Arctic sea ice extent over time compare with the Antarctic changes? If they are different, why do you think that might be? Consider as many possibilities as you can.

P. 368, QB-3: Based on your plot and calculations in part 2, would you say that the amount of Arctic sea ice as measured in September of each yea r is decreasing , increasing, or staying about the same? Explain.

- The data and graph indicate a decreasing trend in the amount of September sea ice in the Artic

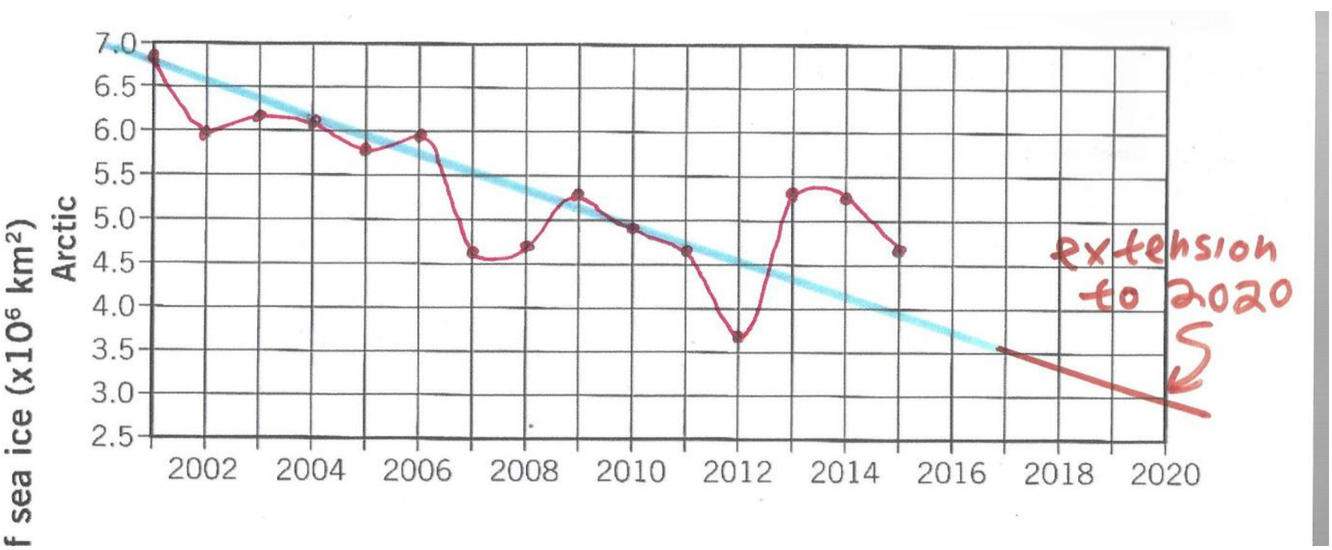
p. 368, QB-4: What do you predict the extent of Arctic sea ice will be in 2020? SOLUTION

- Step 1. Extend the blue projection line from p. 367 Question B-3 to 2020.



p. 368, QB-4: What do you predict the extent of Arctic sea ice will be in 2020? SOLUTION

- **Step 1. Extend the blue projection line from p. 367 Question B-3 to 2020.**



Step 2. Read the projected amount off of the graph: 3.0 million square kilometers.

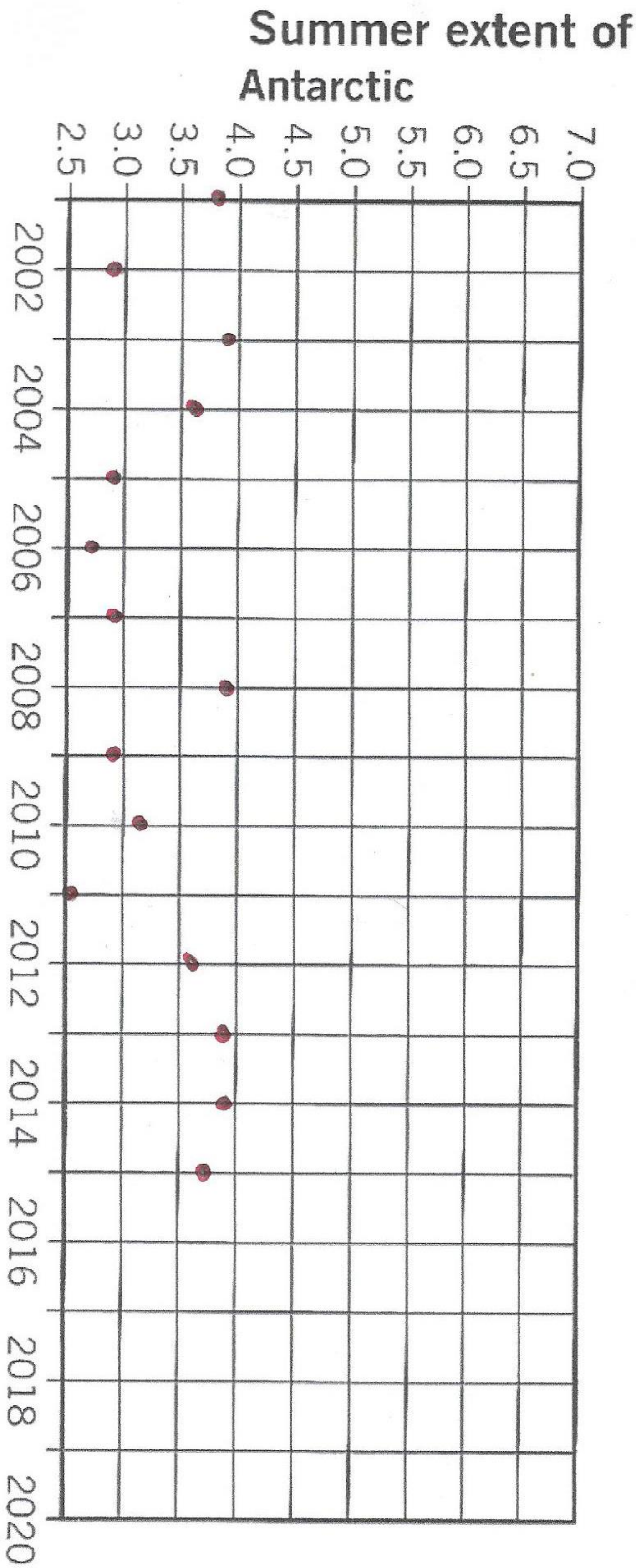
P. 368, QB-6: Plot all of the data for the extent of Antarctic sea ice from 2001 to 2015 on the graph labeled "Antarctic" in Fig. A13.1.1, and then use a ruler to estimate a best-fit line through the points. SOLUTION STEP 1

- Step 1. Plot the points from the table

Summer Extent of Sea Ice

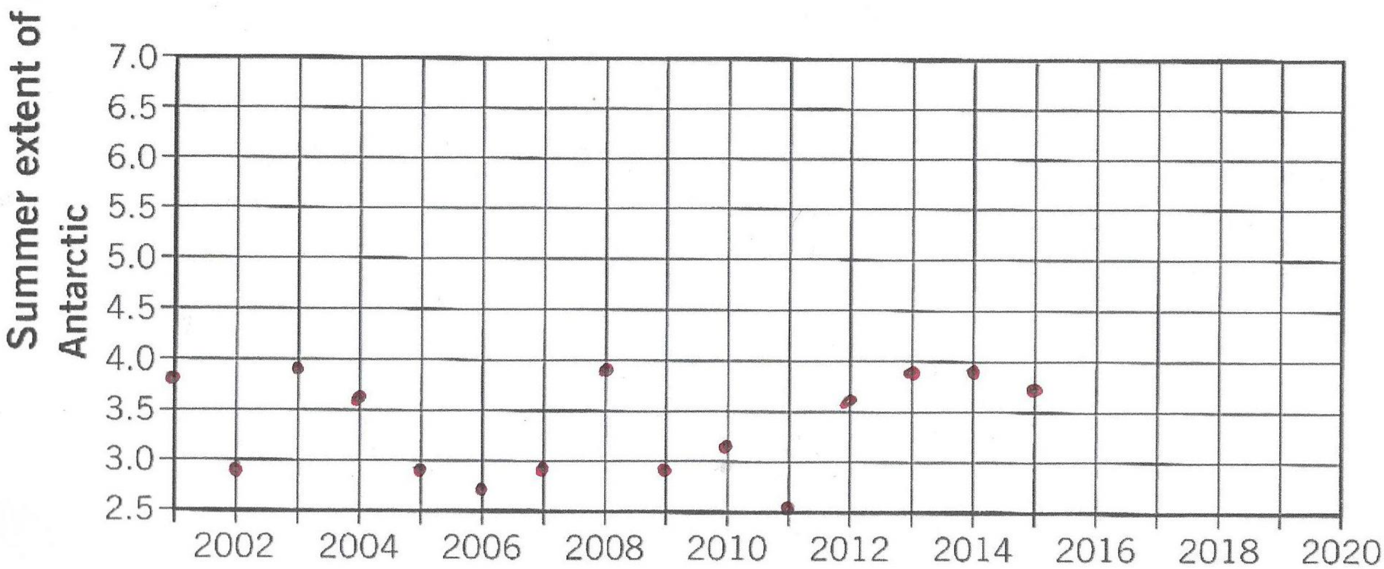
Year	September in Arctic, in millions of square km	February in Antarctic, in millions of square km
2015	4.68	3.77
2014	5.29	3.90
2013	5.35	3.91
2012	3.63	3.61
2011	4.63	2.52
2010	4.93	3.20
2009	5.39	2.98
2008	4.73	3.95
2007	4.32	2.95
2006	5.95	2.69
2005	5.59	2.99
2004	6.08	3.66
2003	6.18	3.92
2002	5.98	2.98
2001	6.78	3.81

Figure A13.1.1



SOLUTION: p. 368 QB-6, Step 1

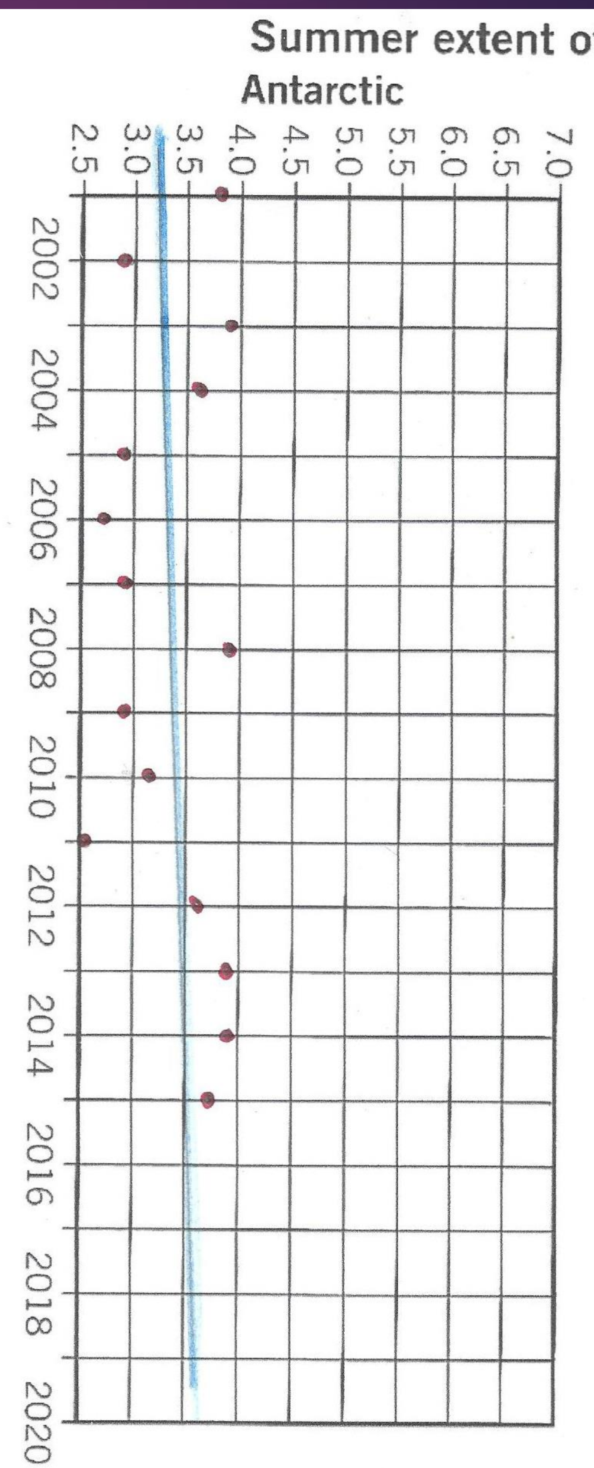
P. 368, QB-6: Plot all of the data for the extent of Antarctic sea ice from 2001 to 2015 on the graph labeled “Antarctic" in Fig. A13.1.1, and then use a ruler to estimate a best-fit line through the points.
SOLUTION STEP 1



SOLUTION: p. 368 QB-6, Step 1

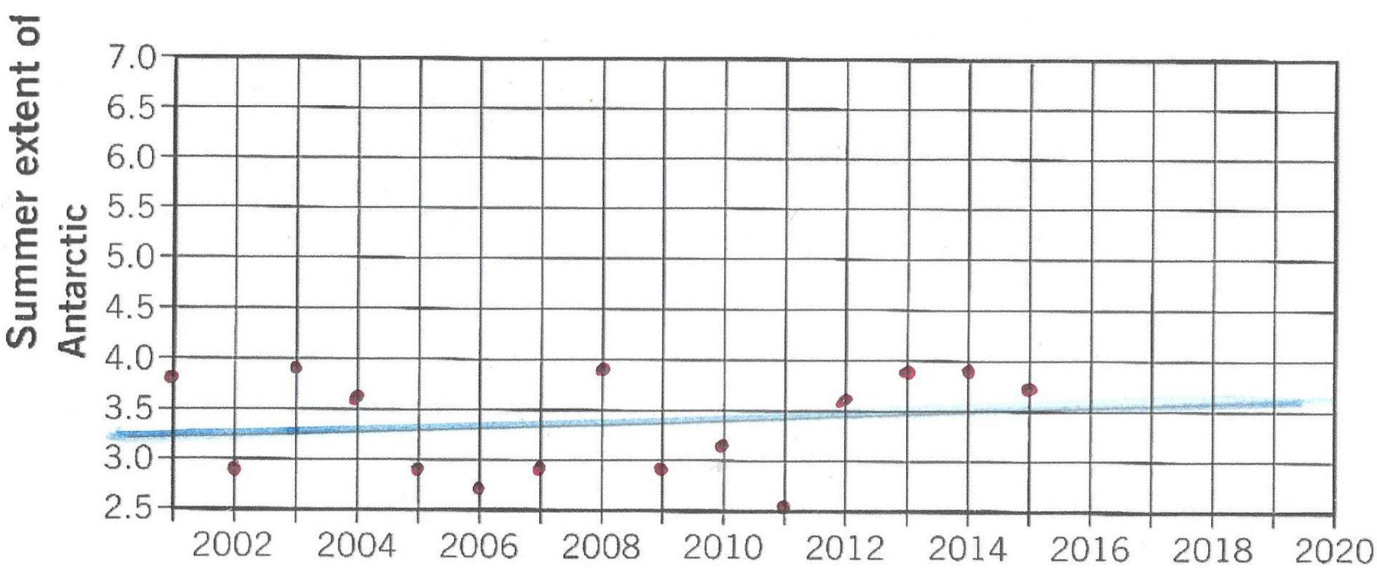
P. 368, QB-6: Plot all of the data for the extent of Antarctic sea ice from 2001 to 2015 on the graph labeled "Antarctic" in Fig. A13.1.1, and then use a ruler to estimate a best-fit line through the points.
SOLUTION STEP 2

- **Step 2. Draw a line showing trend in data**



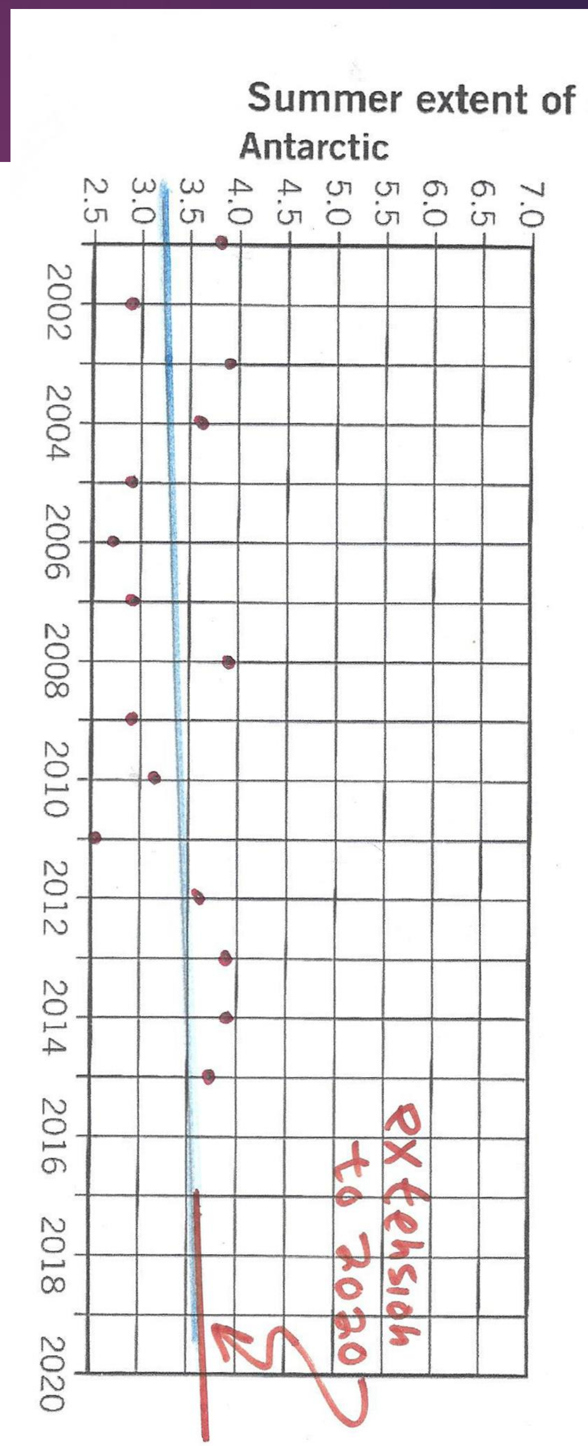
P. 368, QB-6: Plot all of the data for the extent of Antarctic sea ice from 2001 to 2015 on the graph labeled “Antarctic" in Fig. A13.1.1, and then use a ruler to estimate a best-fit line through the points.
SOLUTION STEP 2

- **Step 2. Draw a line showing trend in data**



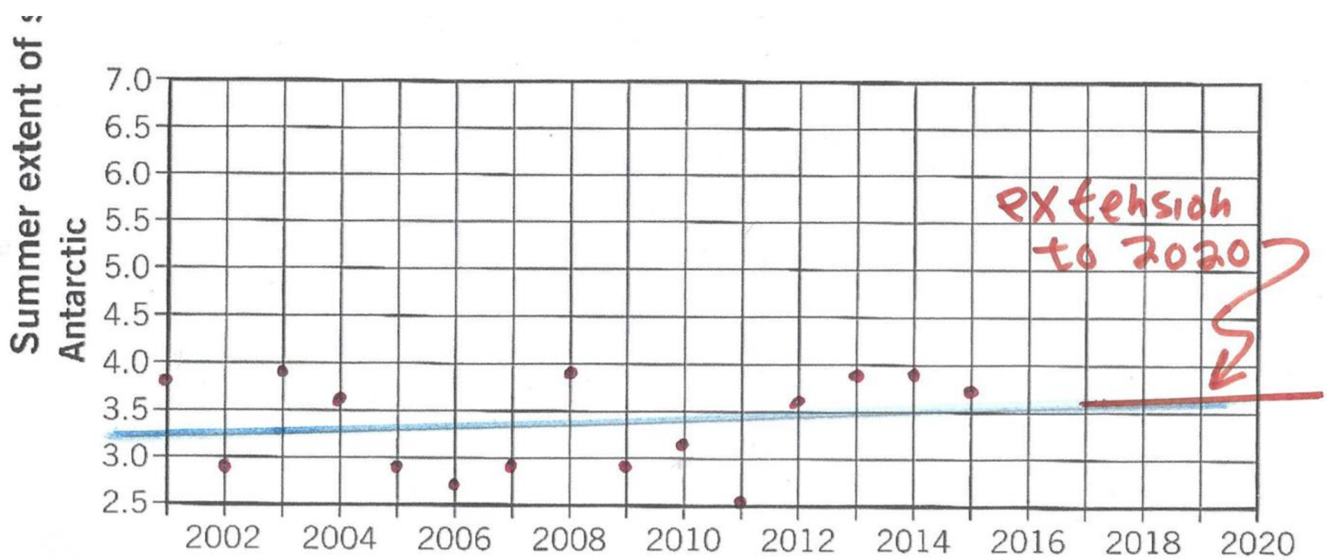
p. 368, QB-7: What do you predict the extent of Antarctic sea ice will be in 2020?

- **Step 1. Extend the line you made in QB-6 to 2020**



p. 368, QB-7: What do you predict the extent of Antarctic sea ice will be in 2020? SOLUTION Steps 1 and 2

- **Step 1. Extend the line you made in QB-6 to 2020**



Step 2. Read the projected amount of Antarctic sea ice in 2020: 3.7 million square km

p. 368, QB-8. Based on your work in response to parts B2 and B5- B7, would you say that the annual amount of Antarctic sea ice as measured in February of each year is decreasing, increasing, or staying about the same? Explain .

- **The trend line in QB-7 is slightly upward. So this interpretation suggests that the amount of Antarctic sea ice is increasing through 2020.**

p. 368, QC. REFLECT & DISCUSS How do the changes in Arctic sea ice extent over time compare with the Antarctic changes?
If they are different, why do you think that might be? Consider as many possibilities as you can .

- **There is dramatic decrease in Artic sea ice and a modest increase in Antarctic sea ice. This is due to**
- **1) Changes in the thermocline ocean circulation system. Less cold water is being removed from the Artic and more cold water is making it back to the Antartic.**
- **2) More land mass in the Antartic promotes accumulation of snow and ice than water-covered Artic.**
- **3) There is increased evaporation from global warming, and more water to be evaporated in the southern hemisphere, so more snow is falling on Antartica than the Artic.**

Name: ____________________ Course/Section: ____________________ Date: ____________

A **Figure 13.12** includes a topographic map of the area between El Capitan to the north (left) and the Cathedral Rocks and Bridalveil Valley to the south (right). This was once the stream-cut valley of the Merced River, but it has repeatedly been reshaped by glaciers during the past ~2.6 million years. The most recent glacier retreated from Yosemite Valley around 10,000 years ago.

1. Use the profile box in **Fig. A13.2.1** to construct a profile across Yosemite Valley from El Capitan to Middle Cathedral Rock (C and C′, respectively, in **Fig. 13.12**). The vertical lines in the profile box are where index contours (the thicker contours with labeled elevations) cross the line of section C–C′ in **Fig. 13.12**, and the profile is started for you on both sides of the profile box. Continue the profile down all the way to the two points connected by a dashed line between elevations 2800 and 3000 feet. This is the depth of the top of the granitic bedrock that was excavated by glaciers, and everything above that curve to the current ground surface is glacial or postglacial sediment.

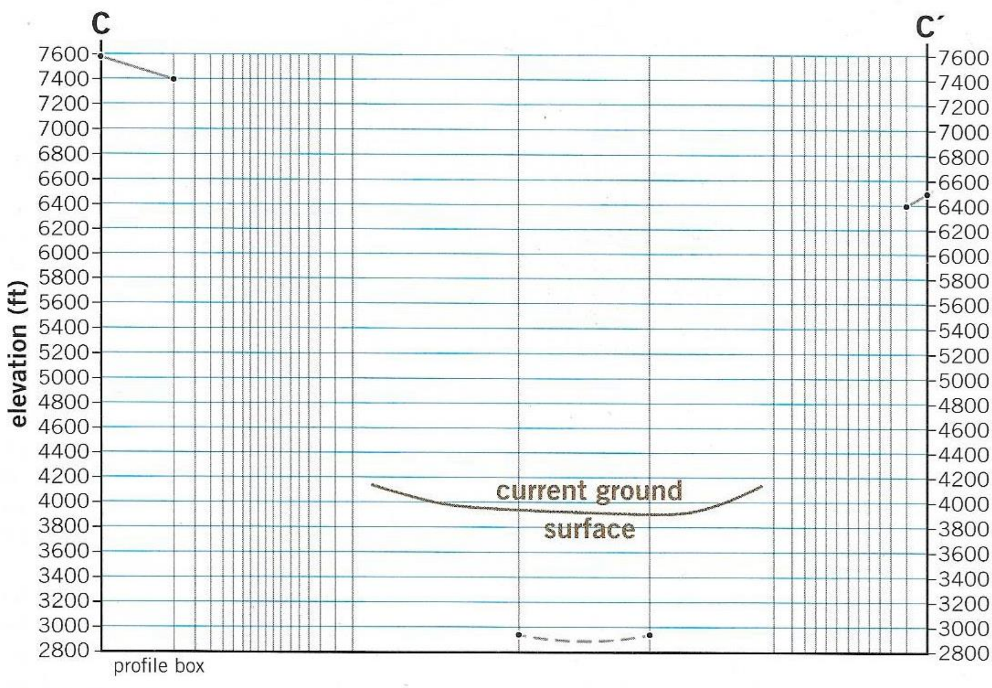


Figure A13.2.1

2. Use the profile box in **Fig. A13.2.2** to construct a profile across Bridalveil Valley from D to D′ in **Fig. 13.12**. The points at D and D′ are provided for you, as is the point along Bridalveil Creek at the bottom middle of the profile box. The vertical lines are where the index contours cross the line of section D–D′ in **Fig. 13.12**.

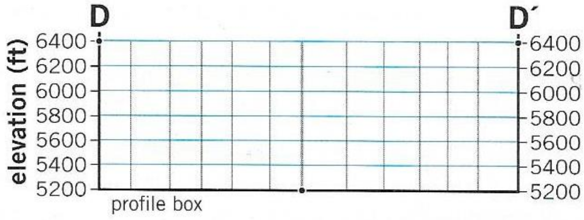


Figure A13.2.2

p. 369, QA. Figure 13.12 includes a topographic map of the area between El Capitan to the north (left) and the Cathedral Rocks and Bridalveil Valley to the south (right). This was once the stream-cut valley of the Merced River, but it has repeatedly been reshaped by glaciers during the past - 2.6 million years. The most recent glacier retreated from Yosemite Valley around 10,000 years ago.

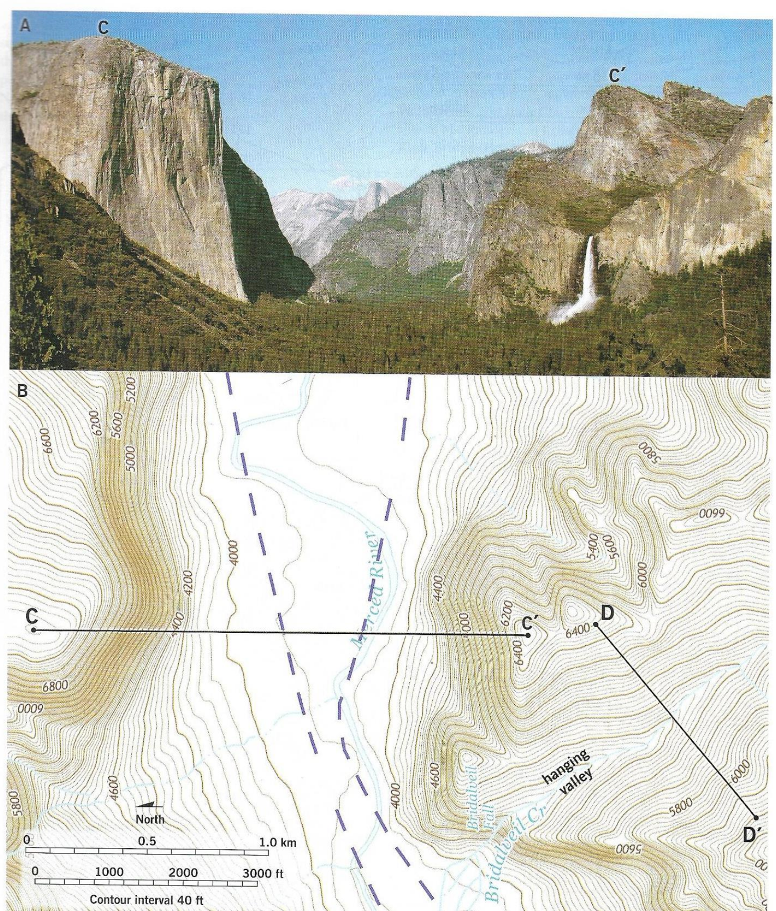


Figure 13.12 Yosemite Valley. **A.** View of glacially modified Yosemite Valley, looking east from Inspiration Point (37.7156°N, 119.6769°W). Points C and C′ are the endpoints of a profile constructed in Activity 13.2. Point C is on El Capitan, and C′ is on Middle Cathedral Rock. Bridal Veil Falls is to the right, and Half Dome is in the background at the center of the photo. **B.** Portion of the USGS 7.5-minute topographic quadrangle map of El Capitan, California. The purple dashed curve is a topographic contour on the top of the granitic basement below all of the glacial sediment in the valley based on geophysical investigations by Gutenberg, Buwalda, and Sharp in the mid-1950s. Sections C–C′ and D–D′ are used in Activity 13.2.

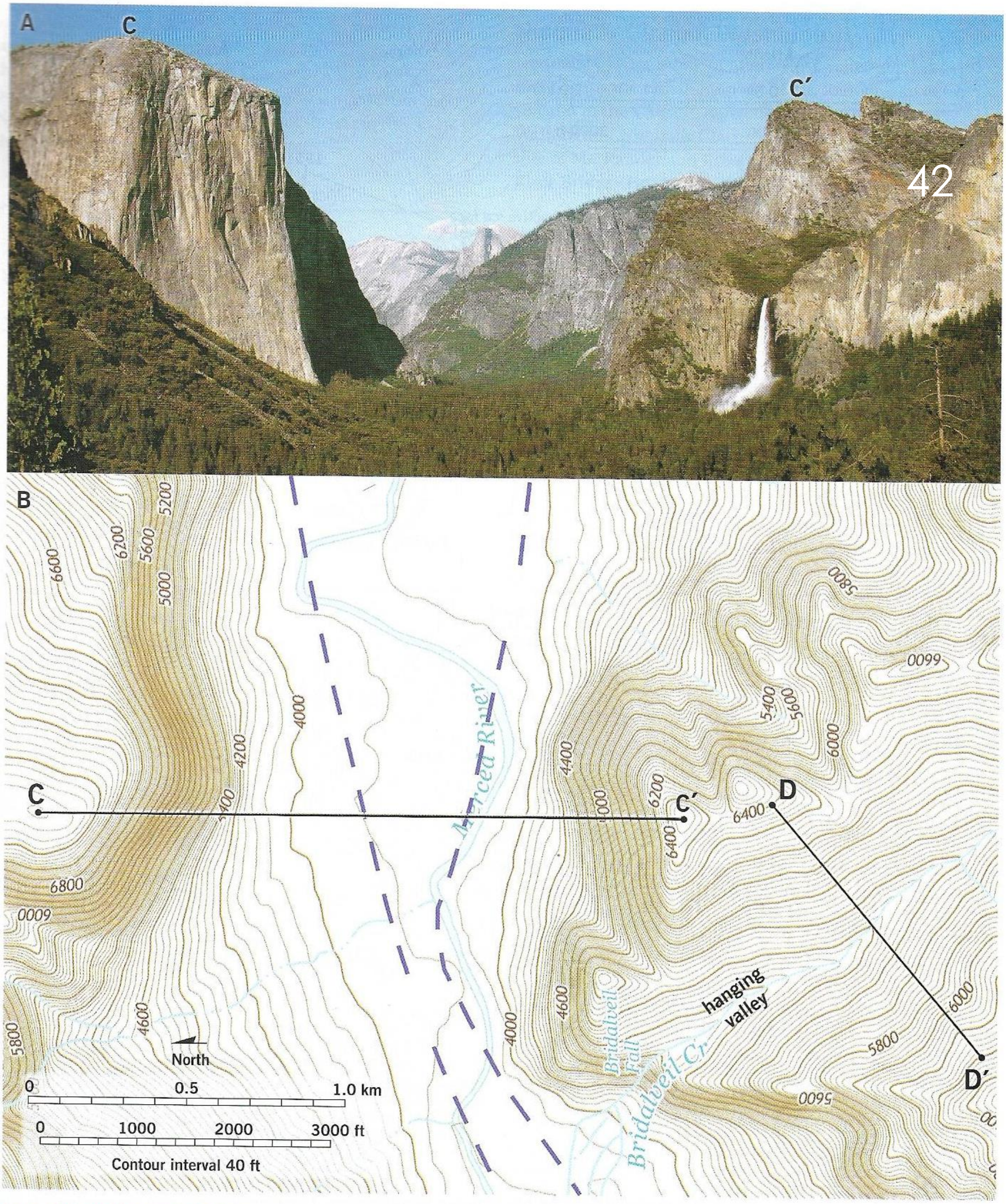
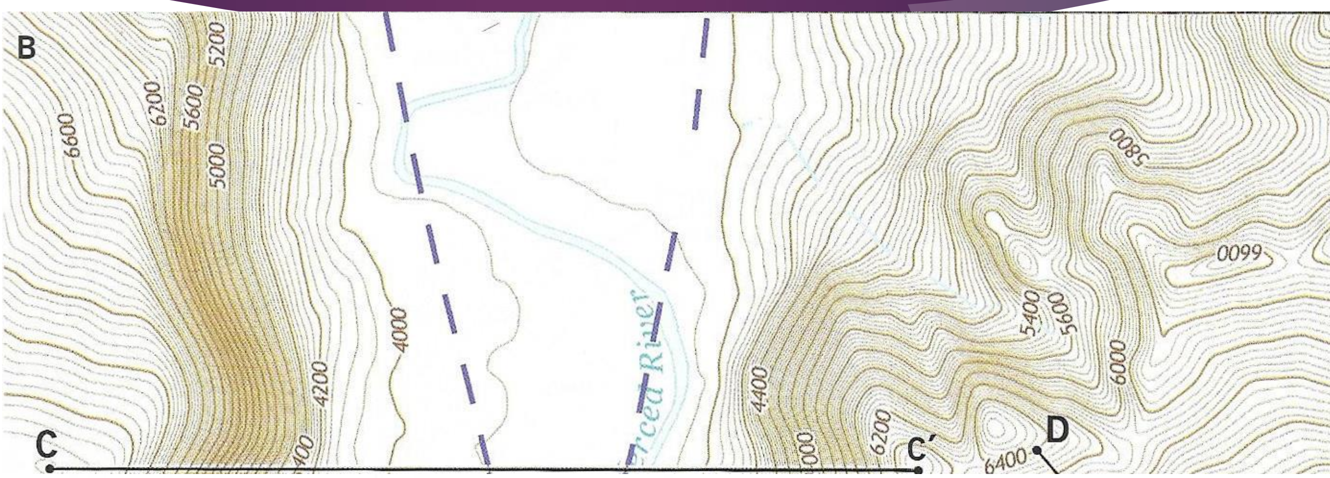


Figure 13.12 Yosemite Valley. **A.** View of glacially modified Yosemite Valley, looking east from Inspiration Point (37.7156°N, 119.6769°W). Points C and C′ are the endpoints of a profile constructed in Activity 13.2. Point C is on El Capitan, and C′ is on Middle Cathedral Rock. Bridal Veil Falls is to the right, and Half Dome is in the background at the center of the photo. **B.** Portion of the USGS 7.5-minute topographic quadrangle map of El Capitan, California. The purple dashed curve is a topographic contour on the top of the granitic basement below all of the glacial sediment in the valley based on geophysical investigations by Gutenberg, Buwalda, and Sharp in the mid-1950s. Sections C–C′ and D–D′ are used in Activity 13.2.

p. 369, QA-1: Use the profile box in Fig. A13.2.1 to construct a profile across Yosemite Valley from El Capitan lo Middle Cathedral Rock (C and C', respectively, in Fig. 13.12) . The vertical lines in the profile box are where index contours (the thicker contours with labeled elevations) cross the line of section C-C' in Fig. 13.12, and the profile is started for you on both sides of the profile box. Continue the profile down all the way to the two points connected by a dashed line between elevations 2800 and 3000 feet. This is the depth of the top of the granitic bedrock that was excavated by glaciers, and everything above that curve to the current ground surface is glacial or postglacial sediment

p. 369, QA-1, Solution Step 1. Use the graph in Figure A13.2.1 with the map in Fig. 13.12 on p. 359. Step 1. Print this slide



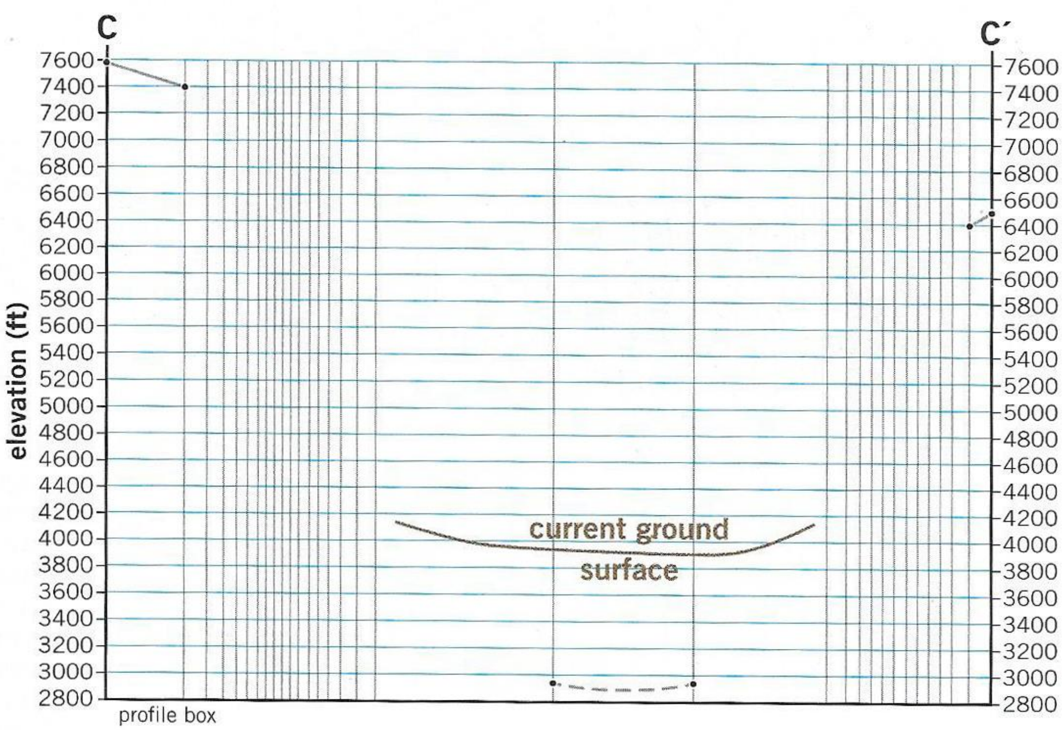


Figure A13.2.1

p. 369, QA-1, Solution Step 2. Add points to the graph (Fig. A13.2.1) on p. 369.

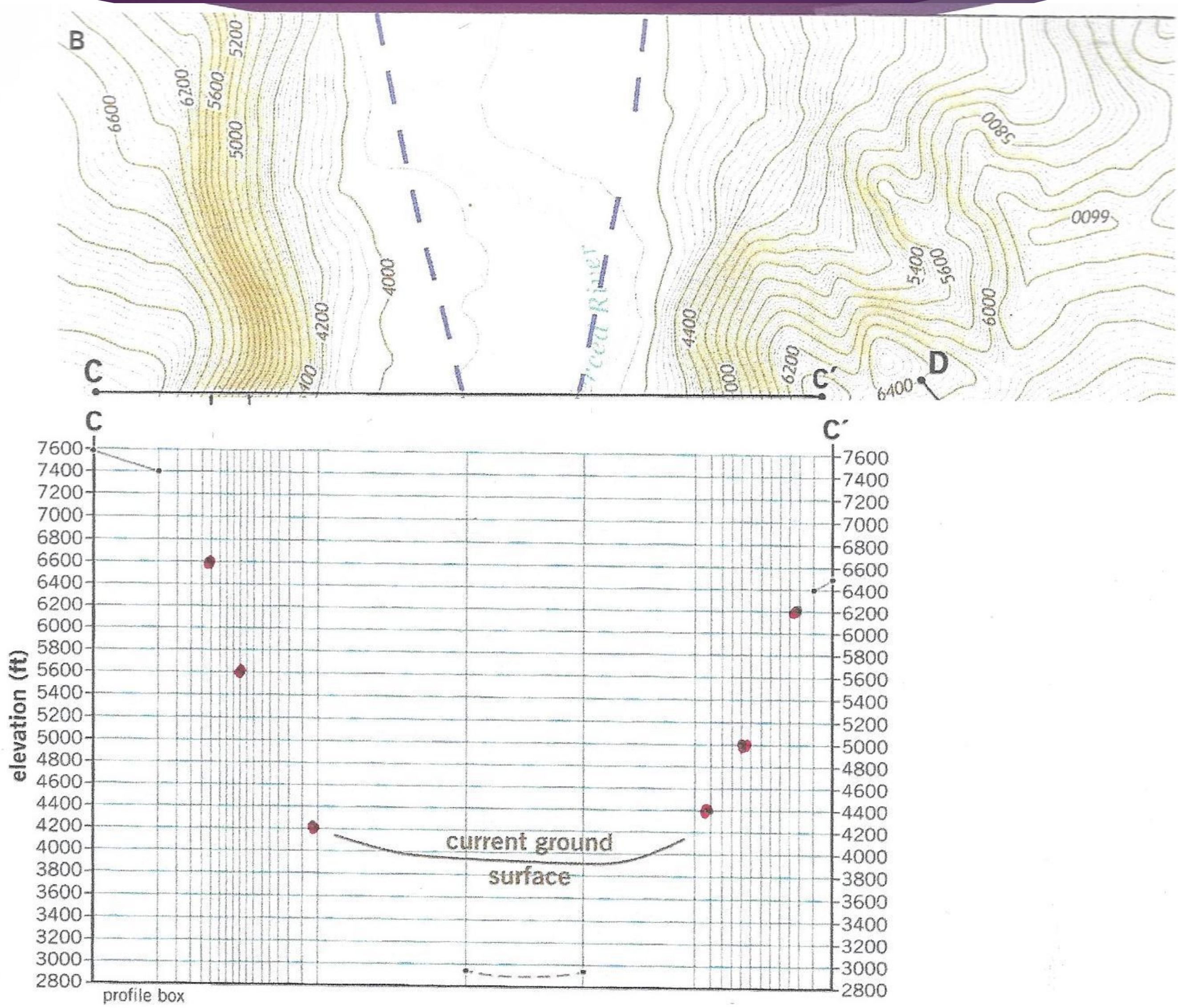


Figure A13.2.1

p. 369, QA-1, Solution Step 3. Connect the dots to complete the profile.

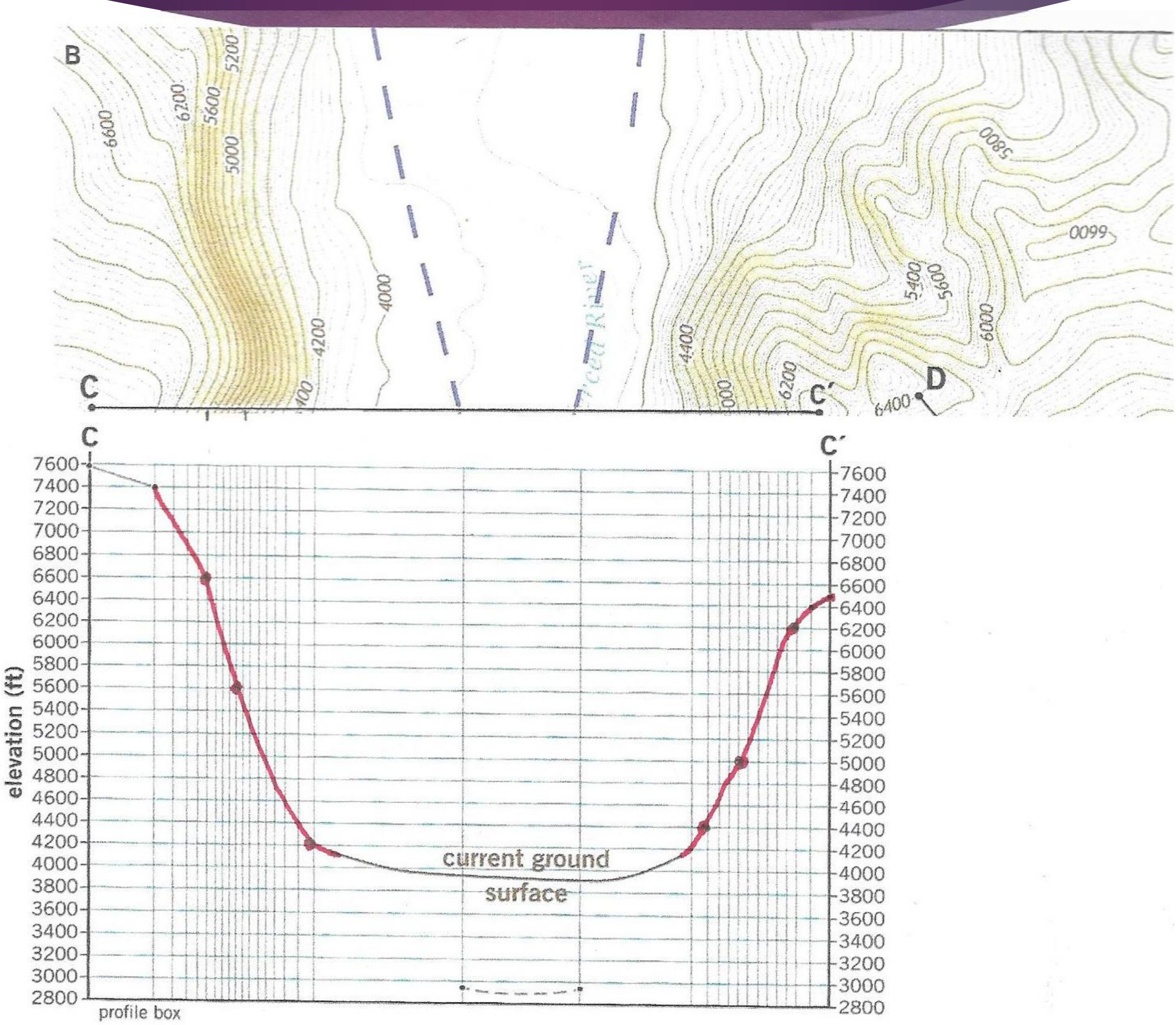
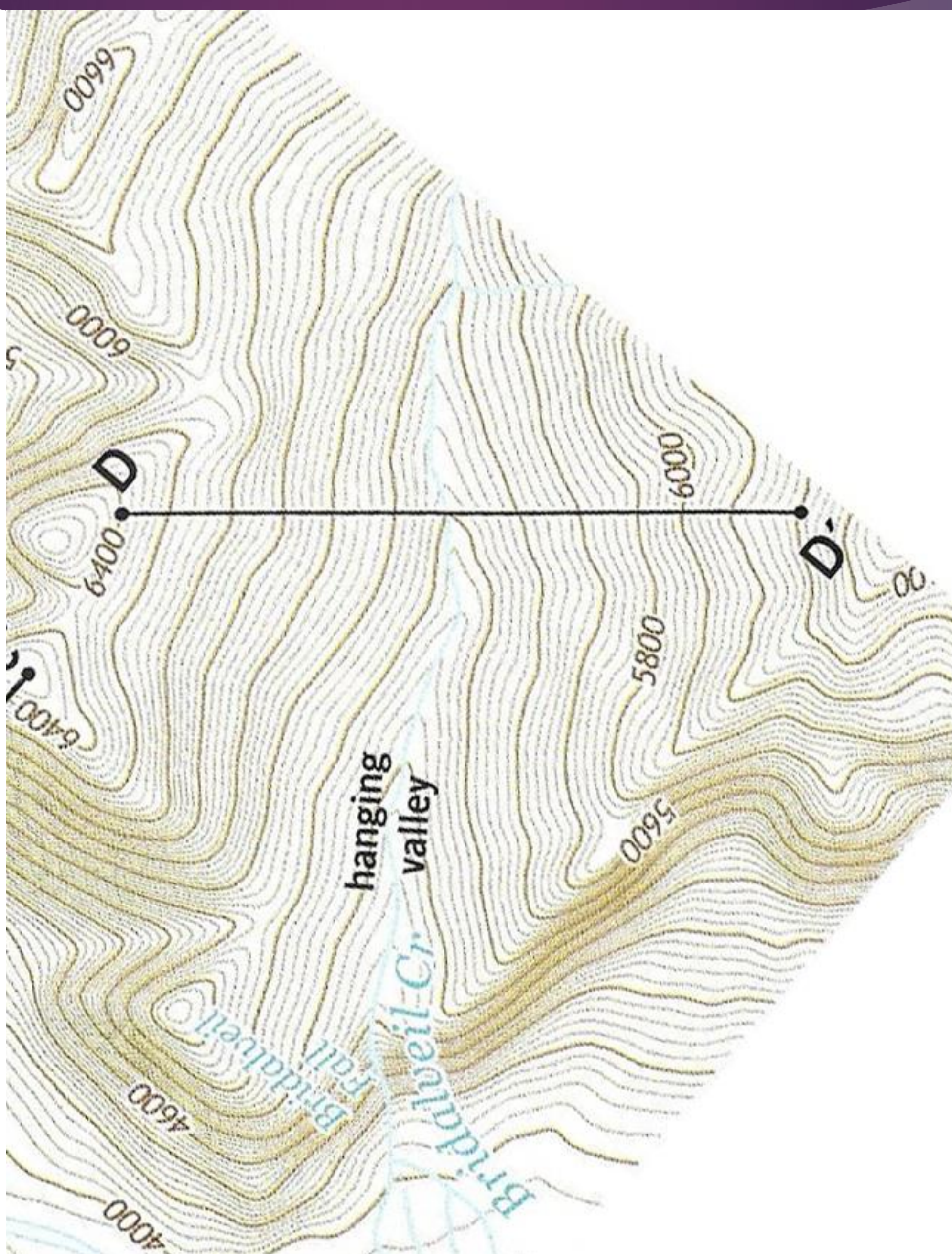
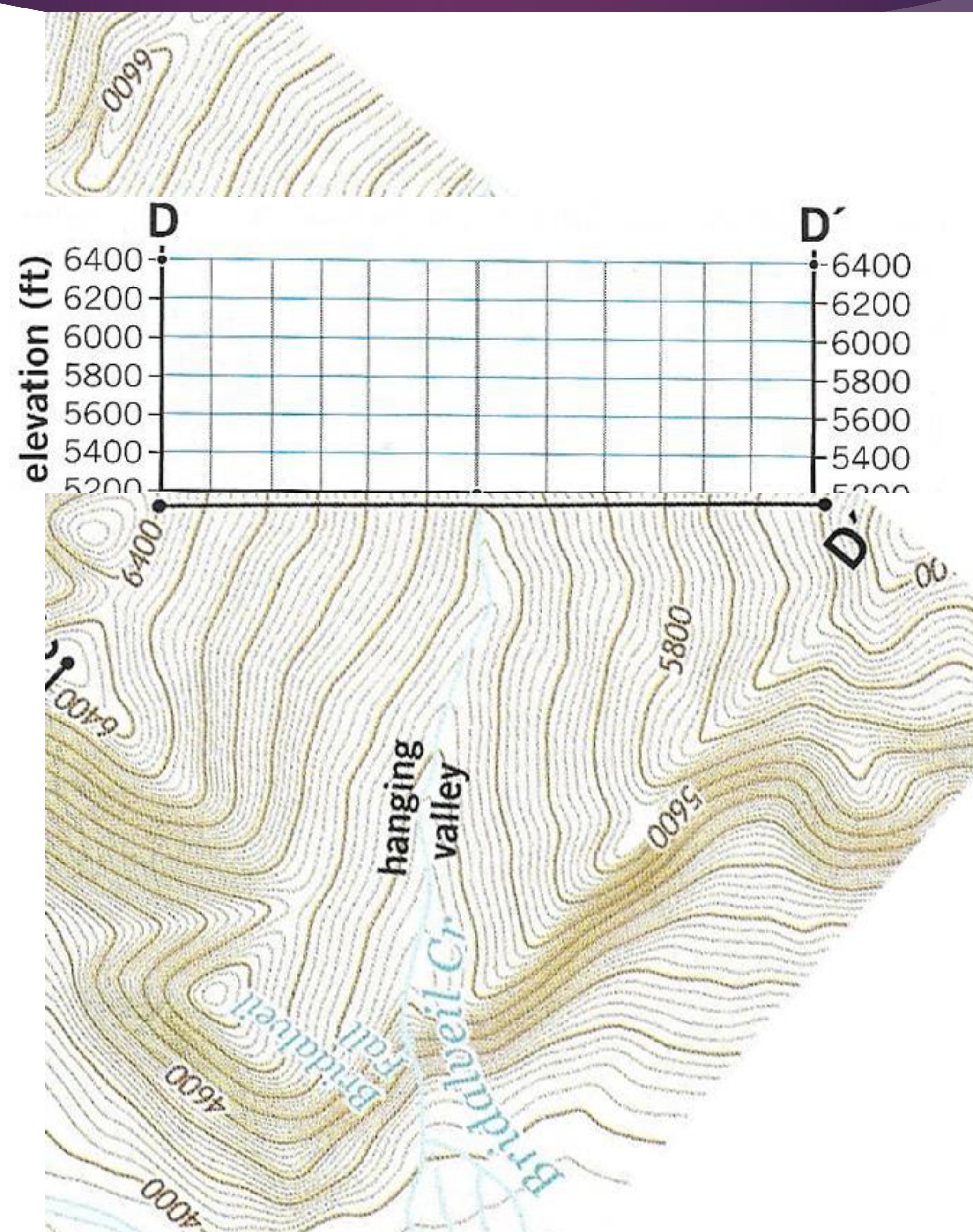


Figure A13.2.1

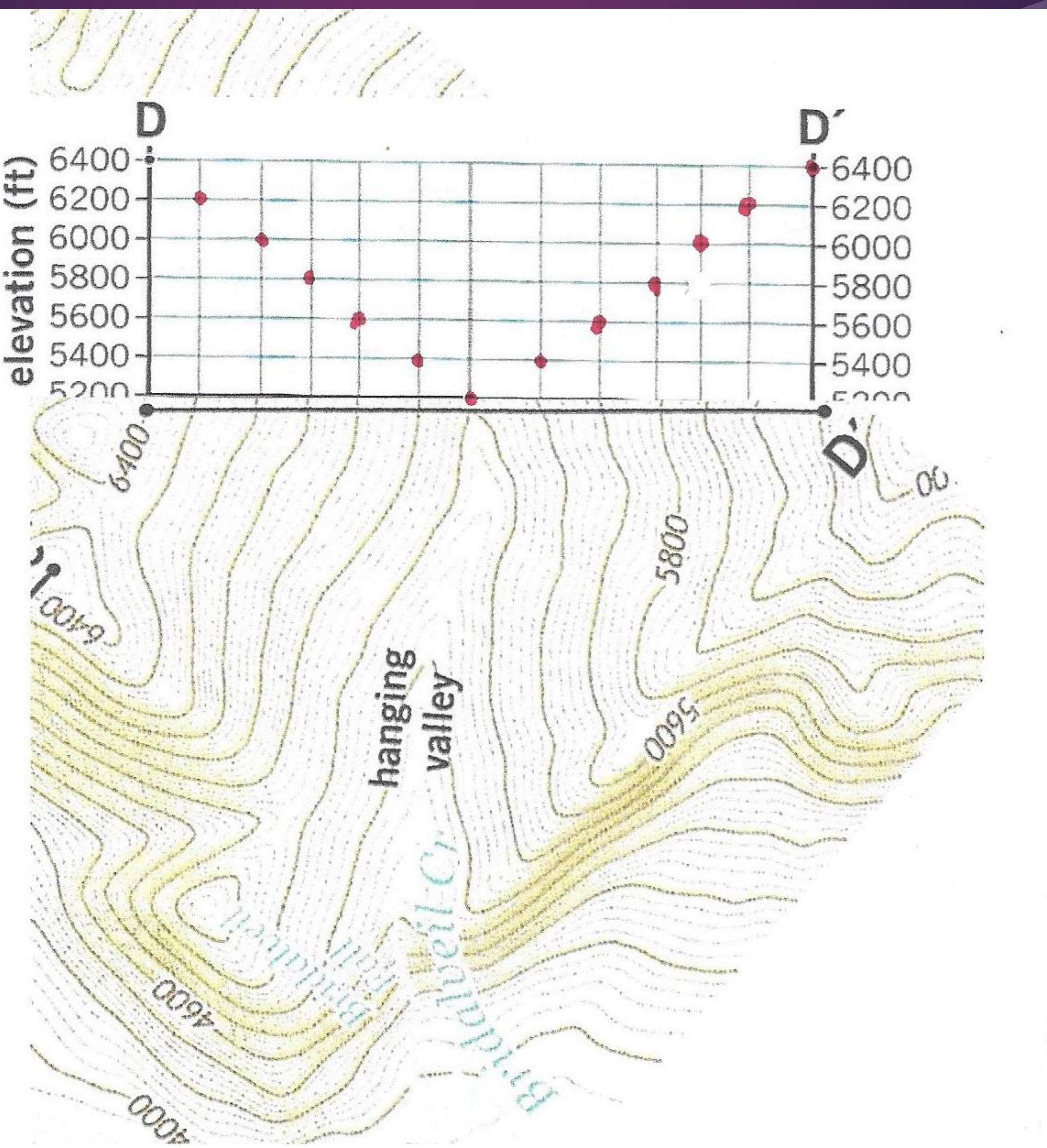
p. 369, QA-2: Use the profile box in Fig. A13.2.2 to construct a profile across Bridalveil Valley from D to D' in Fig. 13.12. The points at D and D' arc provided for you, as is the point along Bridalveil Creek at the bottom middle of the profile box. The vertical lines are where the index contours cross the line of section D- D' in Fig. 13.12.



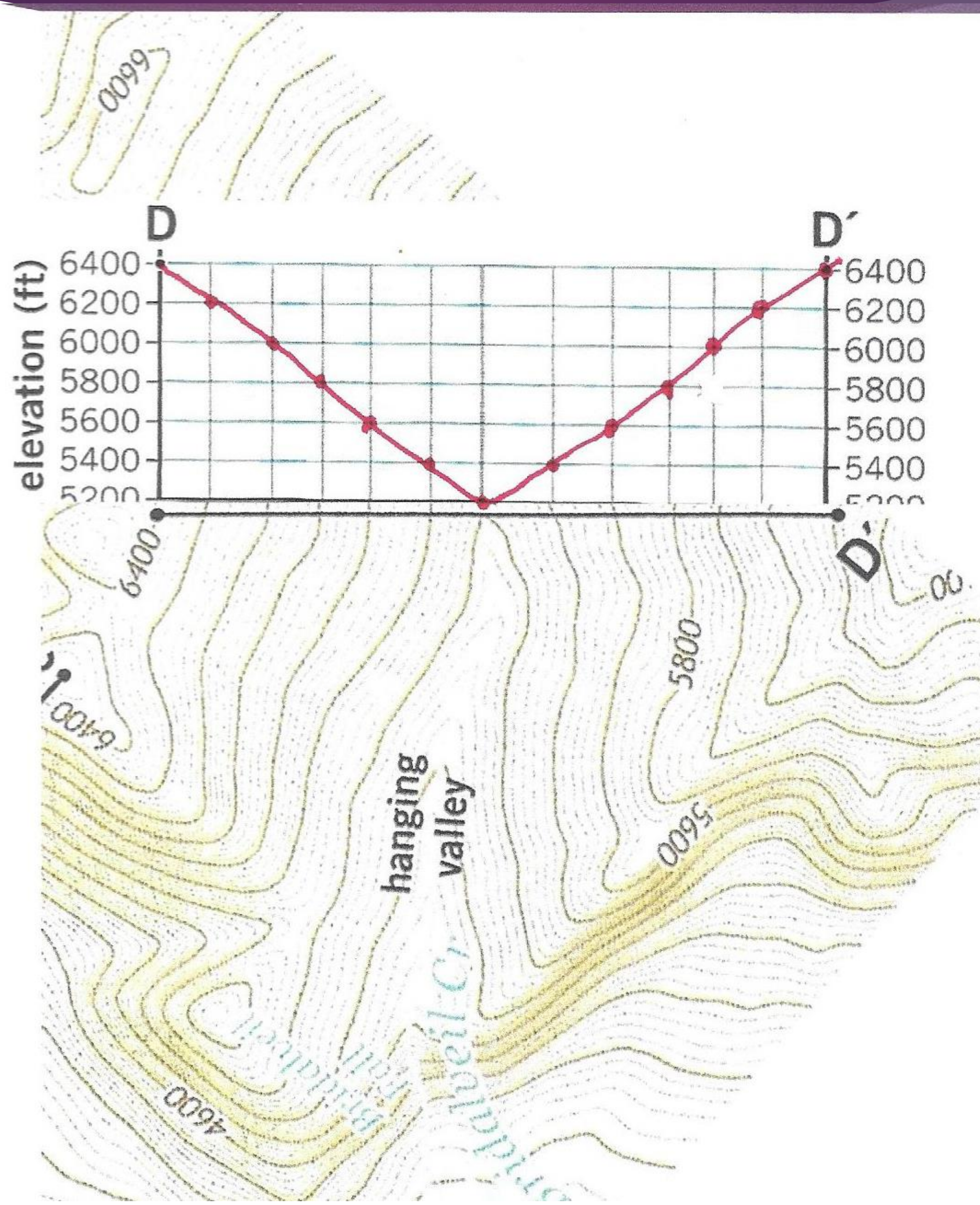
p. 369, QA-2: Use the profile box in Fig. A13.2.2 to construct a profile across Bridalveil Valley from D to D' in Fig. 13.12. The points at D and D' arc provided for you, as is the point along Bridalveil Creek at the bottom middle of the profile box. The vertical lines are where the index contours cross the line of section D- D' in Fig. 13.12. SOLUTION STEP 1. Print this page



p. 369, QA-2: SOLUTION STEP 2. Plot elevation points from the map to the cross section



p. 369, QA-2: SOLUTION STEP 3. Connect the dots to complete the profile



3. **Figure A13.2.3** includes a topographic map and profile box across the Merced River downstream from Yosemite Valley. Carefully construct the profile of section E–E′ in the profile box. There aren't any vertical lines this time to help you, so learn from your previous experience in parts **A1** and **A2** of this activity, or ask your teacher for help.

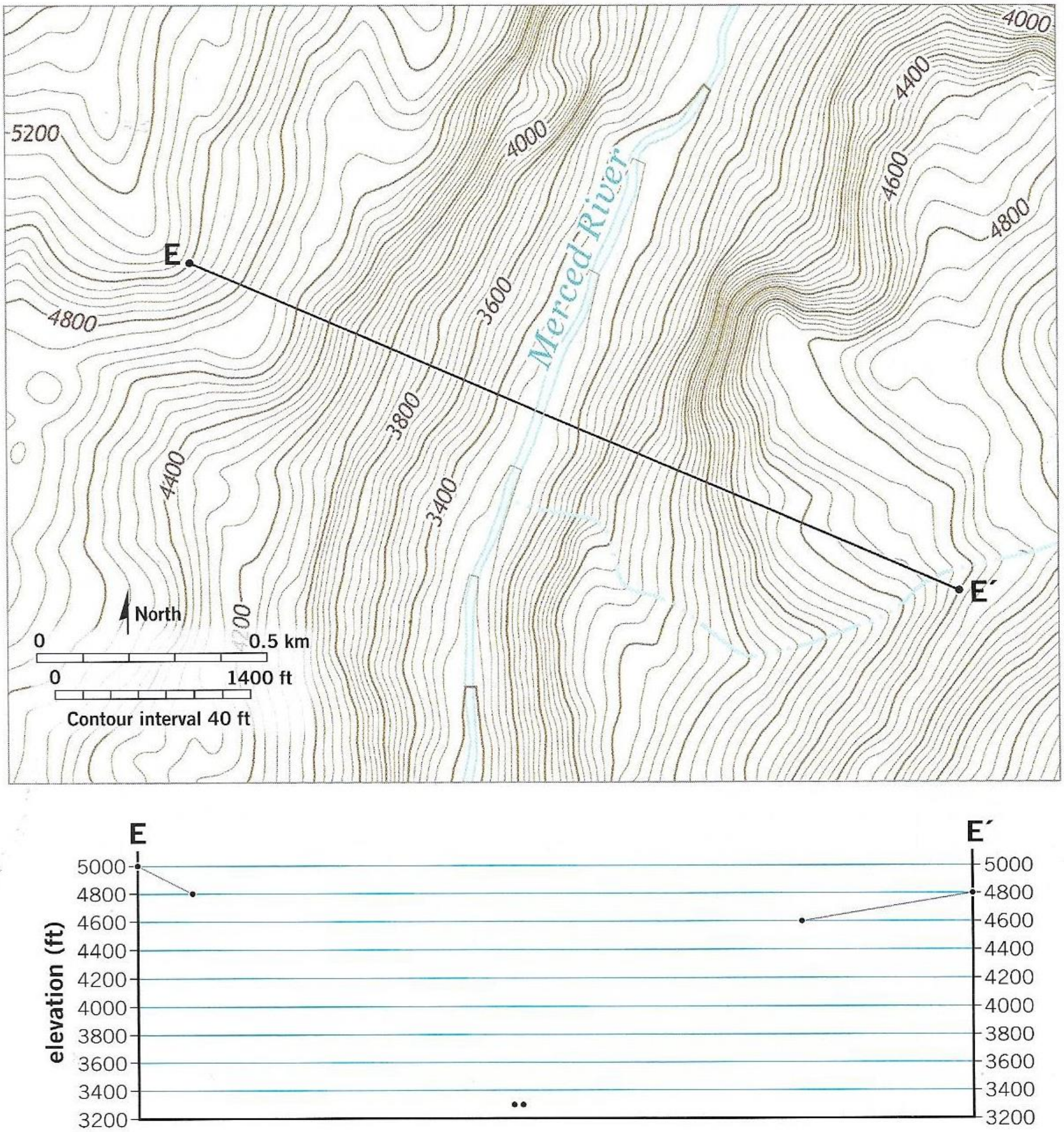


Figure A13.2.3

4. Geoscientists think that the upper part of this valley was modified by a very large glacier early in the Pleistocene Ice Age, but that the lower part of the valley was primarily or exclusively cut by the Merced River. Of course, the water and sediment from every glacial episode in Yosemite Valley was carried away by the Merced River, so it had a significant amount of erosive power at those times. Examine your finished profile E–E′. What part of the valley might you interpret as having been carved by the Merced River, and what part might have been modified by a glacier? That is, below what elevation along profile E–E′ is the part of the valley that might have been cut only by the river?

B Generalize your observations into an initial hypothesis by completing the following two problems.

1. Based on your work, complete the following sentence using either a "U" or "V." Valleys eroded by rivers tend to have a ________-shaped profile, whereas valleys modified by glaciers tend to have a ________-shaped profile.

2. Interpret whether Bridalveil Valley (section D–D′) is more likely to have been shaped by a river or modified by a glacier or some contribution from both. Explain your reasoning.

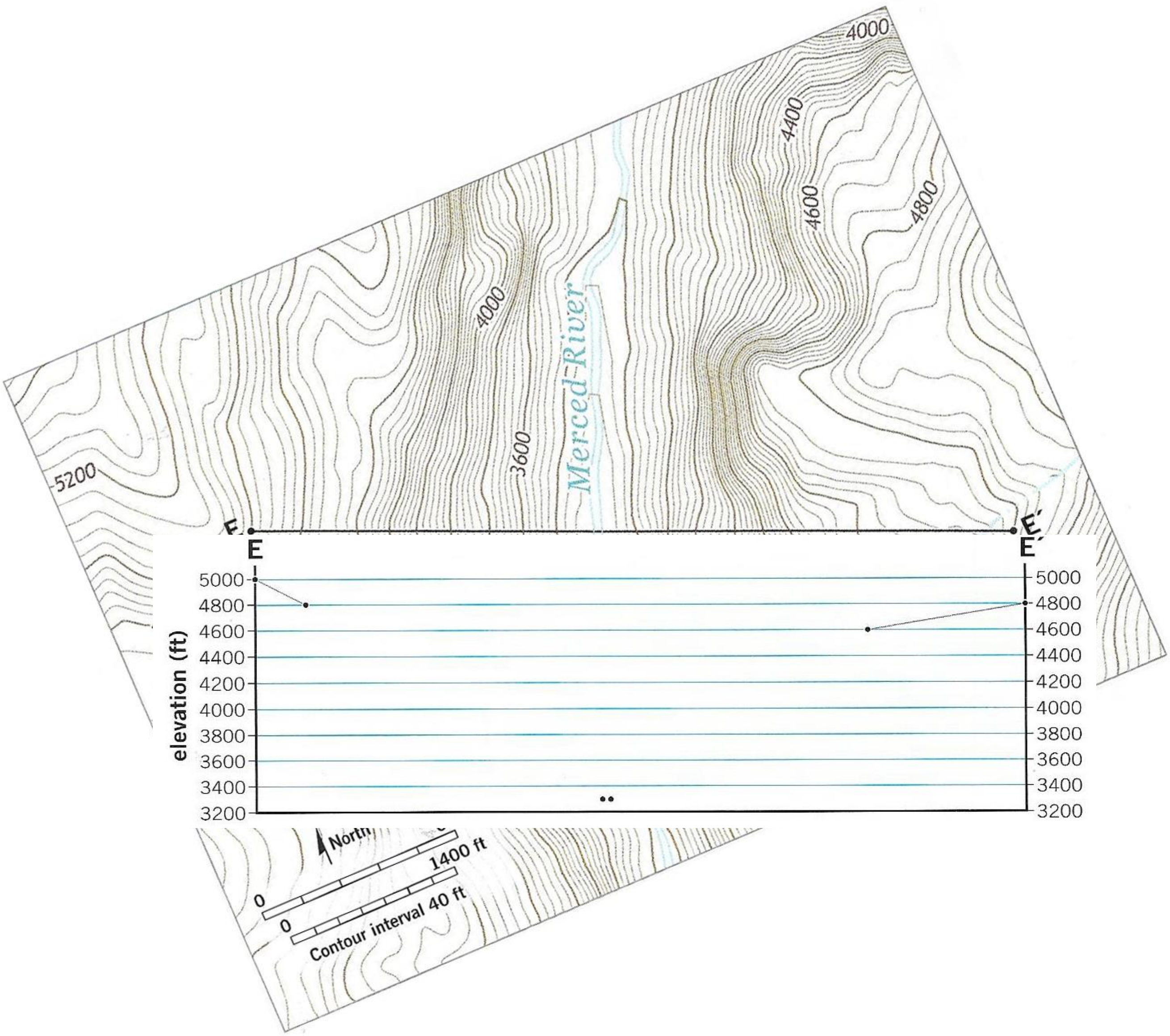
p. 370. QA-3

- **Q3.Figure A13.2.3 includes a topographic map and profile box across the Merced River downstream from Yosemite Valley. Carefully construct the profile of section E- E' in the profile box. There aren't any vertical lines this time to help you, so learn from your previous experience in parts Al and A2 of this activity, or ask your teacher for help**

p. 370, Q3: Solution Step 1

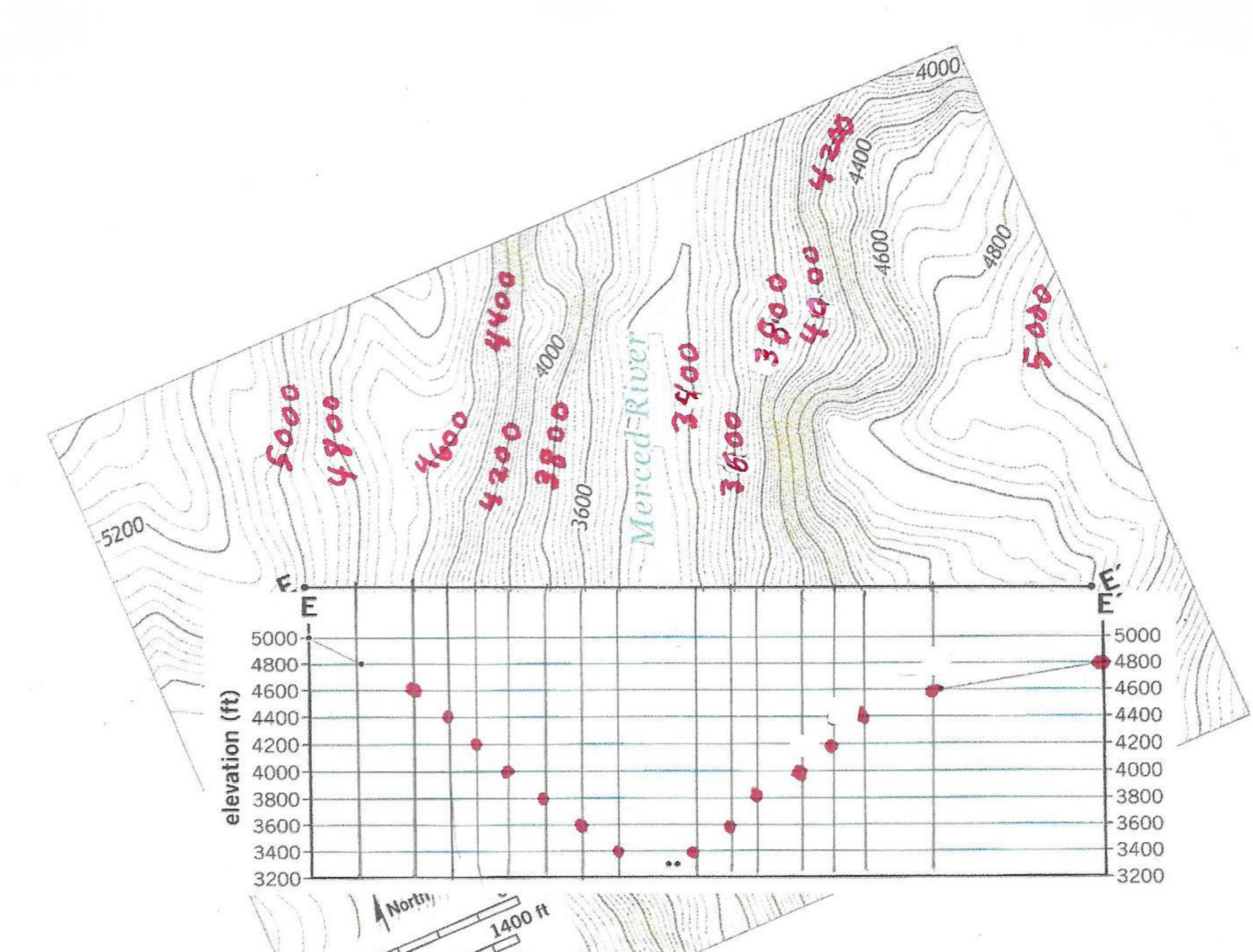
- Copy p. 370. Cut out the Cross Section in Figure A13.2.3. Fold the cross section along the top where E and E' are. Position the cross section along the line on the map in Figure A13.2.3

p. 370, Q3: Solution Step 1
Print this slide



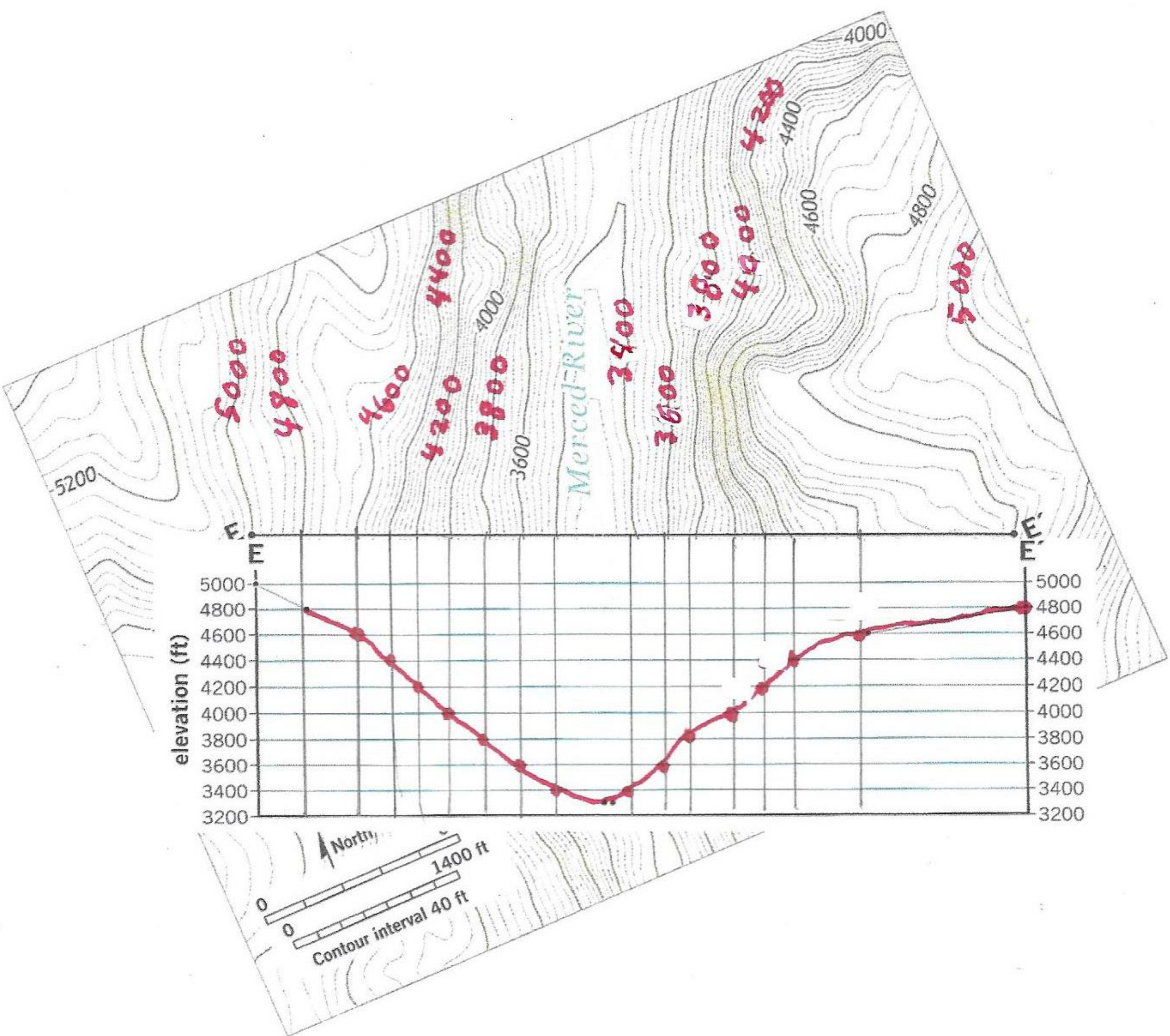
p. 370 QA-3. Solution Step 2

- **Label the dark contour lines on the printout you made for slide 53. Then using the dark contour lines from the map, plot the elevations on to the cross**



p. 370 QA-3. Solution Step 3

- **Connect the dots to complete the profile**



p. 370, QA-4

- **4. Geoscientists think that the upper part of this valley was modified by a very large glacier early in the Pleistocene Ice Age, but that the lower part of the valley was primarily or exclusively cut by the Merced River. Of course, the water and sediment from every glacial episode in Yosemite Valley was carried away by the Merced River, so it had a significant amount of erosive power at those times. Examine your finished profile E-E'. What part of the valley might you interpret as having been carved by the Merced River, and what part might have been modified by a glacier ? That is, below what deviation along profile E-E' is the part of the valley that might have been cut only by the river?**

p. 370, QA-4. SOLUTION

- **The profile interpretation on slide 56 sow a bench on the right side of the profile at 3,800 feet. The rock above this elevation was excavated by the glacier on both sides of the Merced River Canyon**

- **The rocks below 3,800 feet were carved by the Merced River.**

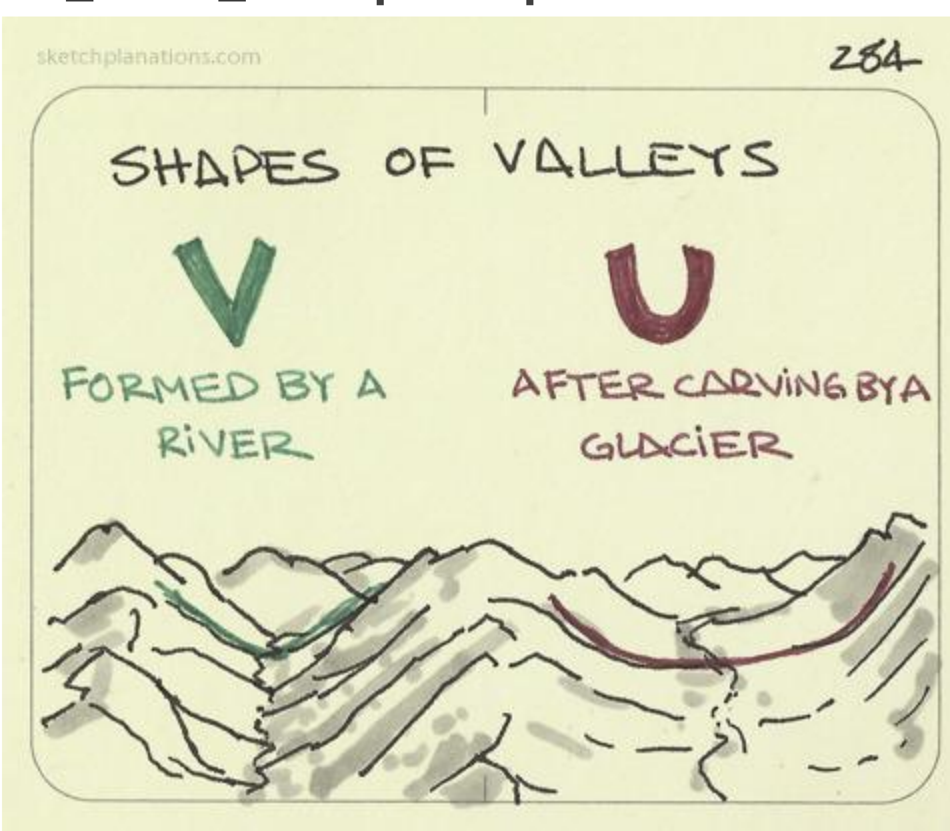
p. 370, QB-1 and B-2.

B. Generalize your observations into an initial hypothesis by completing the following two problems.

- **1. Based on your work, complete the following sentence using either a "U" or "V." Valleys eroded by rivers tend to have a _ _ _ -shaped profile, whereas valleys modified by glaciers tend to have a _ _ _ -shaped profile.**
- **2. Interpret whether Bridalveil Valley (section D - D ') is more likely to have been shaped by a river or modified by a glacier or some contribution from both. Explain your reasoning.**

p. 370, QB-1 SOLUTION

- 1. **Based on your work, complete the following sentence using either a "U" or "V." Valleys eroded by rivers tend to have a _ V _ -shaped profile, whereas valleys modified by glaciers tend to have a _ U _ -shaped profile.**



p. 370, QB-2 SOLUTION

- **2. Interpret whether Bridalveil Valley (section D - D ') is more likely to have been shaped by a river or modified by a glacier or some contribution from both. Explain your reasoning.**
- **Bridaleveil canyon is up high and abandoned on the walls of Yosemite valley. It was originally a side glacier. Later, stream erosion converted its shape from U to V.**

Nisqually Glacier Response to Climate Change

Activity 13.3

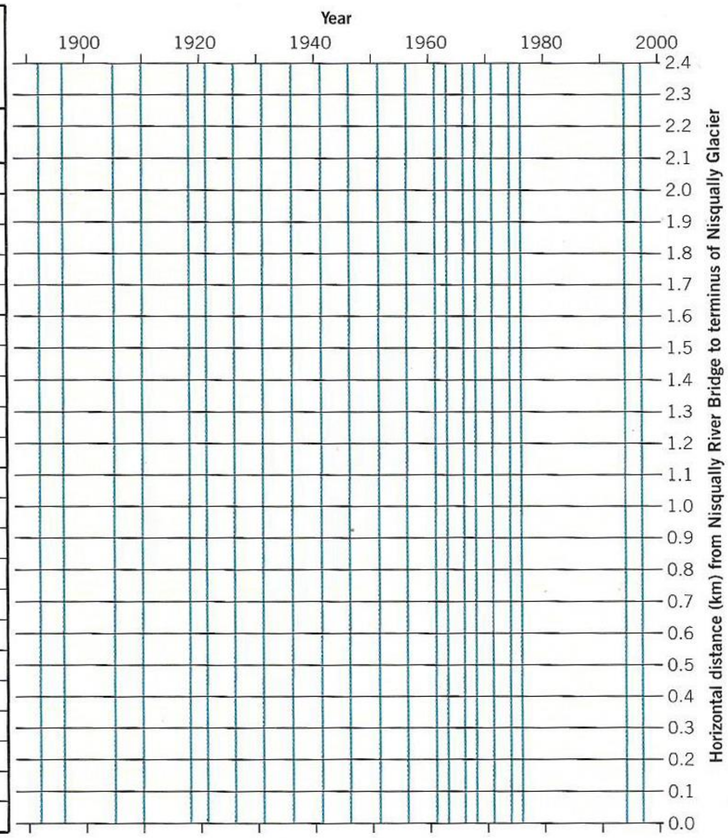
Name: ______________________ Course/Section: ______________________ Date: ______________

Nisqually Glacier is a mountain glacier located on the south side of Mt. Rainier, Washington. Mt. Rainier is considered by the USGS to be one of the most threatening volcanoes in the Cascade Mountains. It has not erupted for more than a century, perhaps not for the past ~500 years.

A Complete the following tasks to compile a data table showing the location of the end of Nisqually Glacier relative to the Nisqually River Bridge at different times.

1. Measure the horizontal distance from Nisqually River Bridge to each of the small yellow dots on **Fig. 13.13** that show where the end (terminus) of Nisqually Glacier was in the past. Record your map measurements (in mm) on the data table in **Fig. A13.3.1**.

Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier	
	mm on map	km on ground
1892		
1896		
1905		
1910		
1918		
1921		
1926		
1931		
1936		
1941		
1946		
1951		
1956		
1961		
1963		
1966		
1968		
1971		
1974		
1976		
1994		
1997		



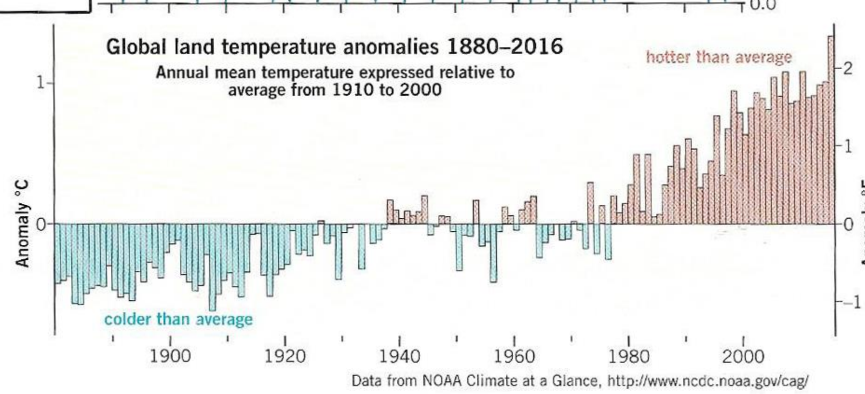


Figure A13.3.1

p. 371. Introduction

- Nisqually Glacier is a mountain glacier located on the south side of Mt. Rainier, Washington. Mt. Rainier is considered by the USGS to be one of the most threatening volcanoes in the Cascade Mountains. It has not erupted for more than a century, perhaps not for the past - 500 years.

p. 371, QA-1.

- **A. Complete the following tasks to compile a data table showing the location of the end of Nisqually Glacier relative to the Nisqually River Bridge at different times.**
- **1. Measure the horizontal distance from Nisqually River Bridge to each or the small yellow dots on Fig. 13.13 that show where the end (terminus) of Nisqually Glacier was in the past. Record your map measurements (in mm) on the data table in Fig.A13.3.1.**

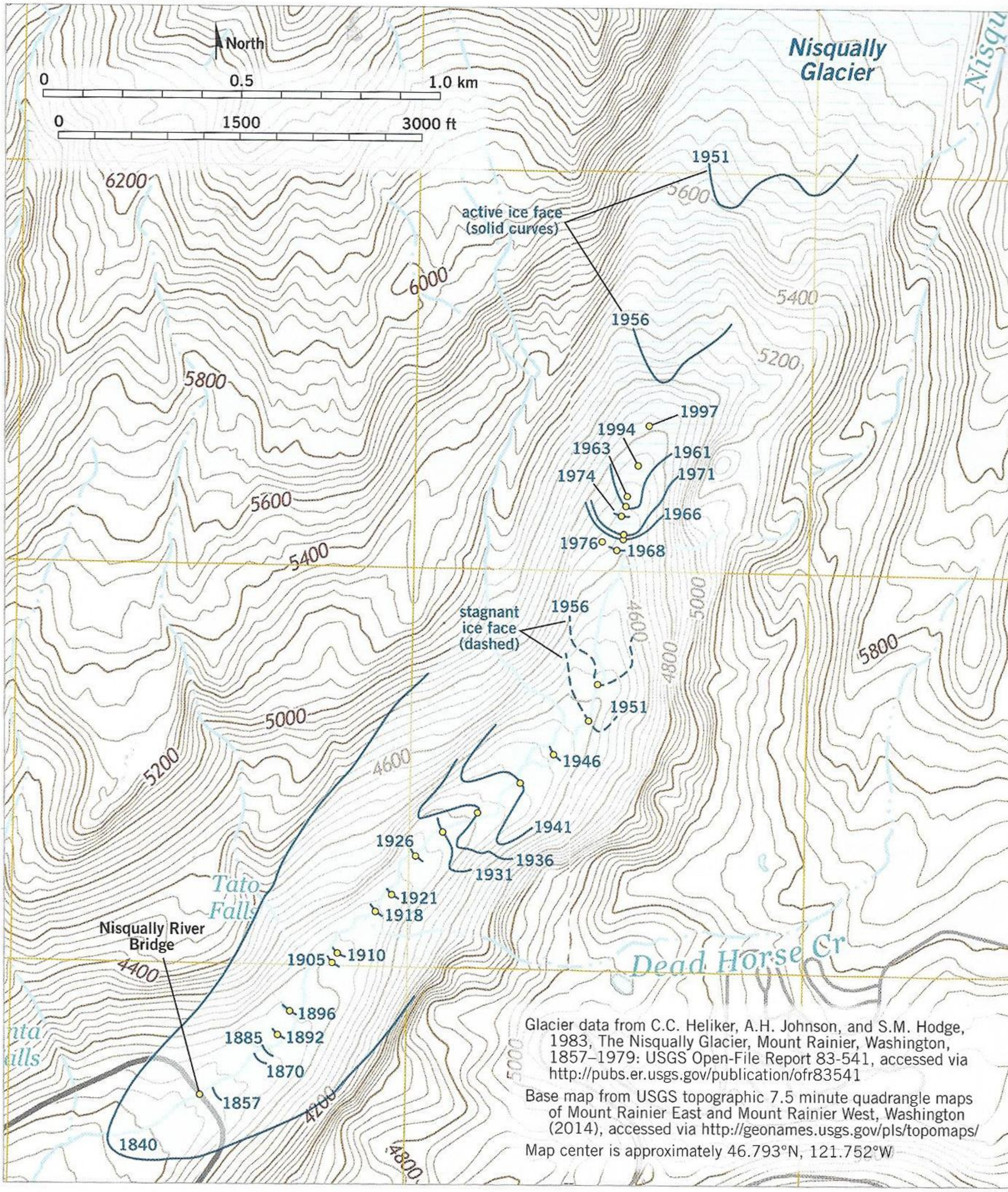
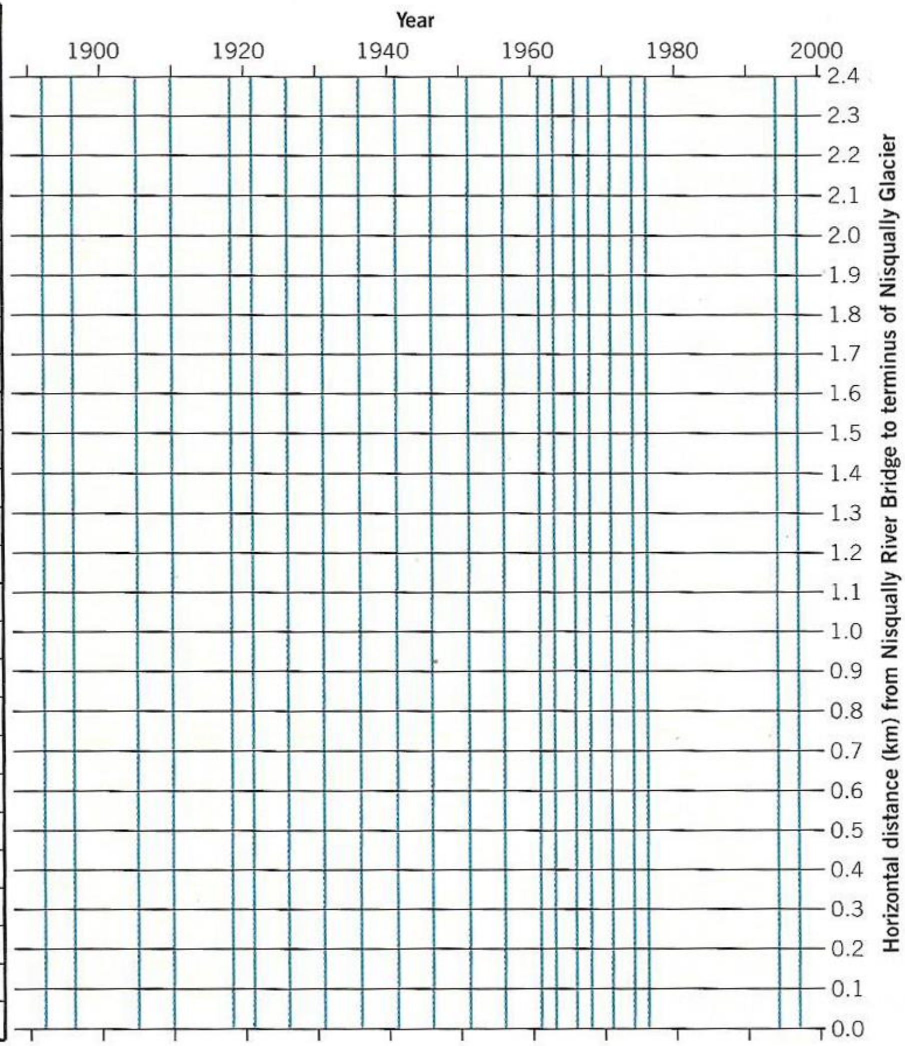


Figure 13.13 Variation in length of Nisqually Glacier on Mt. Rainier, Washington. This map shows where the end (terminus) of Nisqually Glacier was located between 1840 and 1997. Yellow dots are points used in Activity 13.3.

p. 371, QA-1. Solution Step 1

Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier	
	mm on map	km on ground
1892		
1896		
1905		
1910		
1918		
1921		
1926		
1931		
1936		
1941		
1946		
1951		
1956		
1961		
1963		
1966		
1968		
1971		
1974		
1976		
1994		
1997		



Solution: Use a clear ruler to measure distances from Bridge to each yellow dots in mm. Record on graph.

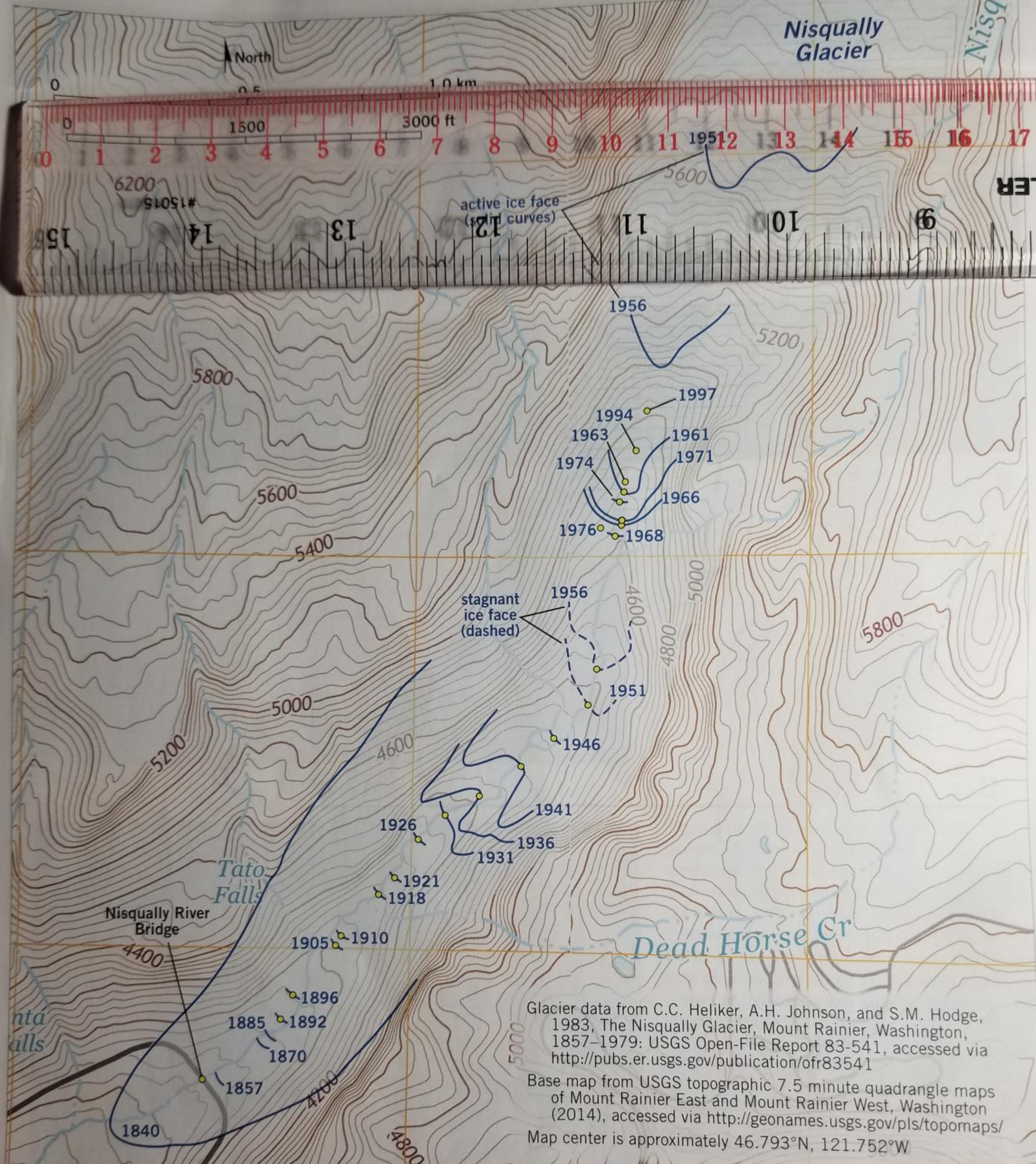


Figure 13.13 Variation in length of Nisqually Glacier on Mt. Rainier, Washington. This map shows where the end (terminus) of Nisqually Glacier was located between 1840 and 1997. Yellow dots are points used in Activity 13.3.

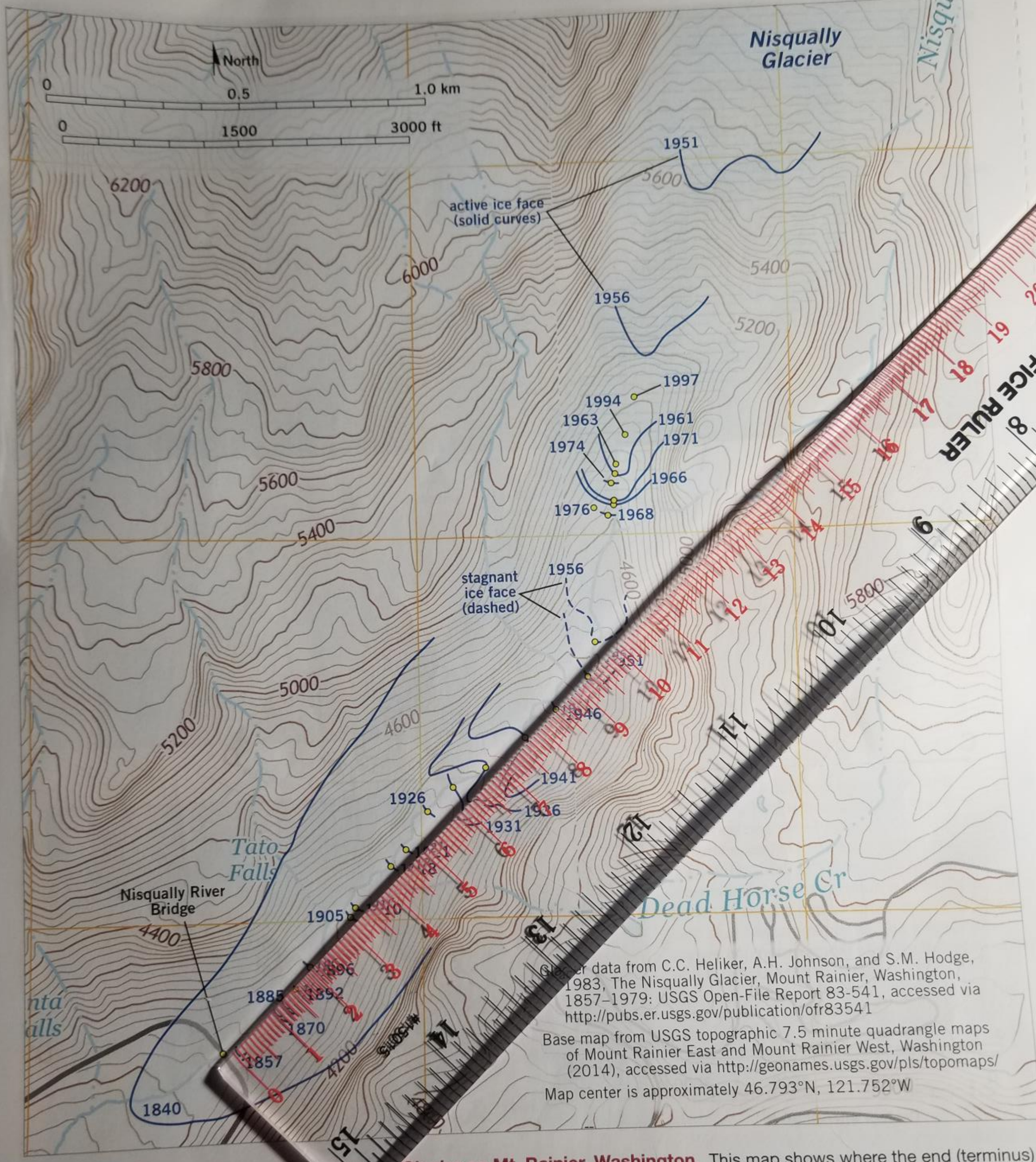


Figure 13.13 Variation in length of Nisqually Glacier on Mt. Rainier, Washington. This map shows where the end (terminus) of Nisqually Glacier was located between 1840 and 1997. Yellow dots are points used in Activity 13.3.

2. Use the bar scale on **Fig. 13.13** and your knowledge of proportions to convert your map measurements (in mm) to distance measurements at full scale (in km). Record your calculated distances, rounded to the hundredth of a km, on the data table in **Fig. A13.3.1**.

B Plot your data.

1. The vertical lines on the graph in **Fig. A13.3.1** represent the years for which data have been compiled. The horizontal lines correspond to horizontal distances between the bridge and the glacier terminus in tenths of km. Carefully plot the data you have compiled on the graph as a set of points.
2. Lightly draw a smooth pencil line through each of the data points in the correct sequence.
3. Notice that the glacier terminus retreated up the valley at some times but advanced back down the valley at other times. Summarize these changes in a brief written description that includes the specific time intervals when the glacier retreated or advanced.

C There is a bar chart below the graph you just completed, and the horizontal time axis in the bar chart is identical to the horizontal axis in the Nisqually Glacier graph. Notice the blue and salmon pink graph of climatic data at the bottom of your graph (part **B**) provided by the NOAA National Climatic Data Center (NCDC). NCDC's global mean temperatures are mean temperatures for Earth calculated by processing data from thousands of observation sites throughout the world (from 1880 to 2009). The temperature data were corrected for factors such as increases in temperature around urban centers and decreases in temperature with elevation. Although NCDC collects and processes data on land and sea, this graph shows the variation in annually averaged global land surface temperature only since 1880.

1. Describe the long-term trend in this graph—how averaged global land surface temperature changed from 1880 to 2015.
2. Lightly in pencil, trace any shorter-term pattern of cyclic climate change that you can identify in the graph. Describe this cyclic shorter-term trend.

D Describe how the changes in position of the terminus of Nisqually Glacier compare to variations in annually averaged global land surface temperature. Be as specific as you can.

E **REFLECT & DISCUSS** Based on all of your work above, do you think Nisqually Glacier can be used as an indicator of climate change? Explain.

p. 372, QA-2: . Use the bar scale on **Fig. 13.13** and your knowledge of proportions to convert your map measurements (in mm) to distance measurements at full scale (in km). Record your calculated distances, rounded to the hundredth of a km, on the data table in **Fig. A13.3.1.**

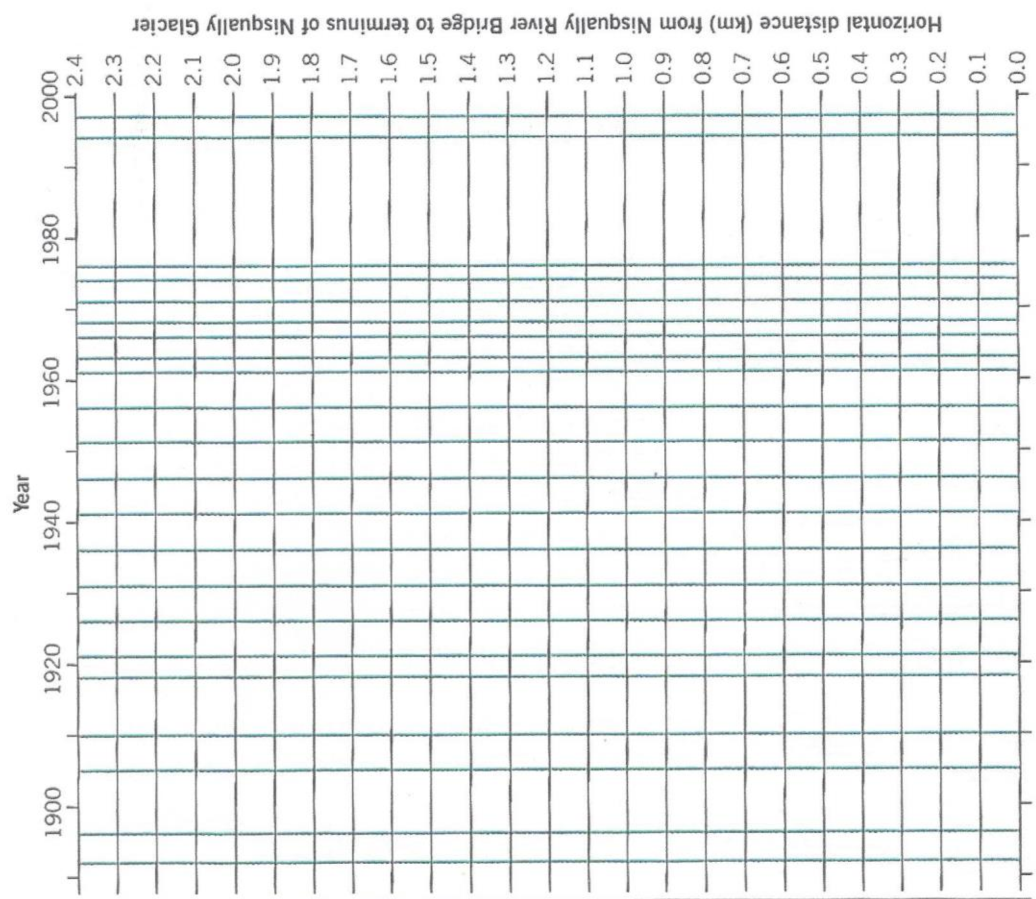
Nisqually Glacier: Distance from Nisqually Bridge to glacier terminus

1 km = 70 mm

Year	mm on map	km on ground
1892	17	0.24
1896	22	0.31
1905	33	0.47
1910	35	0.50
1918	45	0.64
1921	49	0.70
1923	57	0.81
1931	63	0.90
1936	70	1.00
1941	78	1.11
1946	86	1.23
1951	95	1.36
1956	100	1.43
1961	128	1.83
1963	129	1.84
1966	124	1.77
1968	120	1.71
1971	124	1.77
1974	126	1.80
1976	120	1.71
1994	135	1.93
1997	142	2.03

p. 372, QA-2: SOLUTION

Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier	
	mm on map	km on ground
1892	17	0.24
1896	22	0.31
1905	33	0.47
1910	35	0.50
1918	45	0.64
1921	49	0.70
1926	57	0.81
1931	63	0.90
1936	70	1.00
1941	78	1.11
1946	86	1.23
1951	95	1.36
1956	100	1.43
1961	128	1.83
1963	129	1.84
1966	124	1.77
1968	120	1.71
1971	124	1.77
1974	126	1.80
1976	120	1.71
1994	135	1.93
1997	142	2.03



p. 372, QA-2: SOLUTION

Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier	
	mm on map	km on ground
1892	17	0.24
1896	22	0.31
1905	33	0.47
1910	35	0.50
1918	45	0.64
1921	49	0.70
1926	57	0.81
1931	63	0.90
1936	70	1.00
1941	78	1.11
1946	86	1.23
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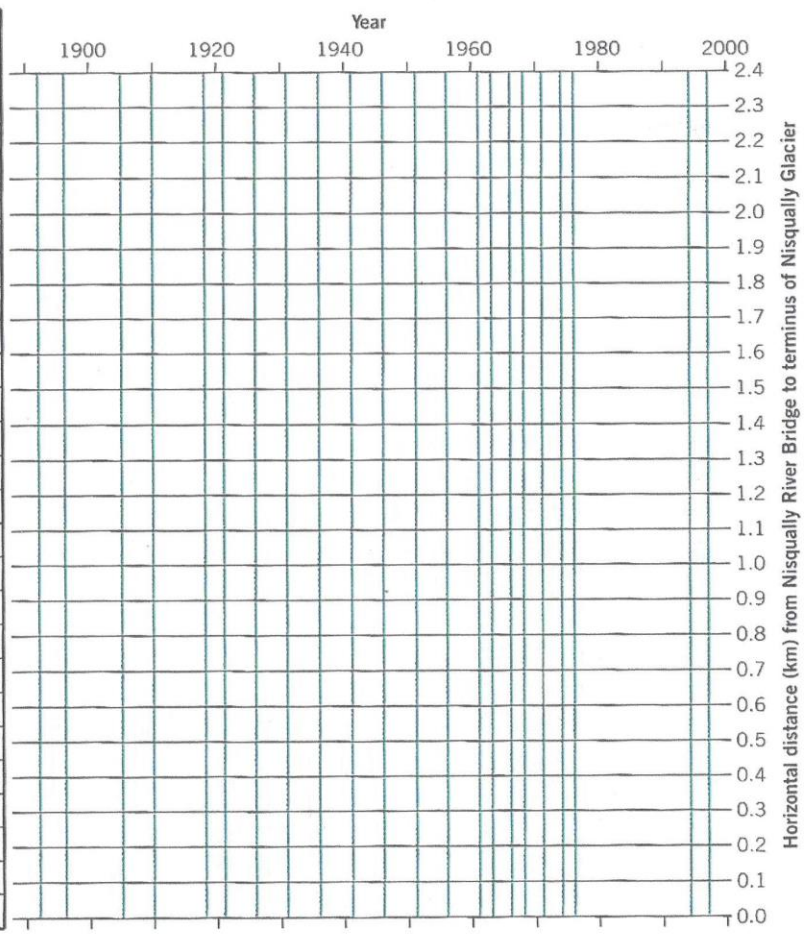
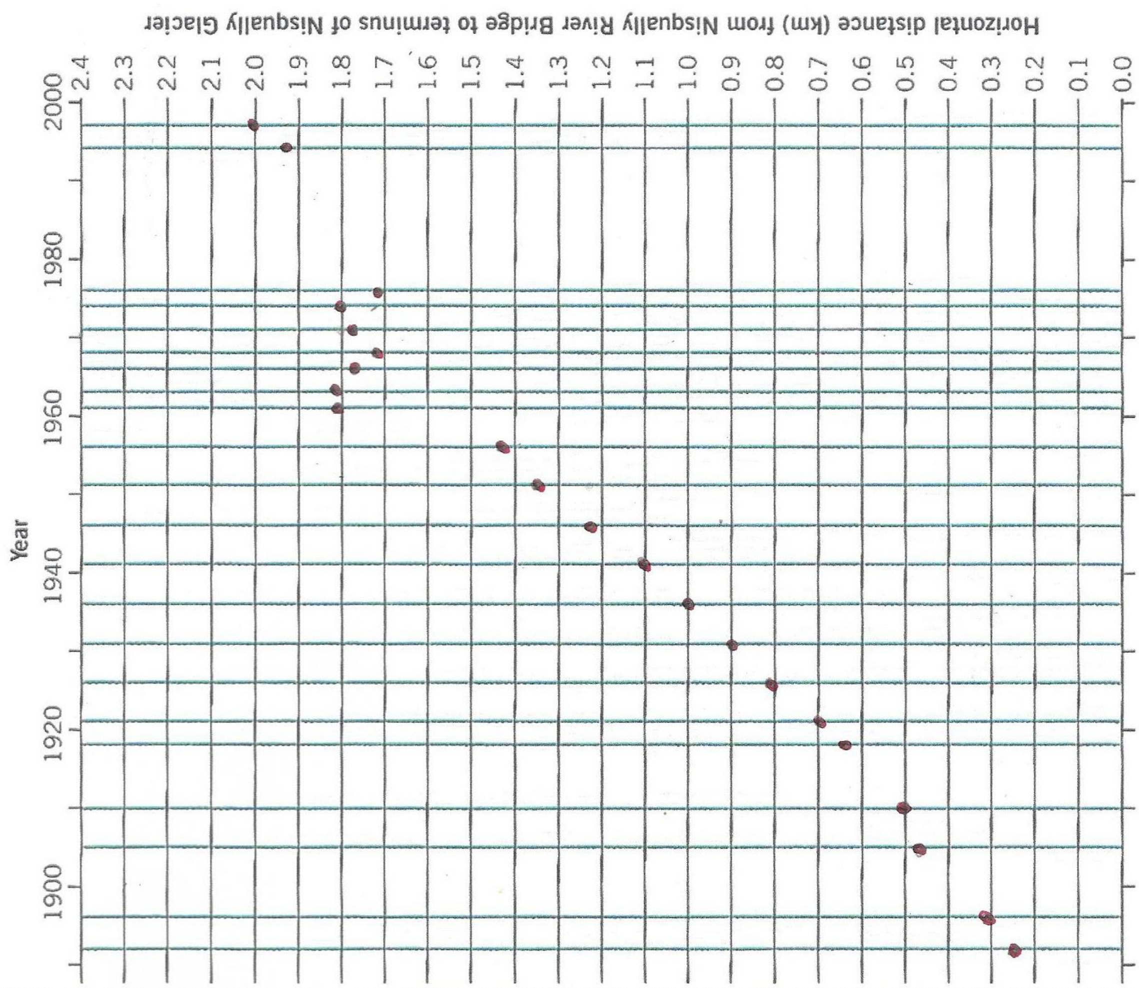
1956	100	1.43
1961	128	1.83
1963	129	1.84
1966	124	1.77
1968	120	1.71
1971	124	1.77
1974	126	1.80
1976	120	1.71
1994	135	1.93
1997	142	2.03



p. 372, QB-1. Plot your data

- **1. The vertical lines on the graph in Fig. A13.3.1 represent the years for which data have been compiled. The horizontal lines correspond to horizontal distances between the bridge and the glacier terminus in tenths of km. Carefully plot the data you have compiled on the graph as a set of points**.

p. 372, QB-1. Plot your data Solution



Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier: mm on map	km on ground
1892	17	0.24
1896	22	0.31
1905	33	0.47
1910	35	0.50
1918	45	0.64
1921	49	0.70
1926	57	0.81
1931	63	0.90
1936	70	1.00
1941	78	1.11
1946	86	1.23
1951	95	1.36
1956	100	1.43
1961	128	1.83
1963	129	1.84
1966	124	1.77
1968	120	1.71
1971	124	1.77
1974	126	1.80
1976	120	1.71
1994	135	1.93
1997	142	2.03

p. 372, QB-1. Plot your data Solution

Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier	
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1892	17	0.24
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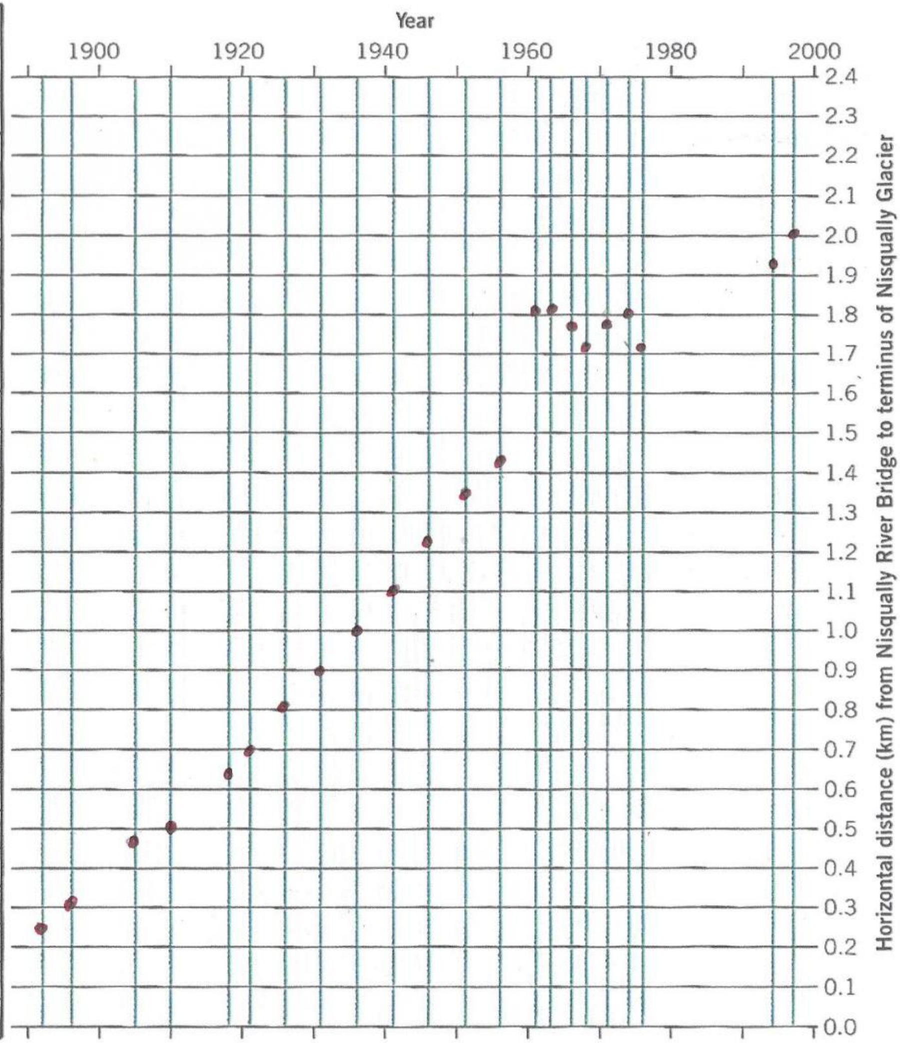
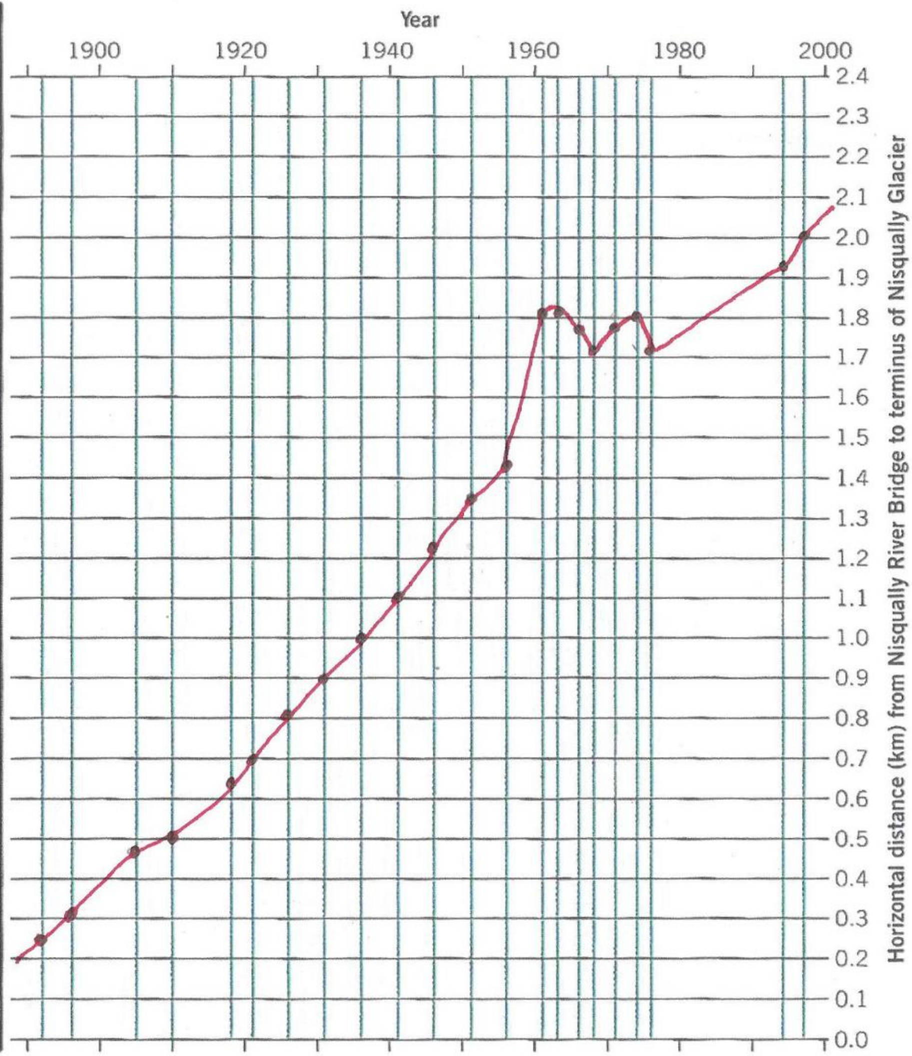
1918	45	0.64
1921	49	0.70
1926	57	0.81
1931	63	0.90
1936	70	1.00
1941	78	1.11
1946	86	1.23
1951	95	1.36
1956	100	1.43
1961	128	1.83
1963	129	1.84
1966	124	1.77
1968	120	1.71
1971	124	1.77
1974	126	1.80
1976	120	1.71
1994	135	1.93
1997	142	2.03



p. 372, QB-2: Lightly draw a smooth pencil line through each of the data points in the correct sequence. SOLUTION

Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier	
	mm on map	km on ground
1892	17	0.24
1896	22	0.31
1905	33	0.47
1910	35	0.50
1918	45	0.64
1921	49	0.70
1926	57	0.81
1931	63	0.90
1936	70	1.00
1941	78	1.11
1946	86	1.23
1951	95	1.36
1956	100	1.43
1961	128	1.83
1963	129	1.84
1966	124	1.77
1968	120	1.71
1971	124	1.77
1974	126	1.80
1976	120	1.71
1994	135	1.93
1997	142	2.03



P. 372, QB-3: Notice that the glacier terminus retreated up the valley at some times but advanced back down the valley at other times. Summarize these changes in a brief written description that includes the specific time intervals when the glacier retreated or advanced .

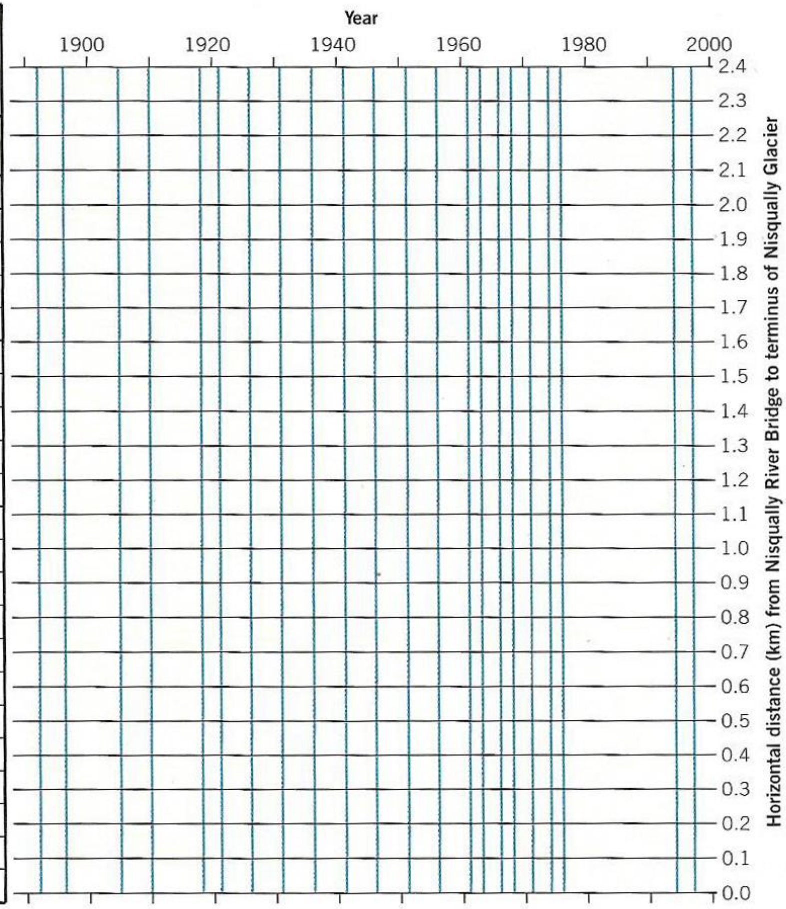
- **Distances measured from bridge**
- **1892 to 1963: Retreat to 1.84 km**
- **1963 to 1968: Advance to 1.71 km**
- **1968 to 1974: Retreat to 1.80 km**
- **1974 to 1976: Advance to 1.71 km**
- **1976 to 1997: Retreat to 2.03 km**

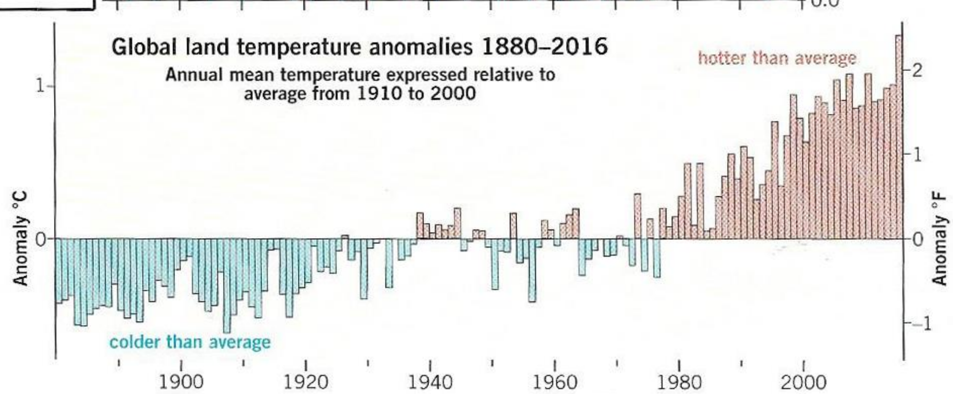
p. 372, QC.

- C. There is a bar chart below the graph you just completed, and the horizontal time axis in the bar chart is identical to the horizontal axis in the Nisqually Glacier graph. Notice the blue and salmon pink graph of climatic data at the bottom of your graph (part B) provided by the NOAA National Climatic Data Center (NCDC). NCDC's global mean temperatures are mean temperatures for Earth calculated by processing data from thousands of observation sites throughout t:he world (from 1880 to 2009). The temperature data were corrected for factors such as increases in temperature around urban centers and decreases in temperature with elevation . Although NCDC collects and processes data on land and sea, this graph shows the variation in annually averaged global land surface temperature only since 1880.

p. 372, QC.

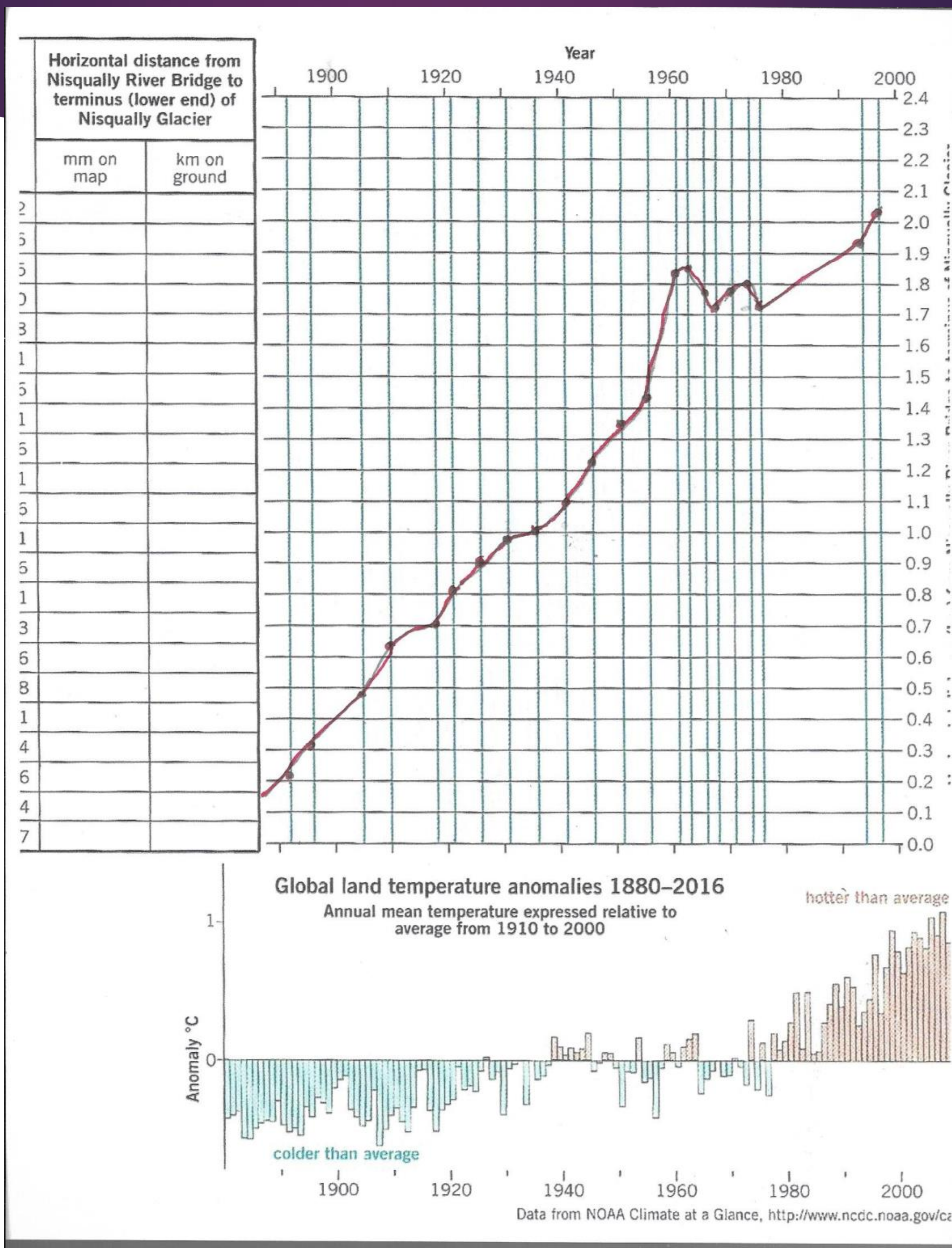
Year	Horizontal distance from Nisqually River Bridge to terminus (lower end) of Nisqually Glacier	
	mm on map	km on ground
1892		
1896		
1905		
1910		
1918		
1921		
1926		
1931		
1936		
1941		
1946		
1951		
1956		
1961		
1963		
1966		
1968		
1971		
1974		
1976		
1994		
1997		



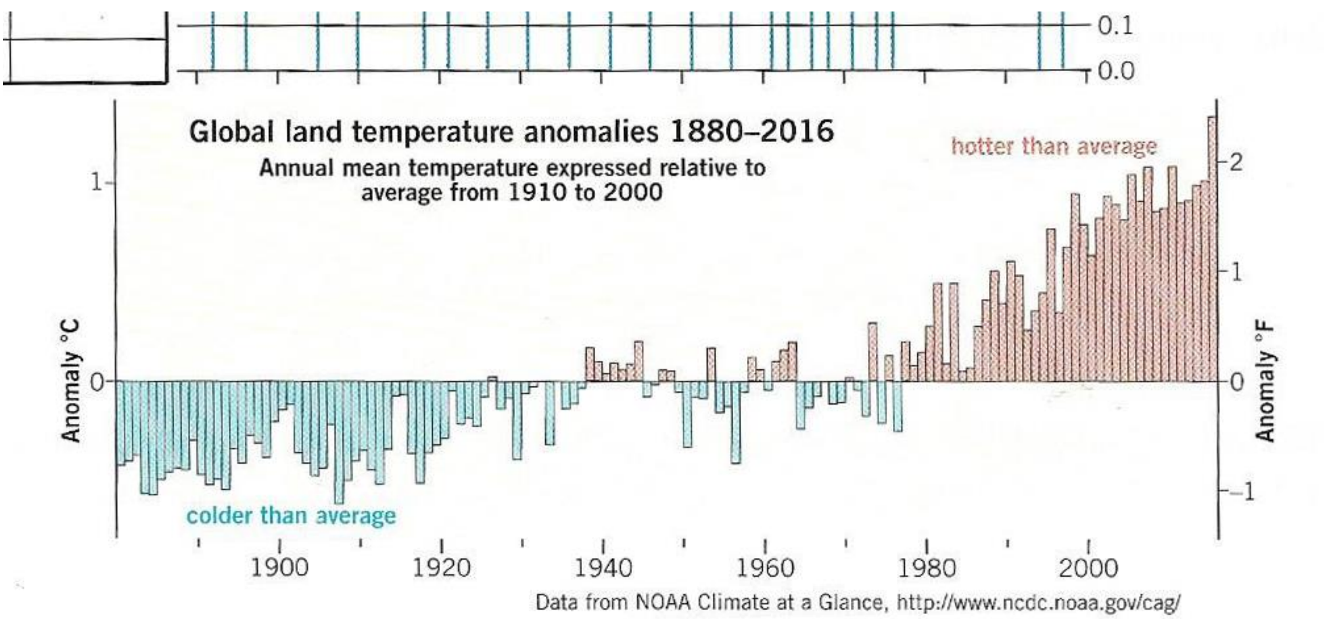


Data from NOAA Climate at a Glance, http://www.ncdc.noaa.gov/cag/

p. 372, QC Solution

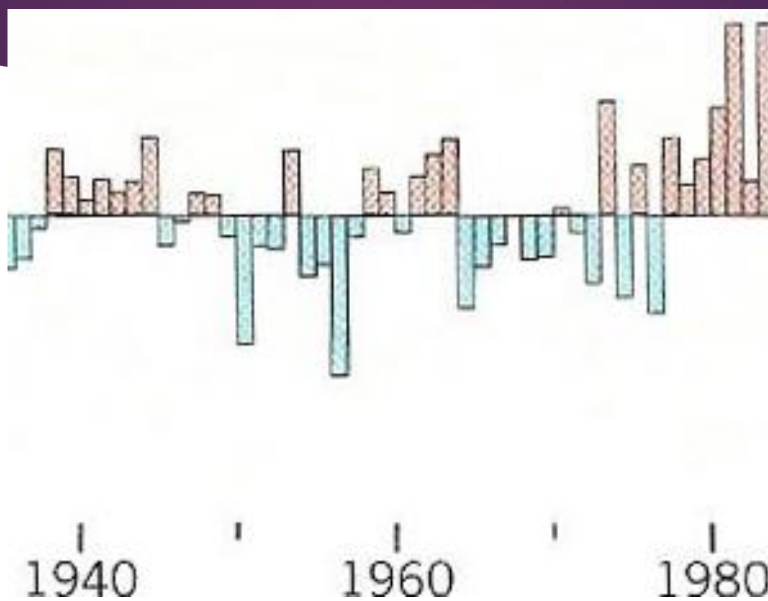


p. 372, QC-1: Describe the long-term trend in this graph- how averaged global land surface temperature changed from 1880 to 2015. SOLUTION



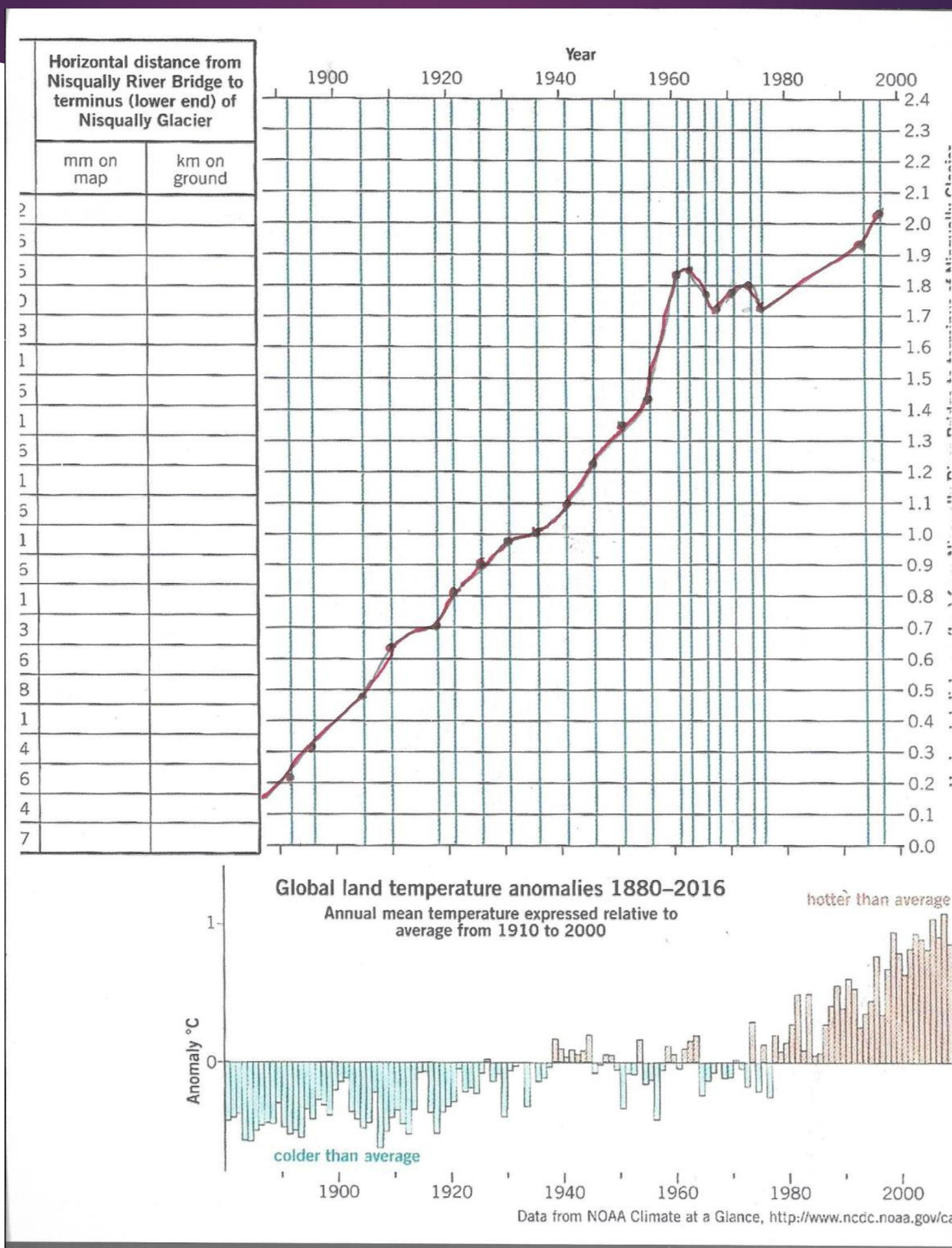
The long-term trend from 1880 to 2015 is a warming of 3 degreed Fahrenheit

p. 372, QC-2: Lightly in pencil, trace any shorter-term pattern of cyclic climate change that you can identify in the graph. Describe this cyclic shorter-term trend. SOLUTION



- **Between 1938 and 1982 there where 4 warm periods interspersed with by three cool periods. The general trend toward warming began again in 1981.**

P. 372, QD: Describe how the changes in position of the terminus of Nisqually Glacier compare to variations in annually averaged global land surface temperature. Be as specific as you can .



P. 372, QD: Describe how the changes in position of the terminus of Nisqually Glacier compare to variations in annually averaged global land surface temperature. Be as specific as you can . SOLUTION

- **The graph on slide 84 shows that the advancement of the Nisqually glacier between 1963 and 1968 corresponded with global land temperature warming 1959 to 1968.**

p. 372, QE: REFLECT & DISCUSS Based on all of your work above, do you think Nisqually Glacier can be used as an indicator of climate change? Explain.

- **The Nisqually glacier can be used in a general way for general long-term trends to indicate global warming. But it is not a precise indicator for short time periods. For example, the graphs on slide 84 show that there was global cooling for 1968 to1974 but Nisqually glacier retreated during that time when it "should" have advanced.**

Name: ____________________ **Course/Section:** ____________________ **Date:** ____________

Refer to the map of Glacier National Park in **Fig. 13.14**.

A List the features of glaciation from **Figs. 13.3–13.10** that you can observe in **Fig. 13.14**.

B Locate Quartz Lake and Middle Quartz Lake in the southwest part of the map. Notice the patrol cabin located between these lakes. Infer the chain of geologic/glacial events (steps) that led to formation of Quartz Lake, the valley of Quartz Lake, the small piece of land on which the patrol cabin is located, and the cirque in which Rainbow Glacier is located today.

C Based on your answers above, what kind of glaciation (mountain versus continental) has shaped this landscape?

D Locate the continental divide on **Fig. 13.14**, and recall that it divides surface water that flows west into the Pacific Ocean from water that flows east into the Atlantic Ocean or Gulf of Mexico. Think of ways that the continental divide may be related to weather and climate in the region. Recall that weather systems generally move across the United States from west to east.

1. Describe how modern glaciers of this region are distributed in relation to the Continental Divide.

2. Based on the distribution you observed, describe the weather/climate conditions that may exist on opposite sides of the Continental Divide in this region.

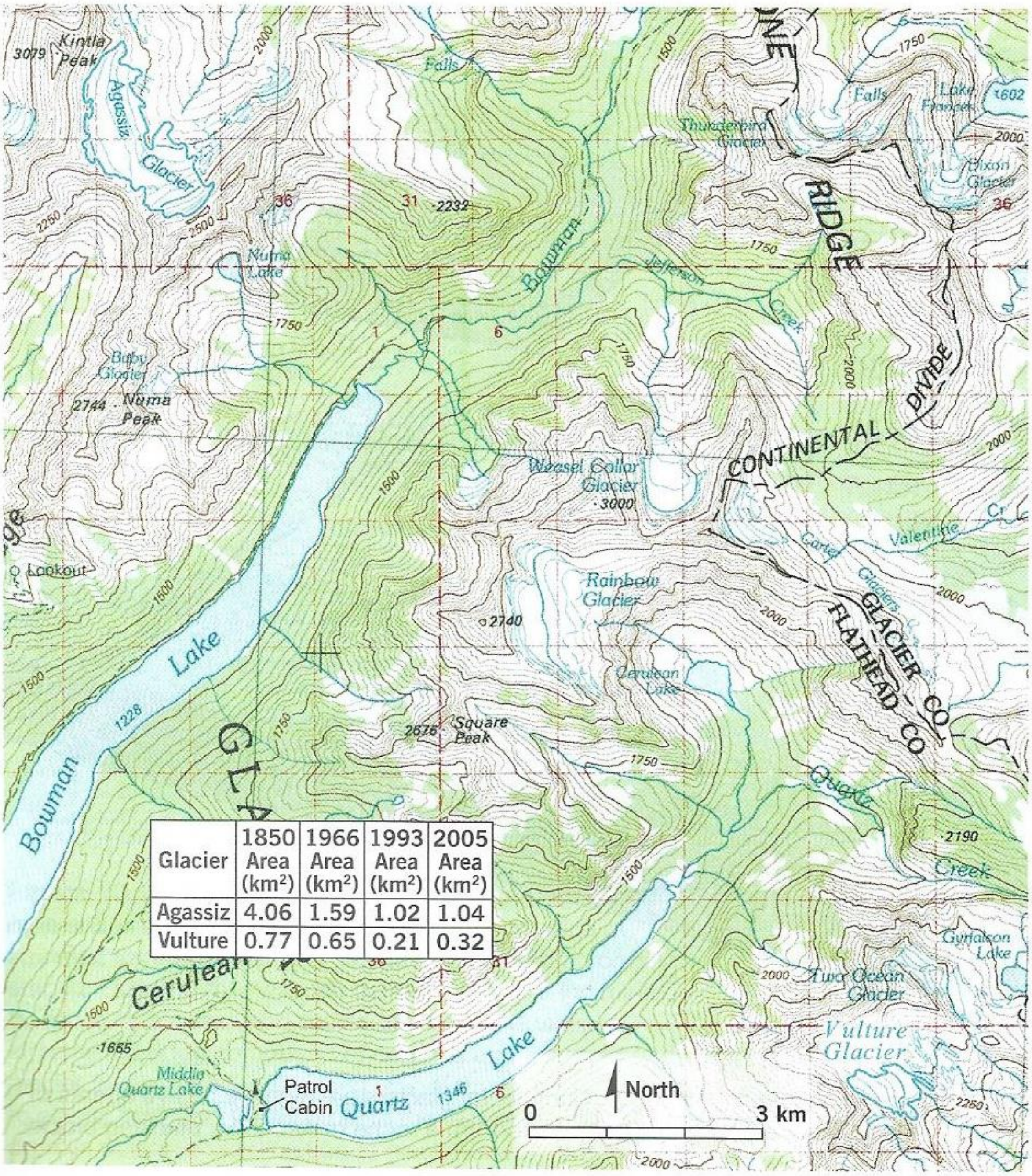
3. Look at the location of glaciers in this map area in relation to ridges and mountain peaks. Do the glaciers tend to occur on the north, south, east, or west sides of these landforms? If so, on what side do most tend to be located? Suggest at least one explanation for this observation.

E Using the data table in **Fig. 13.14**, describe how the area of Agassiz Glacier changed from 1850 to 2005. Agassiz Glacier is in the northwest part of the map.

F Describe how the area of Vulture Glacier changed from 1850 to 2005. Vulture Glacier is in the southeast part of the map.

G **REFLECT & DISCUSS** What do you expect the area (km^2) of Agassiz and Vulture Glaciers to be in 2020? Explain.

p. 373, Refer to the map of Glacier National Pak in Fig. 13.14



Glacier	1850 Area (km^2)	1966 Area (km^2)	1993 Area (km^2)	2005 Area (km^2)
Agassiz	4.06	1.59	1.02	1.04
Vulture	0.77	0.65	0.21	0.32

p. 373, QA: List the features of glaciation from Figs. 13.3-13.10 that you can observe in Fig. 13.14.

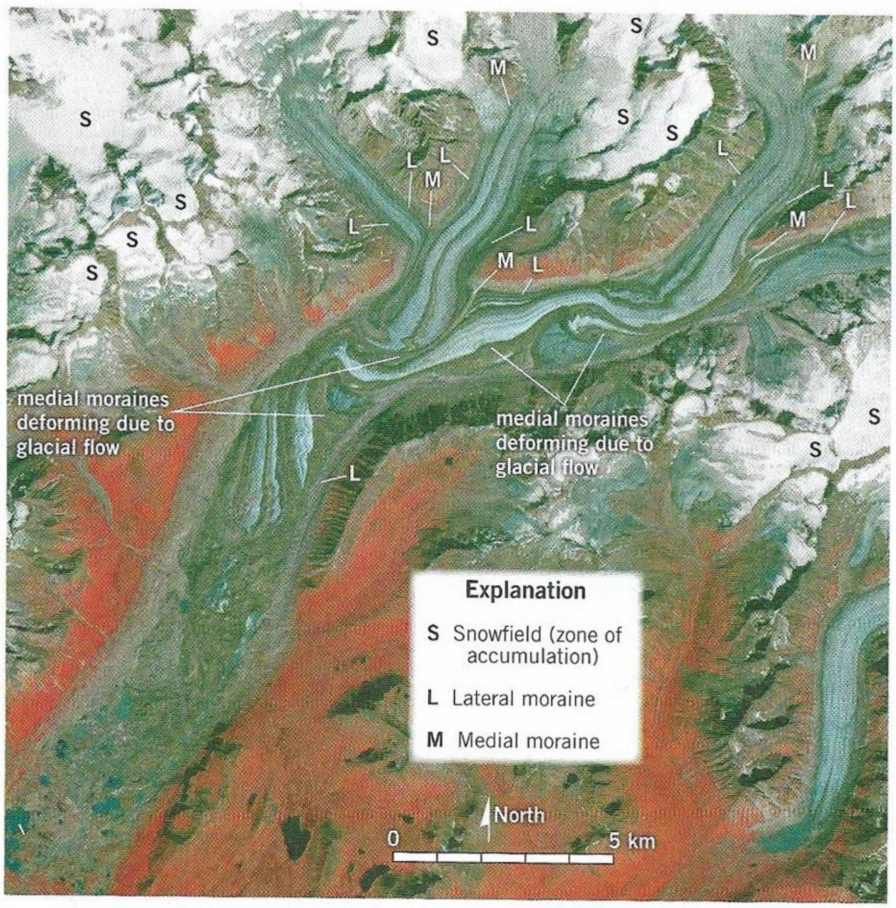


Figure 13.3 Mountain glaciers in Alaska. This is a false-color image of the area around the Susitna Glacier in the Alaska range. The red areas are covered in vegetation. White is snow, light blue-gray is ice, darker blue is water, and where rock and sediment cover the ice in moraines, the glacier appears brown. Some of the moraines are deformed by surging tributary glaciers. (The data for this image were collected by the ASTER instrument on NASA's Terra satellite and were processed by the NASA/METI/AIST/Japan Space Systems and United States/Japan ASTER Science Team.)

- **Figure 13-3, p. 352**

p. 373, QA: List the features of glaciation from Figs. 13.3-13.10 that you can observe in Fig. 13.14.

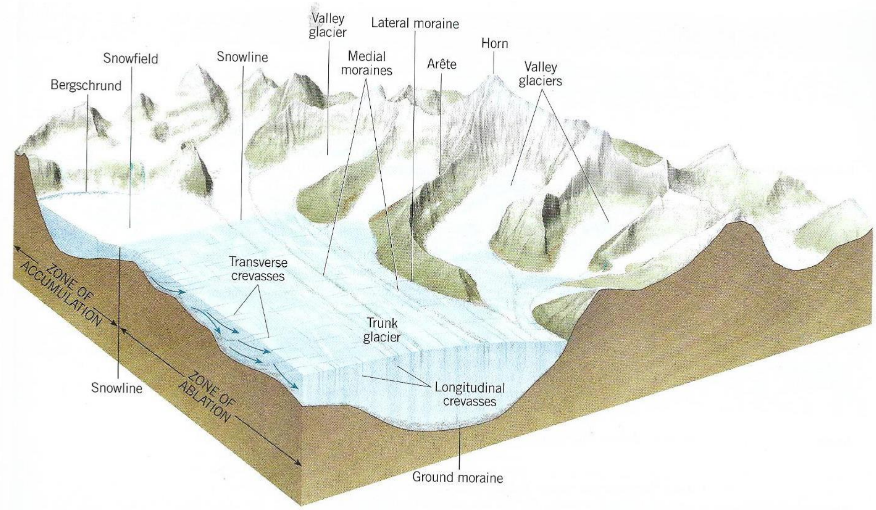


Figure 13.7 Typical features of an active mountain glacier system.

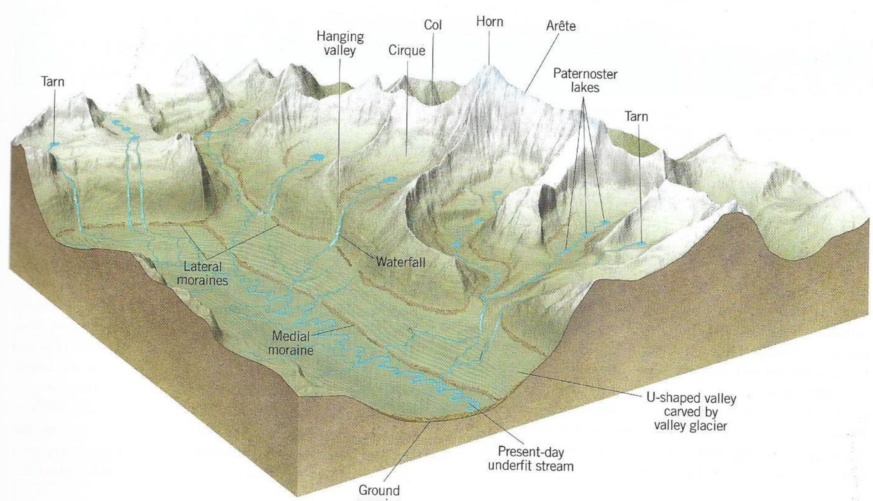


Figure 13.8 Typical erosional and depositional effects of mountain glaciation. Most of the terms used in this figure are defined in Figs. 13.4–13.6.

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- **Figure 13-8, p. 356**

p. 373, QA: List the features of glaciation from Figs. 13.3-13.10 that you can observe in Fig. 13.14.

- **Figure 13-10, p. 358**

p. 373, QA: List the features of glaciation from Figs. 13.3-13.10 that you can observe in Fig. 13.14. SOLUTION

- **Figure 13-3, p. 358:**
- **---Lateral Moraines**

- **Figure 13-8, p. 356**
- **---valley glaciers**
- **---arete**
- **---cirque**
- **---hanging valley**
- **---tarn**
- **---water fall**
- **---U shaped valley**
- **---lateral moraine**

- **Figue 3-10**
- **---terminus of glacier**
- **---lateral moraine**

p. 373, QB: Locate Quartz Lake and Middle Quartz Lake in the southwest part of the map. Notice the patrol cabin located between the lakes. Infer the chain of geologic / glacial events (steps) that led to formation of Quartz Lake, the valley of Quartz Lake, the small piece of land on which the patrol cabin is located, and the cirque in which Rainbow Glacier is located today.

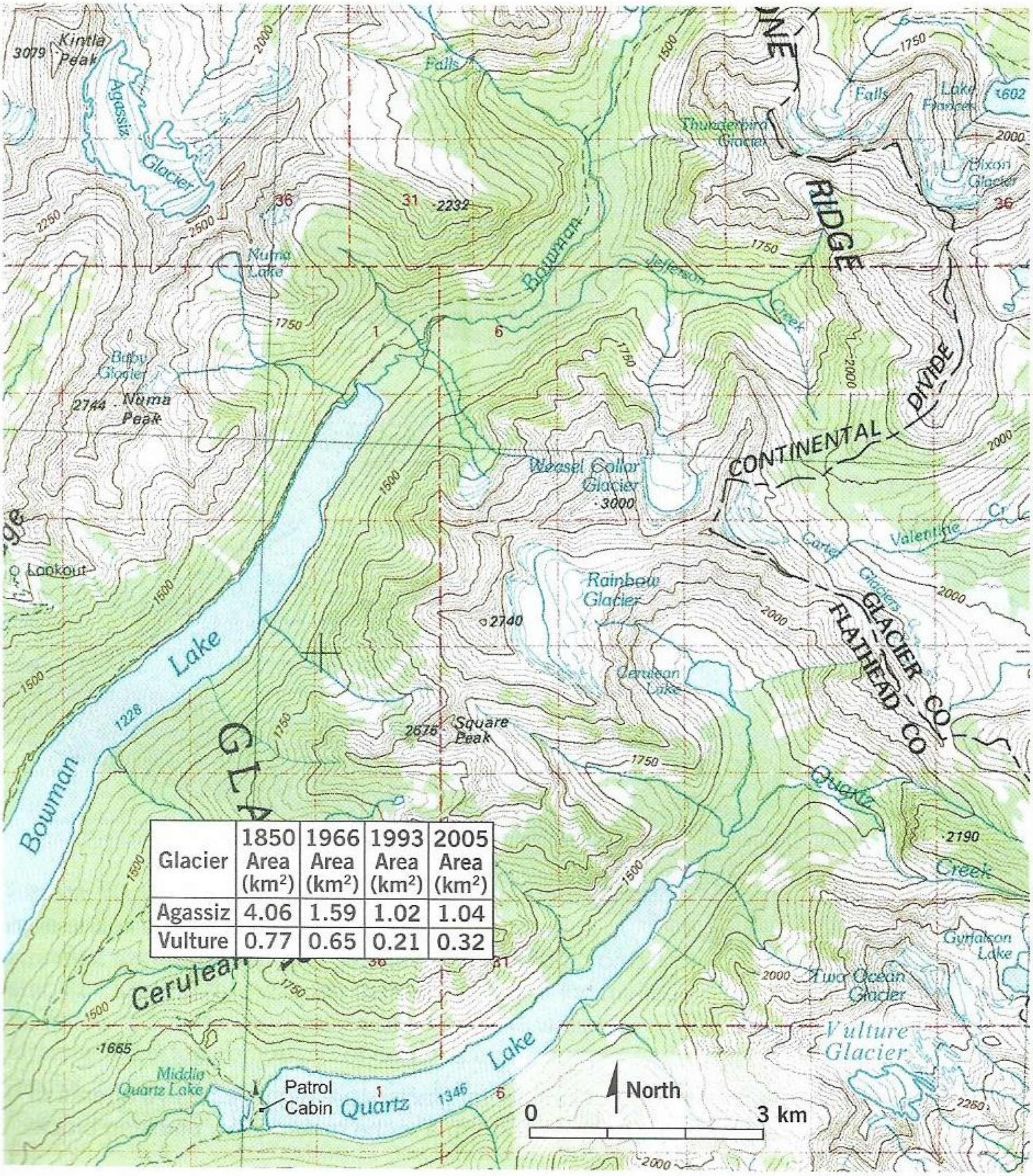
- **There once was a river valley.**
- **It filled with ice and hosted a glacier.**
- **The glacier converted the v-shaped stream valley to a U-shaped glacial valley (Quartz Lake Valley).**
- **Lateral moraines were deposited on the sides of the Quartz Lake glacier.**
- **A terminal moraine formed at the terminus of the Quartz Lake Glacier. The Patrol Cabin is now on the debris left behind in this terminal moraine.**
- **Outwash from the retreating glacier over-topped Quartz Lake and filled the tarn lake below the terminal morain.**
- **Glacial plucking at the top of the Quartz Lake Valley glacier lead to formation of a cirque there**

p. 373, QC: Based on your answers above, what kind of glaciation (mountain versus continental) has shaped this landscape? SOLUTION

- **Mountain Glacier**

P. 373, QD:

- **Locate The continental divide on Fig. 13.14, and recall that it divides surface water that flows west into the Pacific Ocean from water that flows east into the Atlantic Ocean or Gulf of Mexico. Think of ways that the continental divide may be related to weather and climate in the region. Recall that weather systems generally move across the United States from west to east.**



Glacier	1850 Area (km^2)	1966 Area (km^2)	1993 Area (km^2)	2005 Area (km^2)
Agassiz	4.06	1.59	1.02	1.04
Vulture	0.77	0.65	0.21	0.32

p. 373, QD-1: Describe how modern glaciers of this region are distributed in relation to the Continental Divide. SOLUTION

- **Most mountain glaciers are to the west of the Continental Divide. The Continental Divide forms a rain-snow shadow and results in less precipitation falling to the east of it. So there is less snow to the east of the Continental Divide to make glaciers.**

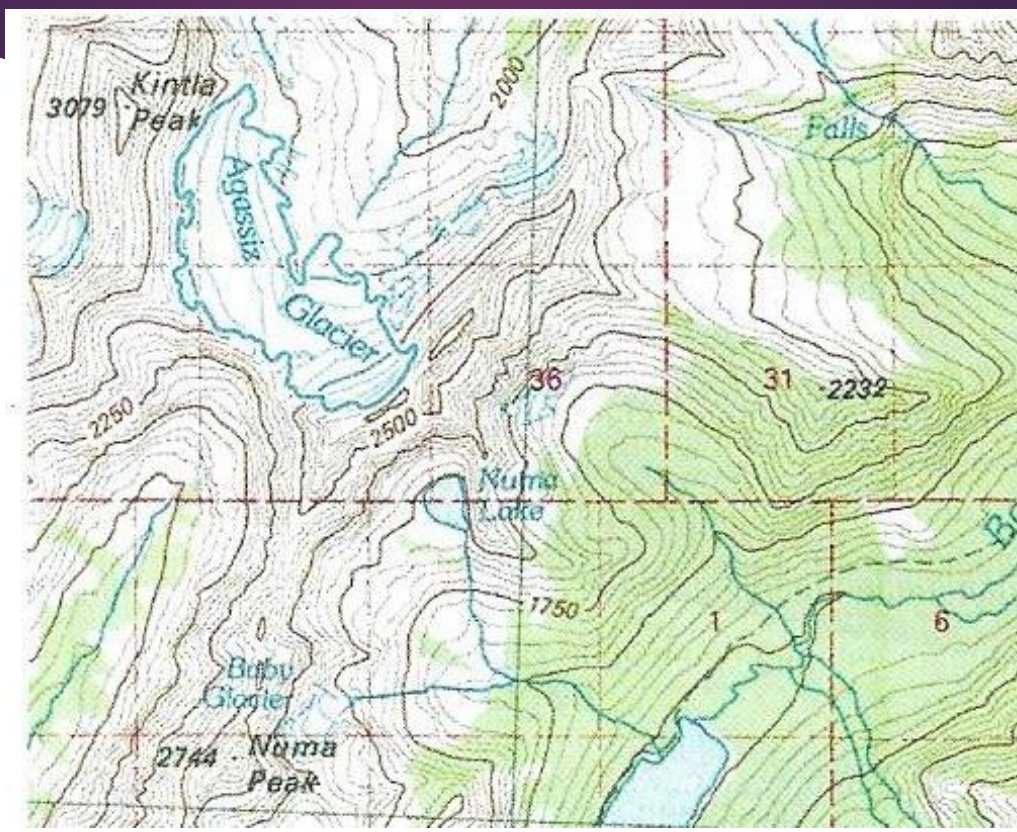
p. 373, QD-2: Based on the distribution you observed, describe the weather / climate conditions that may exist on opposite sides of the Continental Divide in this region.

- **West of the Continental Divide there will be more snow and rain.**
- **East of the Continental Divide there will be less precipitation.**

p. 373, QD-3: Look at the location of glaciers in this map area in relation to ridges and mountain peaks. Do the glaciers tend to occur on the north , south, east, or west sides of these landforms? If so, on what side do most tend to be located? Suggest at least one explanation for this observation .

- **Glaciers mostly occur on the southwest side of landforms in this area.**
- **They are mainly between features that lay to the northwest and southeast.**
- **This structural grain is due to underlying geology. The structures may be faults or inclined beds or other stratigraphic features.**

p. 373, QE: Using the data table in Fig . 13.14, describe how the area of Agassiz Glacier changed from 1850 to 2005. Agassiz Glacier is in the northwest part of the map.

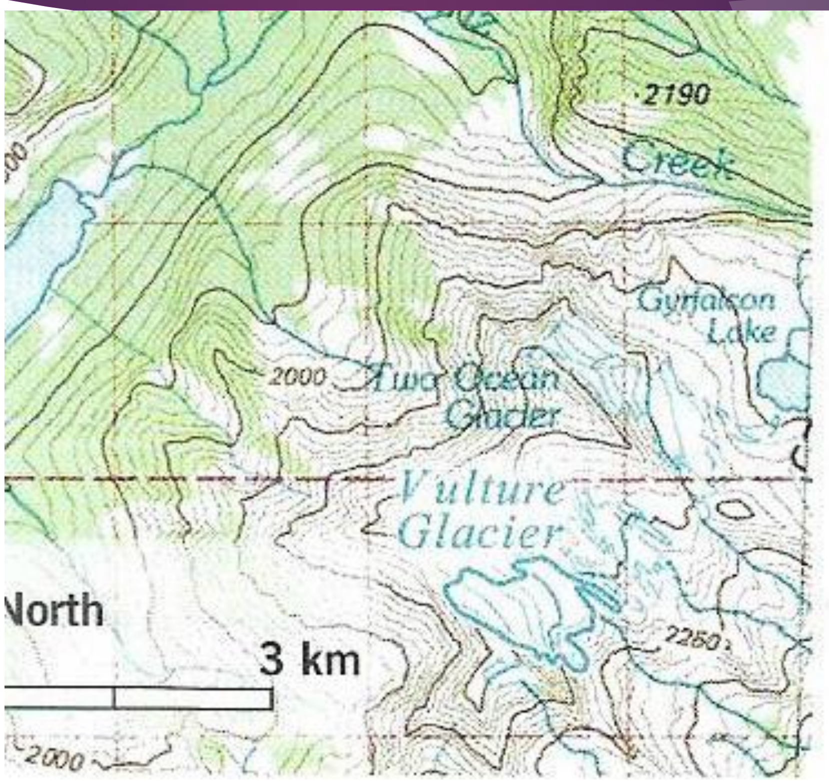


Glacier	1850 Area (km²)	1966 Area (km²)	1993 Area (km²)	2005 Area (km²)
Agassiz	4.06	1.59	1.02	1.04
Vulture	0.77	0.65	0.21	0.32

p. 373, QE: Using the data table in Fig . 13.14, describe how the area of Agassiz Glacier changed from 1850 to 2005. Agassiz Glacier is in the northwest part of the map. SOLUTION

Between 1850 and 2005, the Agassiz Glacier was reduced in size from 4.06 to 1.02 square kilometers

p. 373, QF: Describe how the area of Vulture Glacier changed from 1850 to 2005. Vulture Glacier is in the south east part of the map.



- **Between 1850 and 2005, the Vulture Glacier was reduced in size from 0.77 to 0.32 square kilometers**

p. 373, QG: REFLECT & DISCUSS What do you expect the area (km) of Agassiz and Vulture Glaciers to be in 2020? Explain.

Glacier	1850 Area (km^2)	1966 Area (km^2)	1993 Area (km^2)	2005 Area (km^2)
Agassiz	4.06	1.59	1.02	1.04
Vulture	0.77	0.65	0.21	0.32

- **By 2020, the size of these glaciers will continue to be reduced or may entirely disappear.**

Activity 13.5 Some Effects of Continental Glaciation

Name: ______________________ **Course/Section:** ______________ **Date:** __________

A A topographic map of an area near Whitewater, Wisconsin, shows many landscape features that are characteristic of continental glaciation (**Fig. 13.19**). Many of those features are listed in **Figs. 13.4–13.6** and **13.15–13.18**.

1. Study the size and shape of the short, oblong rounded hills in the northwestern part of **Fig. 13.19**. Detail map A shows one of these hills. Fieldwork has revealed that they are made of till. What type of feature are they, and how did they form?

2. Toward what direction did the glacial ice flow in this area, and how can you tell?

3. Find the long, narrow, sinuous ridge that extends into a lake, shown in detail map B. What do you interpret this feature to be, and how do you think it formed?

4. In the southeast part of **Fig. 13.19** are many enclosed depressions marked by hachures on topographic contours like the one shown in detail map C. What do you interpret the depression in detail map C to be?

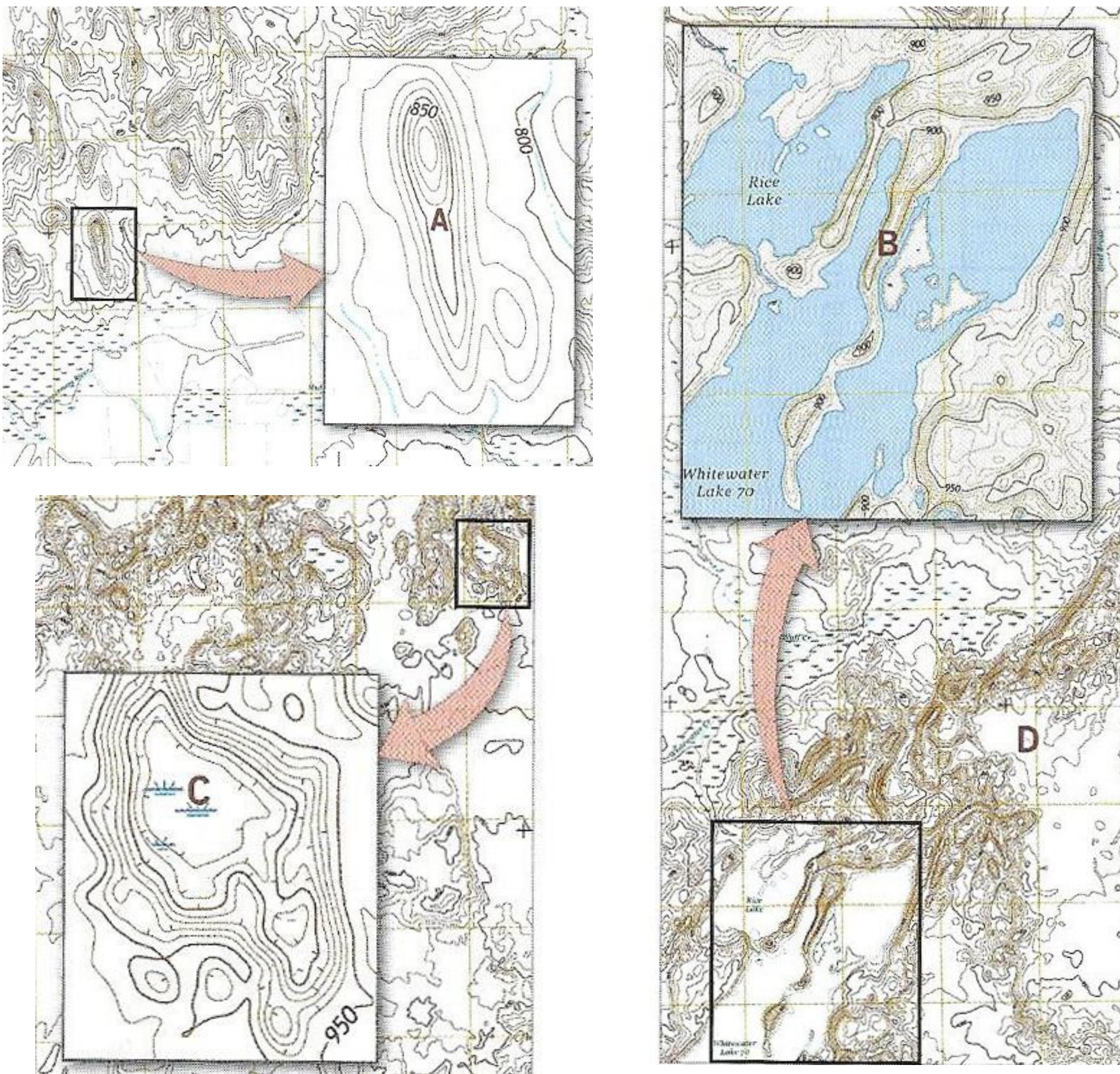
5. The features we just looked at in part **4** are part of an area that is a bit higher than the land to the north and has many small hills and depressions within a topography that seems chaotic. That area starts parallel to a line from point D to D′, and extends to the southeast corner of the map. What glacial landform do you interpret this area to be?

6. Note the marshy area running from the west-central edge of **Fig. 13.19** to the northeastern corner, separating the features shown in detail map A from those labeled B, C, and D–D′. Describe the probable origin of this flat marshy area. (More than one answer is possible.)

7. List the features of glaciated regions that you can recognize in **Fig. 13.19**.

B **REFLECT & DISCUSS** How is the glaciated area of **Fig. 13.19** different from areas affected by mountain glaciation, and how are they the same?

p. 374, QA: A topographic map of an a rea near Whitewater, Wisconsin , shows many lands cape features that are characteristic of continental glaciation (Fig. 13.19) . Many of those features are listed in Figs. 13.4-13.6 and 13.15- 13.18.



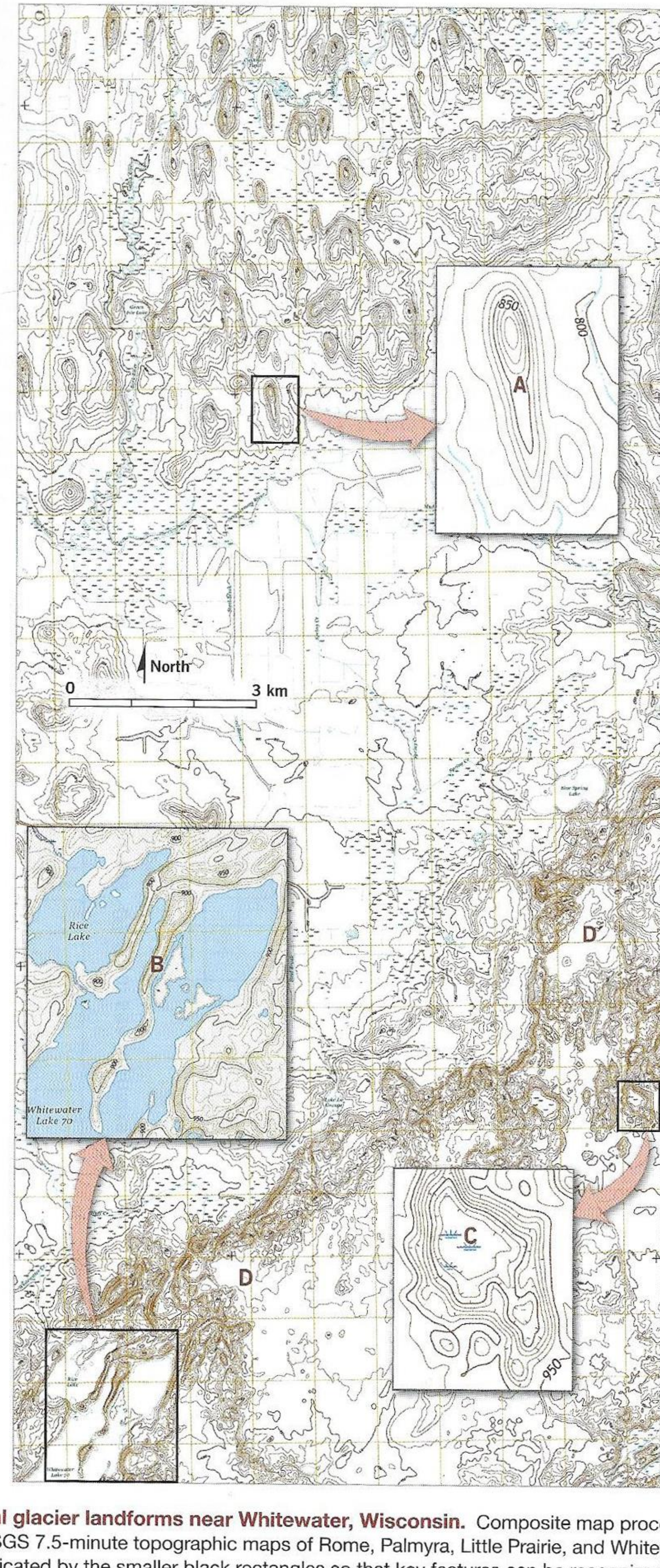
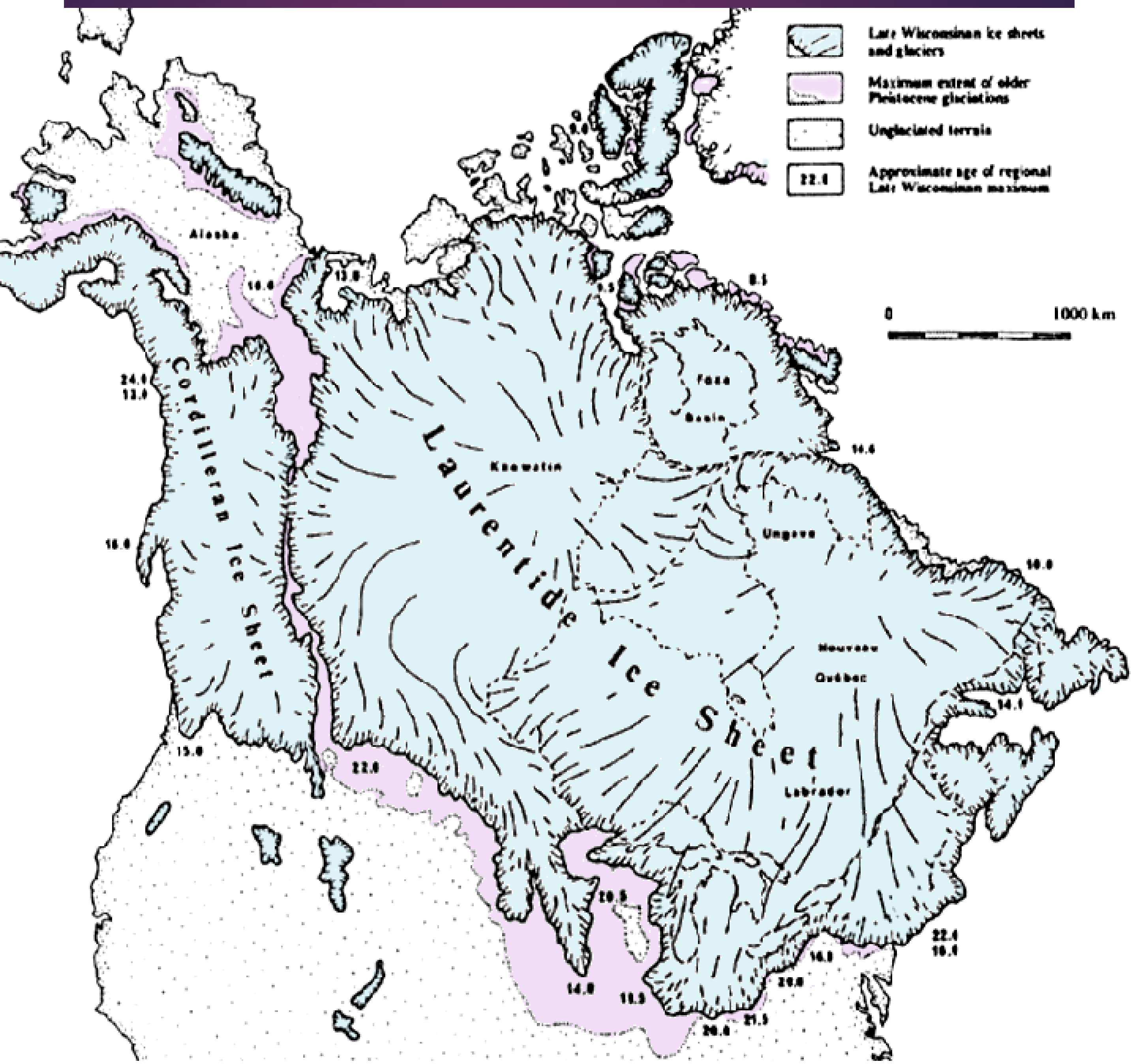
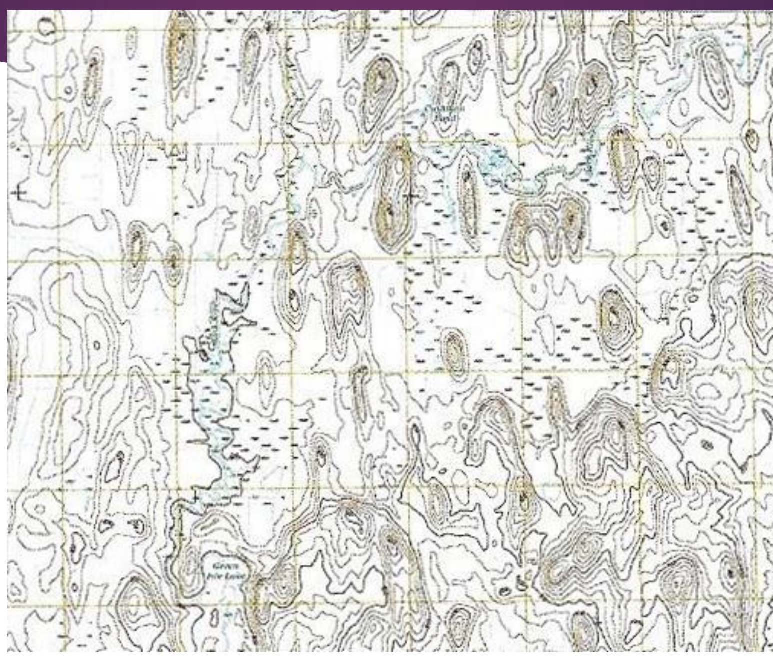


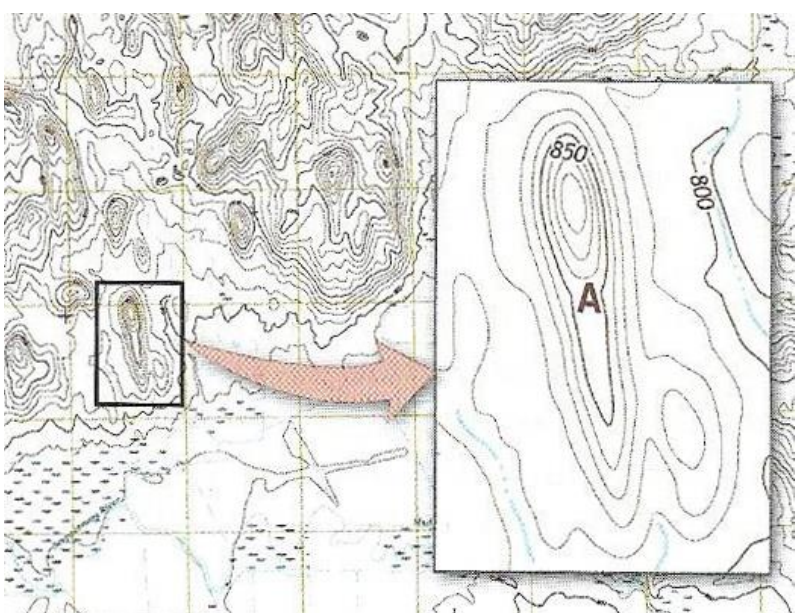
Figure 13.19 Continental glacier landforms near Whitewater, Wisconsin. Composite map processed to accentuate glacial landforms, derived from USGS 7.5-minute topographic maps of Rome, Palmyra, Little Prairie, and Whitewater, Wisconsin. The inset maps expand the areas indicated by the smaller black rectangles so that key features can be recognized in Activity 13.5.

Extent of the Pleistocene Continental Glaciations

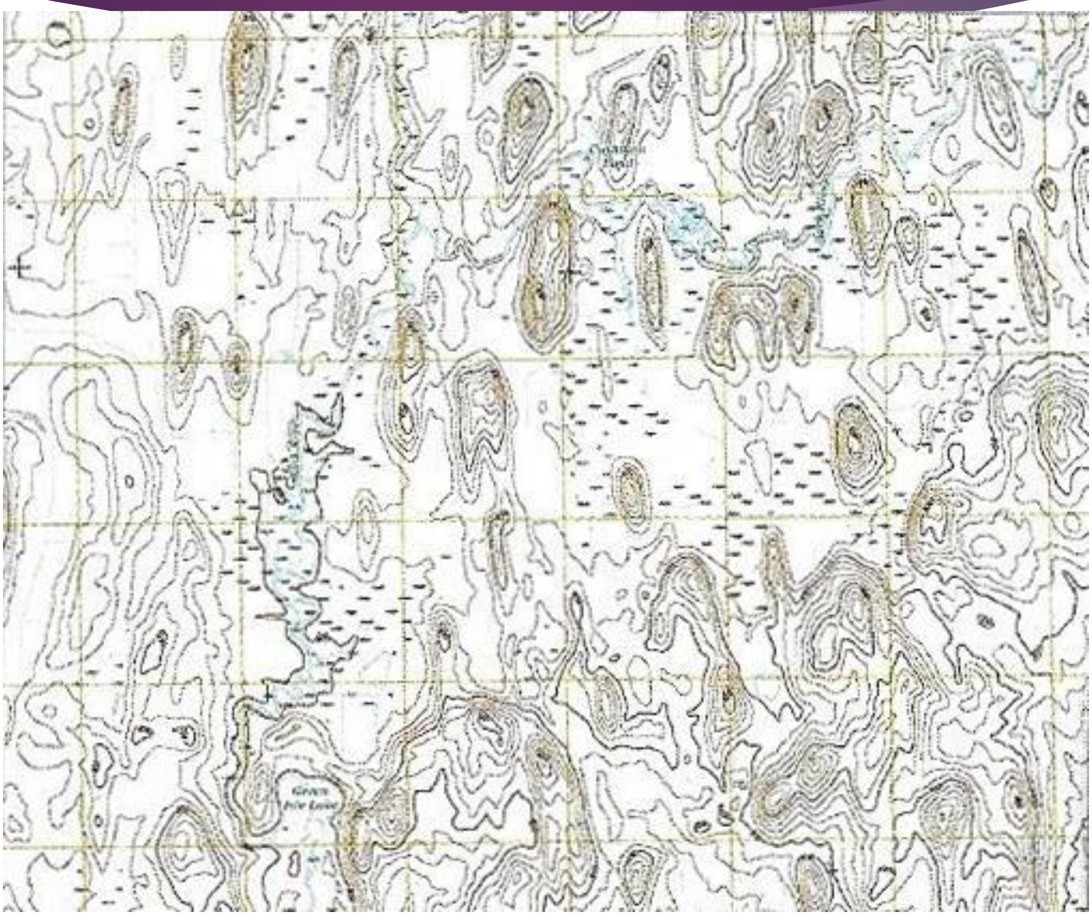


P. 374, QA-1: Study the size and shape of the short, oblong rounded hills in the north western part of Fig. 13.19. Detail map A shows one of these hills. Fieldwork has reveled that. they a re made of till. What type of feature are they, and how did they form?





P. 374, QA-1: Study the size and shape of the short, oblong rounded hills in the north western part of Fig. 13.19. Detail map A shows one of these hills. Fieldwork has reveled that. they a re made of till. What type of feature are they, and how did they form?: SOLUTION



The elongated hills with the wider part to the north are a drumline field. See Figure 13.16 and 13.17 on p. 363.

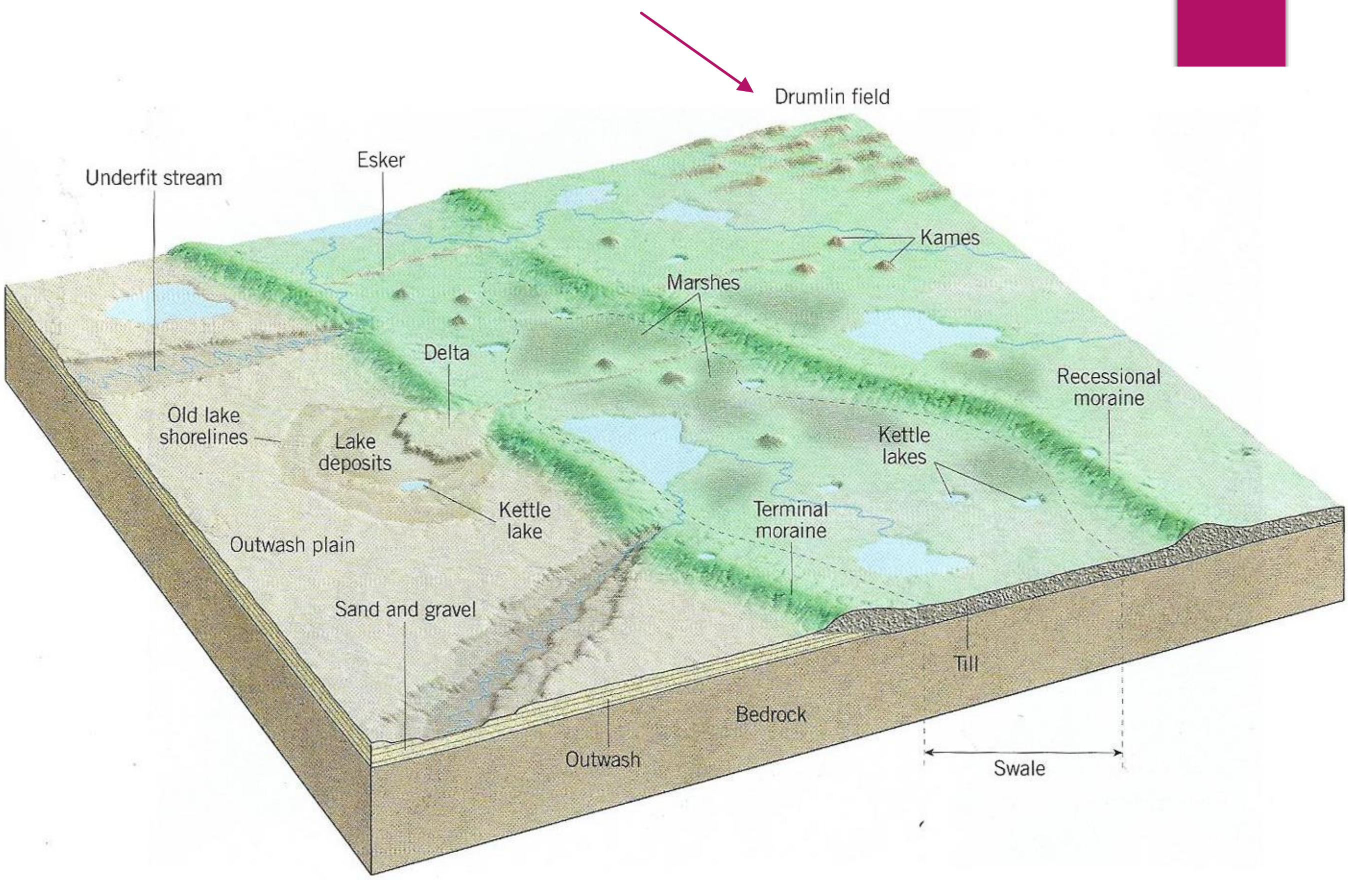


Figure 13.16 Typical erosional and depositional effects of continental glaciation. Continental glaciation leaves behind many characteristic landforms after the ice melts. Most of the terms used in this figure are defined in **Figs. 13.4–13.6.**

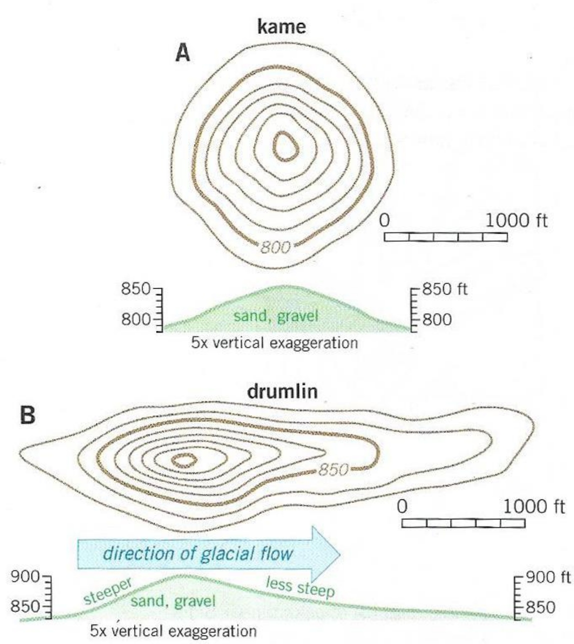
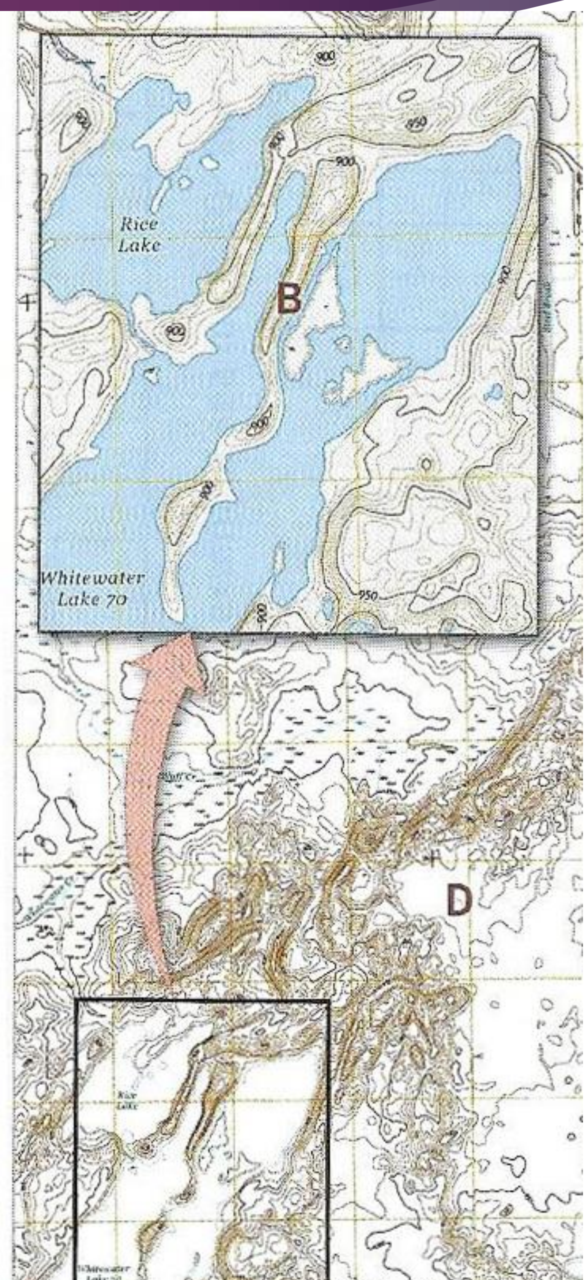


Figure 13.17 Kames and drumlins. A. Topographic map and profile of a kame—a mound or short ridge of stratified (layered) sediment originally deposited on or below stagnant ice and that was left behind when that ice melted. **B.** Topographic map and profile of a typical drumlin—a streamlined ridge composed of compacted till formed under a glacier by glacial flow. The long axis of the drumlin is parallel to glacial flow, and the long tail of the less steep side of the drumlin points in the direction of glacial flow.


p. 374, QA-3: Find the long, narrow, sinuous ridge that extends into a lake, shown in detail map B. What do you interpret this feature to be, and how do you think it formed?

- These features are called eskers. See Figure 13.16 on page 336



p. 374, QA-3: Find the long, narrow, sinuous ridge that extends into a lake, shown in detail map B. What do you interpret this feature to be, and how do you think it formed?
SOLUTION

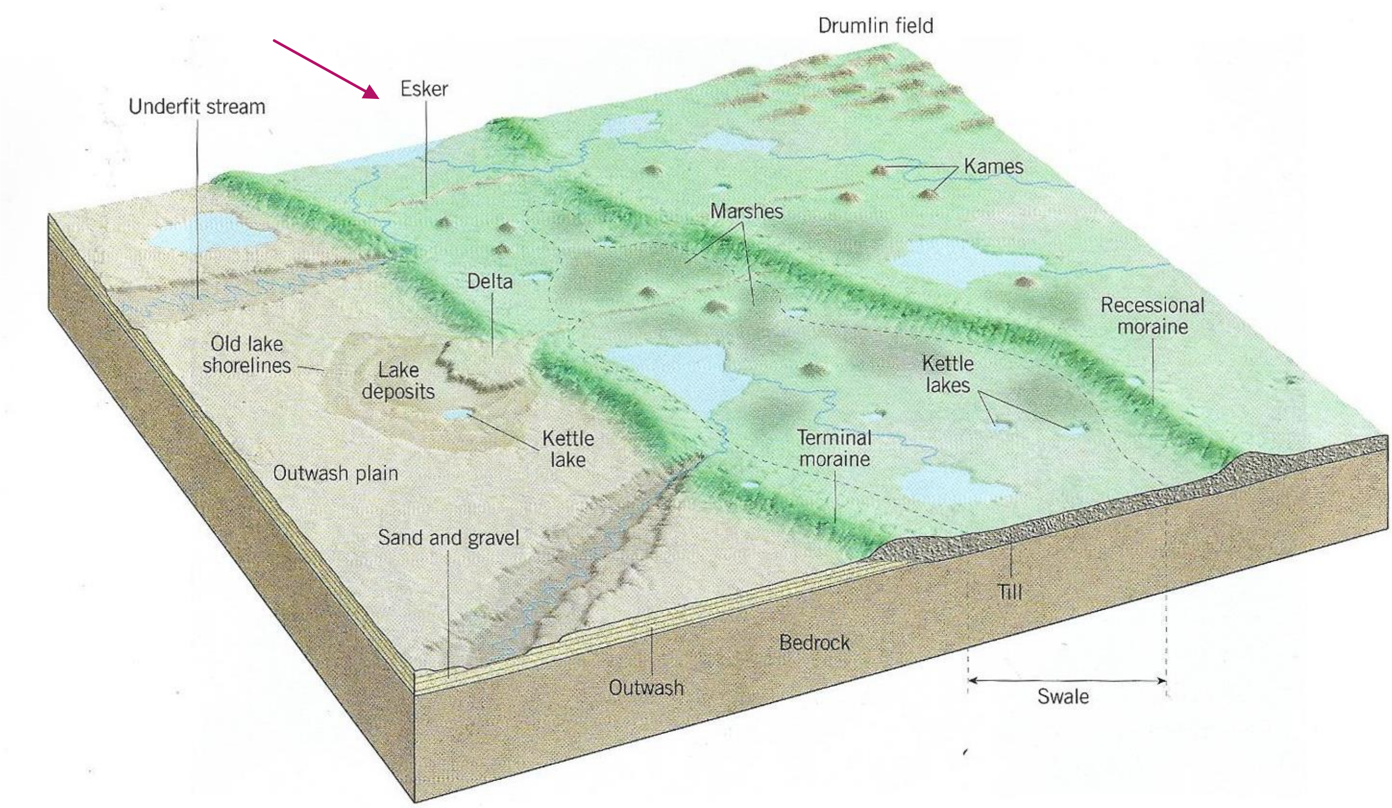
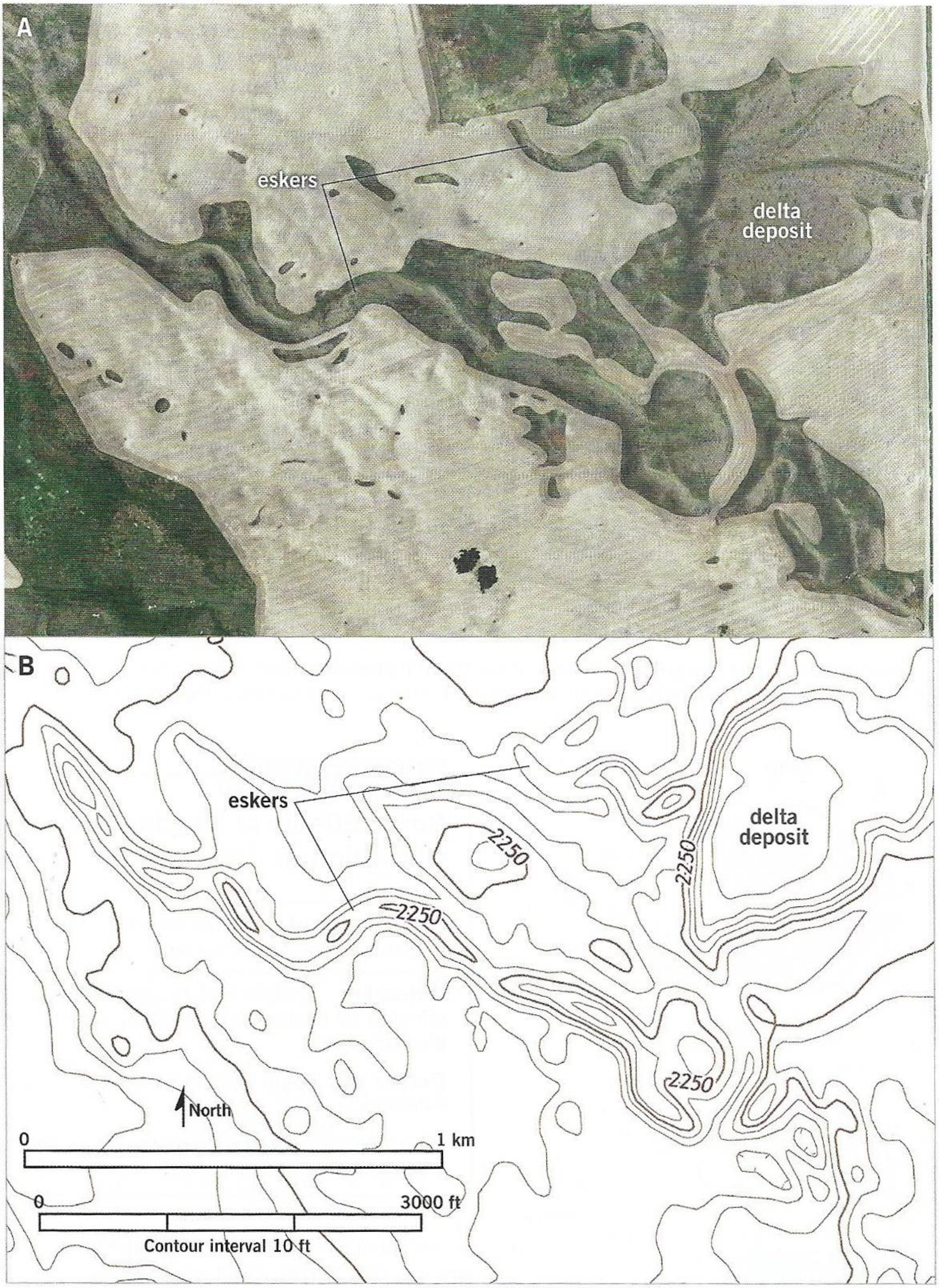


Figure 13.16 Typical erosional and depositional effects of continental glaciation. Continental glaciation leaves behind many characteristic landforms after the ice melts. Most of the terms used in this figure are defined in **Figs. 13.4–13.6**.

- Eskers are depositional features formed from rivers running under the glacier


A
eskers
delta deposit
B
eskers
2250
2250
2250
2250
delta deposit
North
0
1 km
0
3000 ft
Contour interval 10 ft


P. 374, QA-4: In the southeast part of Fig. 13.19 are many enclosed depressions marked by hachure s on topographic contours like the one shown in detail map C. What do you interpret the depression in detail map C to be?

- **The depressions are Kettle Lakes. See Figure 13.16.**

Kettle Lakes

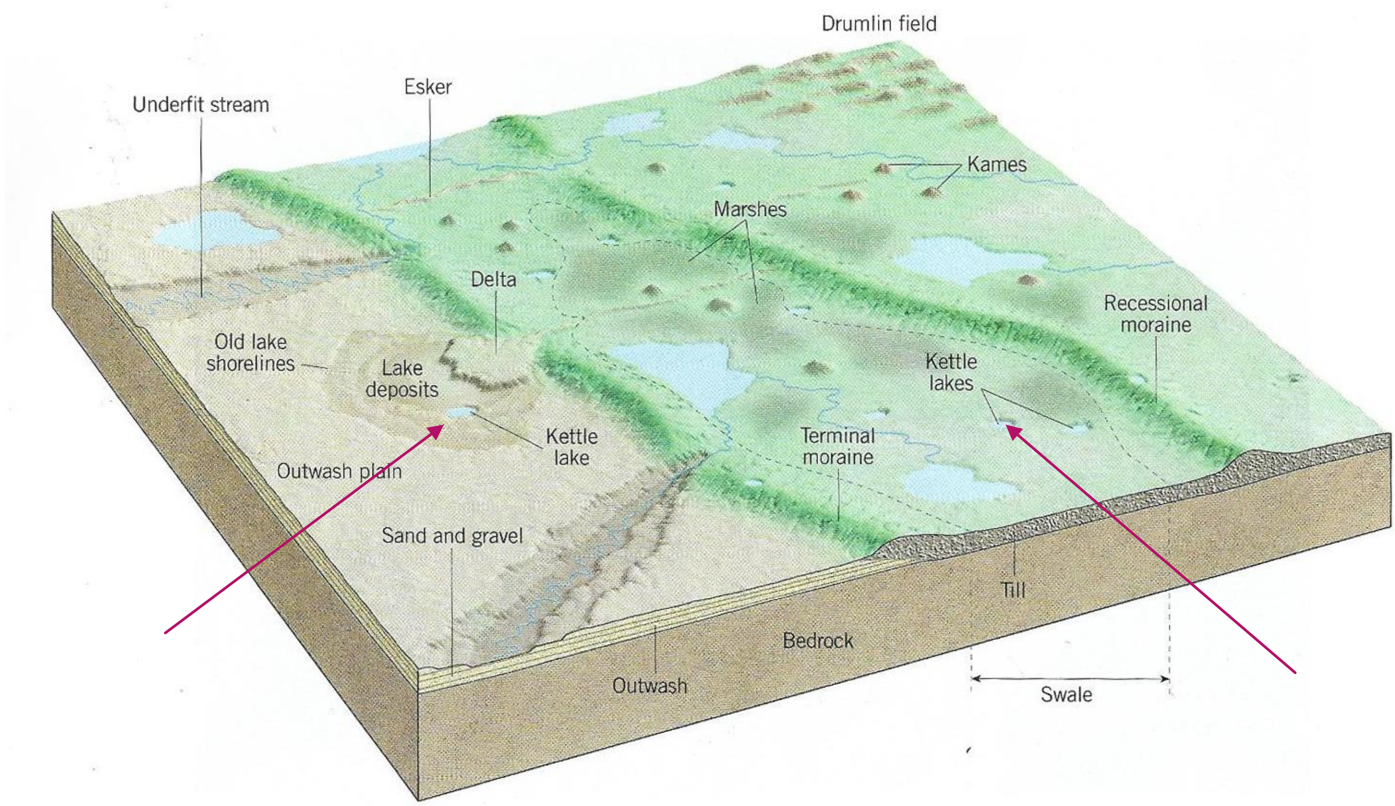
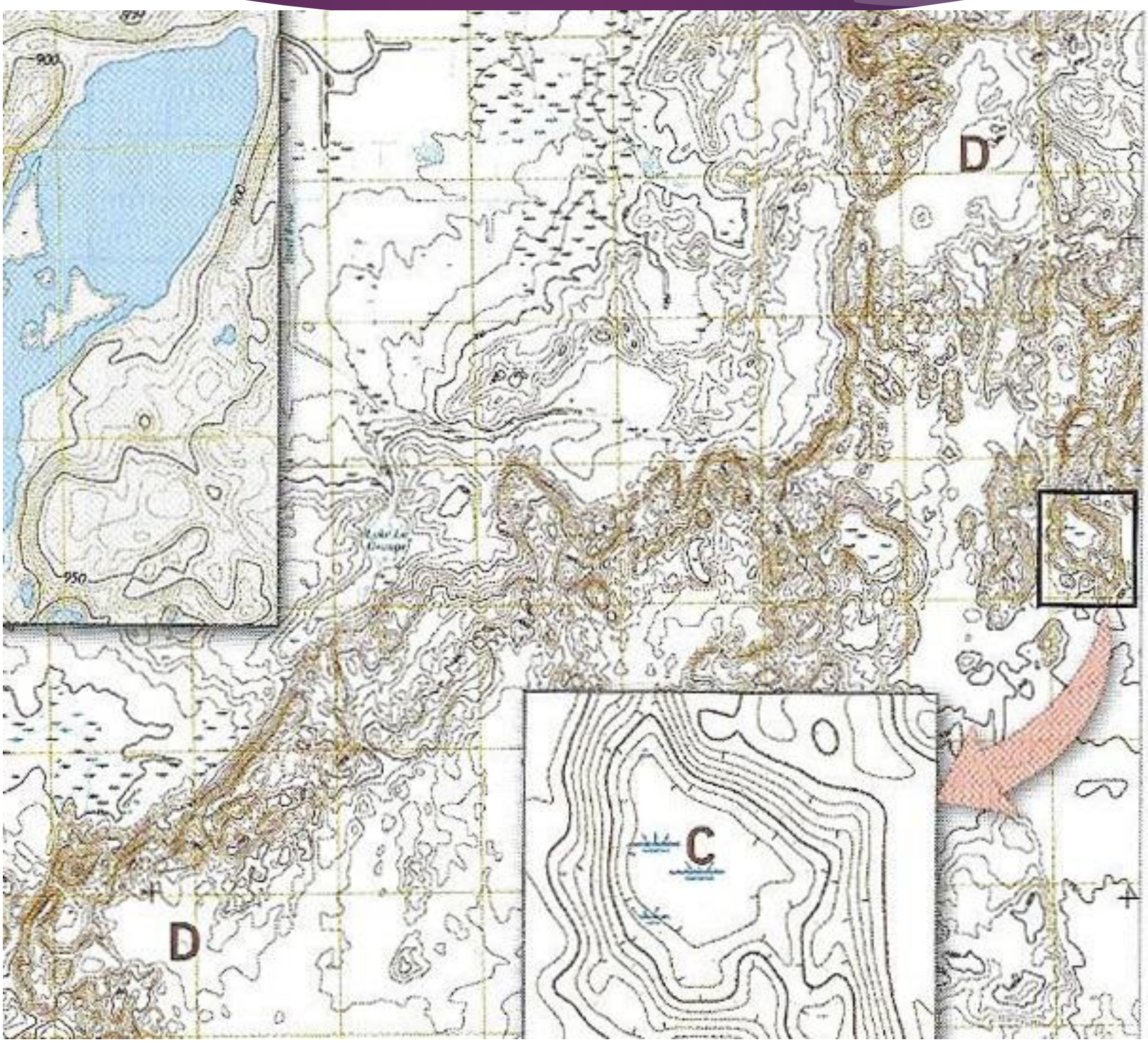


Figure 13.16 Typical erosional and depositional effects of continental glaciation. Continental glaciation leaves behind many characteristic landforms after the ice melts. Most of the terms used in this figure are defined in **Figs. 13.4–13.6.**

A kettle (kettle hole, pothole) is a depression/hole in an outwash plain formed by retreating glaciers or draining floodwaters. The kettles are formed as a result of blocks of dead ice left behind by retreating glaciers, which become surrounded by sediment deposited by meltwater streams as there is increased friction.


p. 373, QA-5: The features we just looked at in part 4 are part of an area that is a bit higher than the land to the north and has many small hills and depressions within a topography that seems chaotic. That area starts parallel to a li ne from point D to D' and extends to the southeast corner of the map. What glacial landform do you interpret this area to be?



p. 373, QA-5: The features we just looked at in part 4 are part of an area that is a bit higher than the land to the north and has many small hills and depressions within a topography that seems chaotic. That area starts parallel to a li ne from point D to D' and extends to the southeast corner of the map. What glacial landform do you interpret this area to be? SOLUTION

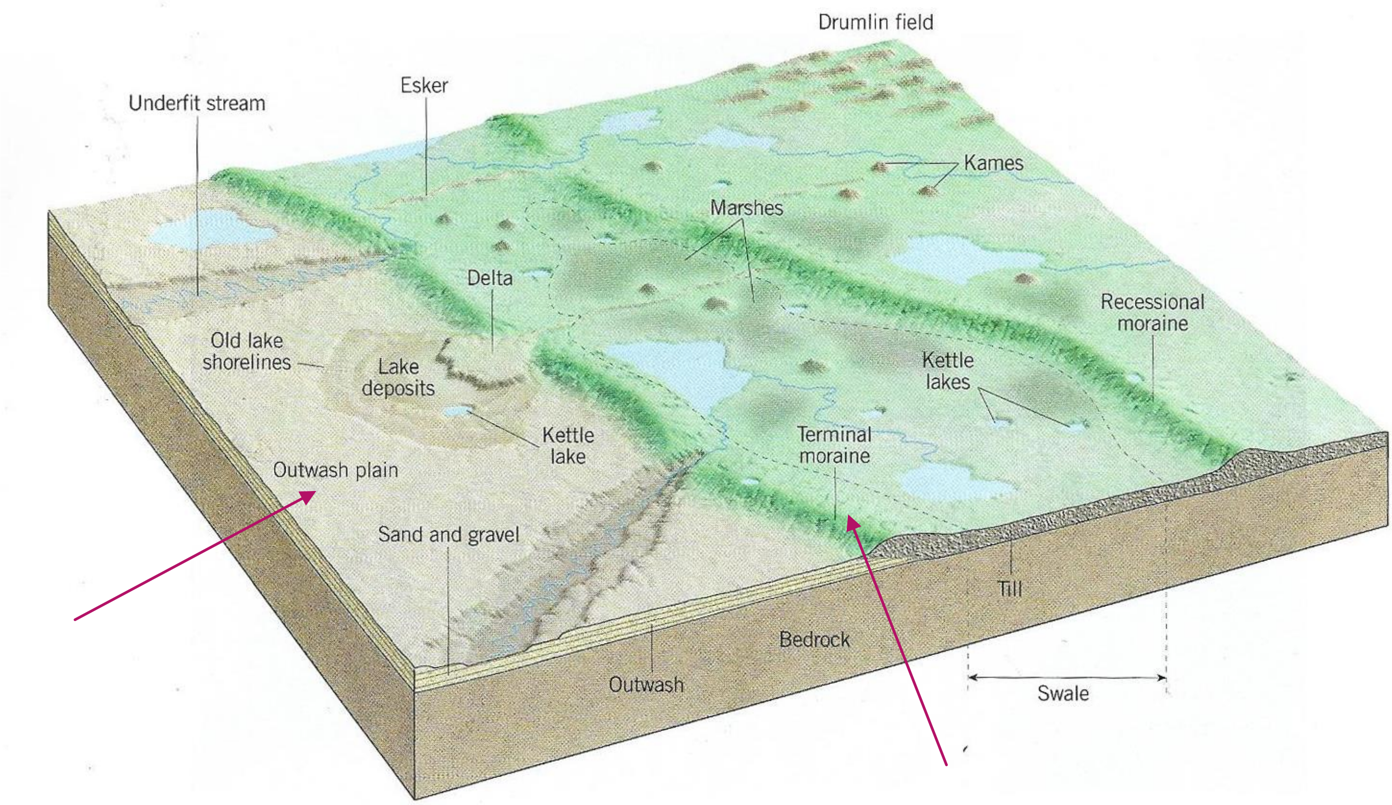
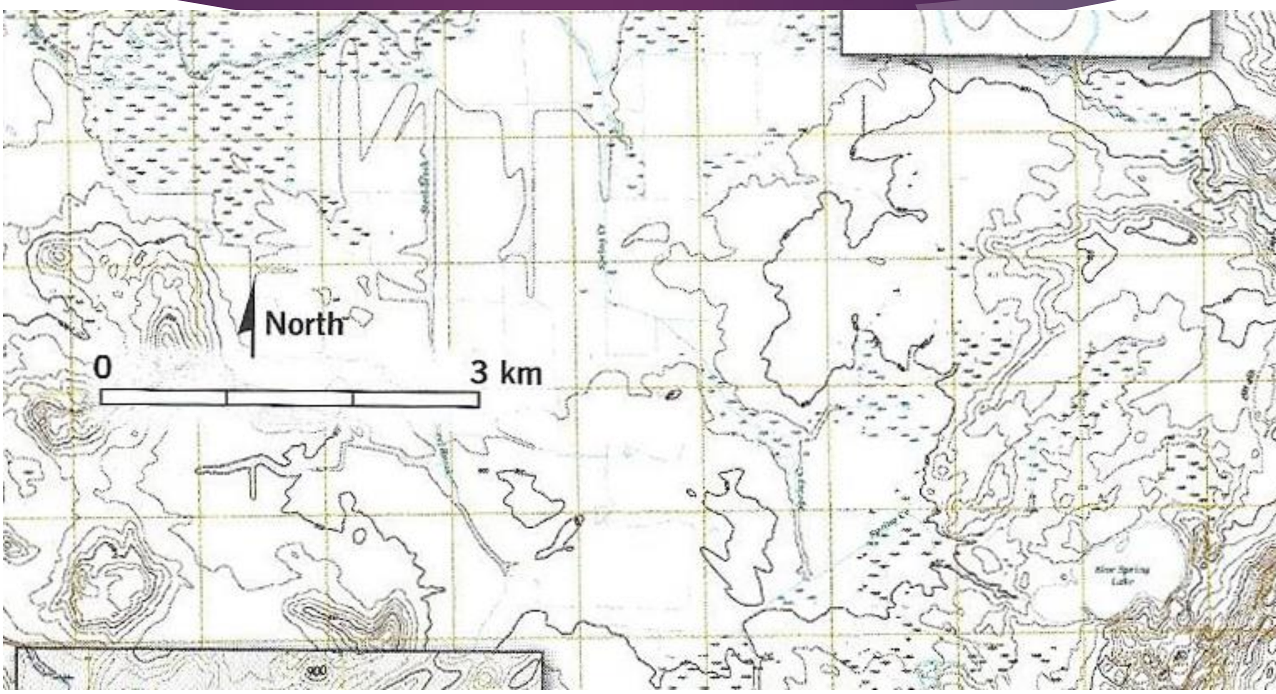


Figure 13.16 Typical erosional and depositional effects of continental glaciation. Continental glaciation leaves behind many characteristic landforms after the ice melts. Most of the terms used in this figure are defined in **Figs. 13.4–13.6**.

The features are the eroded remnants of a terminal Moraine and outwash plain

p. 374, QA-6: Note the marshy area running from the west-central edge of Fig. 13.19 to the northeastern corner, separating the features shown in detail map A from those labeled B, C, and D- D'. Describe the probable origin of this flat marshy area. (More than one answer is possible.) SOLUTION



The marshy area the remnants of older outwash plains formed by a succession of terminal moraines and recessional moraines as the glacier receded.

Marshy Areas

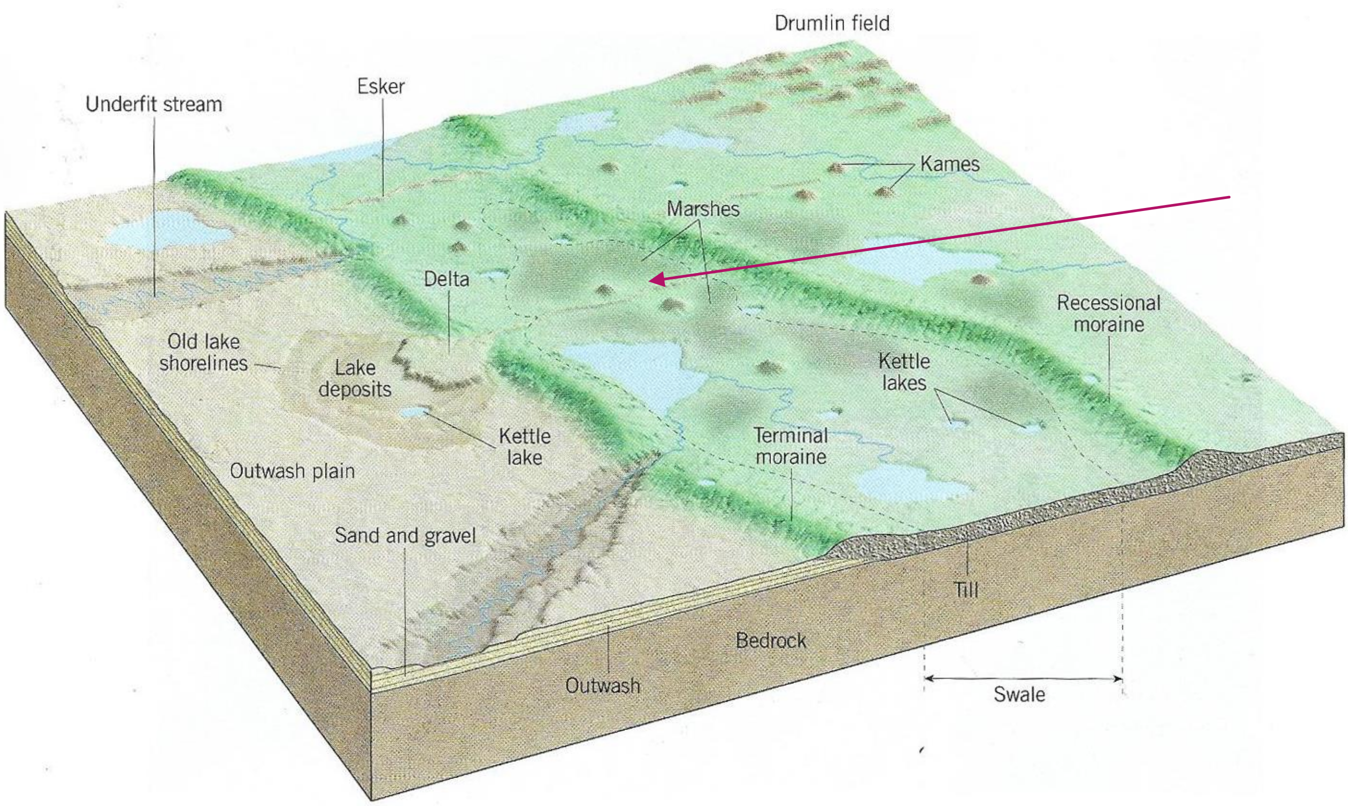
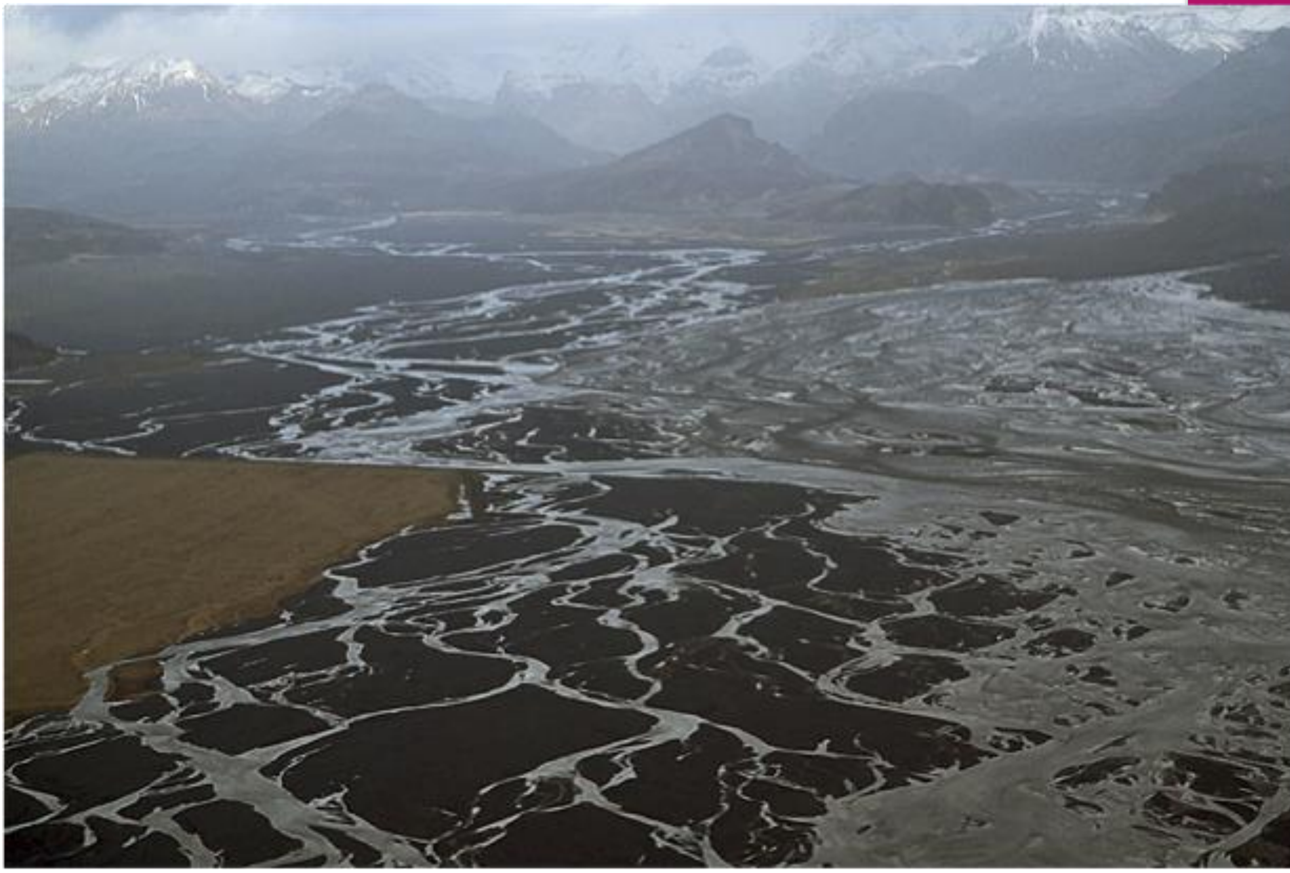


Figure 13.16 Typical erosional and depositional effects of continental glaciation. Continental glaciation leaves behind many characteristic landforms after the ice melts. Most of the terms used in this figure are defined in **Figs. 13.4–13.6**.



p. 374, QA-7: List the features of glaciated regions that you can recognize in Fig. 13.19.

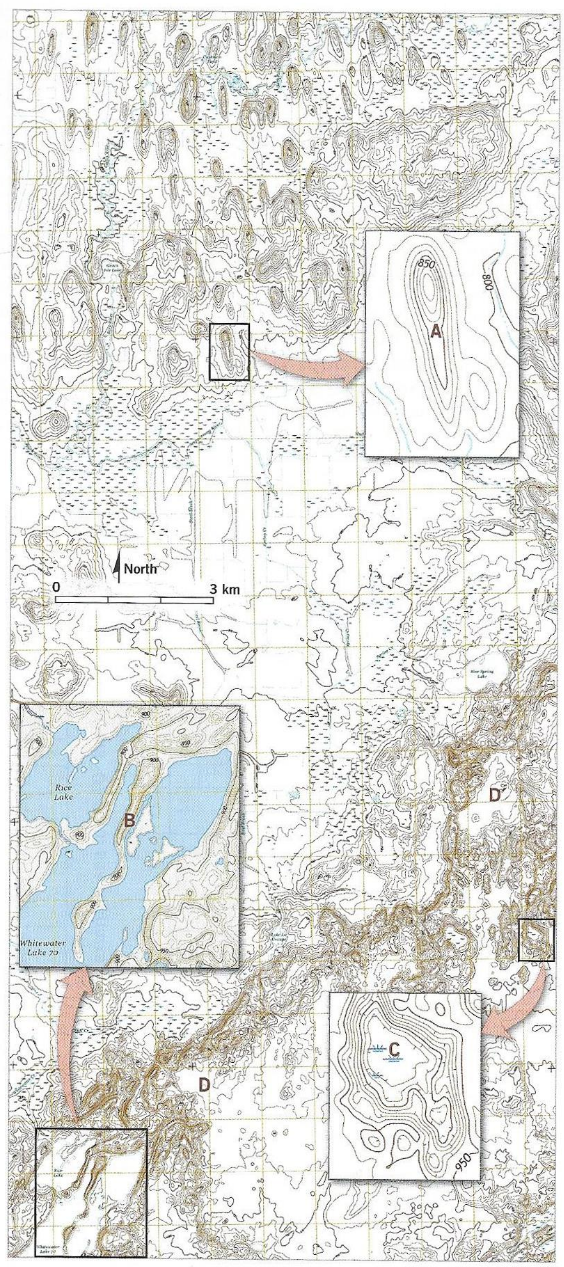


Figure 13.19 Continental glacier landforms near Whitewater, Wisconsin. Composite map processed to accentuate glacial landforms, derived from USGS 7.5-minute topographic maps of Rome, Palmyra, Little Prairie, and Whitewater, Wisconsin. The inset maps expand the areas indicated by the smaller black rectangles so that key features can be recognized in Activity 13.5.

p. 374, QA-7: List the features of glaciated regions that you can recognize in Fig. 13.19. SOLUTION

- **Drumlins**
- **Eskers**
- **Kames**
- **Terminal moraine**
- **Recesional moraine**
- **Lake Deposits**
- **Marshes**
- **Kettle Lakes**
- **Outwash Plain**

p.374, QB: REFLECT &DISCUSS How is the glaciated area of Fig. 13.19 different from areas affected by mountain glaciation, and how are they the same?

- **SIMILARITIES ARE**
- **---both are related to global climate changes**
- **---both are created by ice and melting ice**

- **DIFFERENCES ARE**
- **---the extent**
- **---the duration**
- **---the size**
- **---the resulting features**