



1  **Glaciers****Earth – Chapter 18**2  **Chapter 18 – Glaciers & Glaciation**3  **Glaciers: A Part of Two Basic Cycles**

- A glacier is a thick mass of ice that forms, over hundreds and thousands of years, by the accumulation, compaction, and recrystallization of snow
- Glaciers are parts of two basic Earth cycles:
 - Hydrologic cycle
 - Water can be trapped in a glacier for many to tens of thousands of years
 - Rock cycle

4  **Glaciers: A Part of Two Basic Cycles**

- Valley (Alpine) Glaciers
 - Glaciers that exist in valleys of mountainous areas are called valley or alpine glaciers
 - Flow down valley from an accumulation center
- Ice Sheets
 - Ice sheets exist on a larger scale than valley glaciers, currently exist at both poles
 - Greenland and Antarctica

5  **Valley Glacier**6  **Ice Sheets**7  **Glaciers: A Part of Two Basic Cycles**


- Ice Age Ice Sheets
 - 18,000 years ago, ice sheets covered large portions of North America, Europe, and Siberia
 - Known as the *Last Glacial Maximum*
 - Over the past 2.6 million years, ice sheets have advanced and retreated multiple times
 - Alternating glacial and interglacial periods

8 9  **Glaciers: A Part of Two Basic Cycles**

- Ice Sheets
 - Greenland and Antarctica
 - The Arctic Ocean is covered with sea ice (frozen seawater), not glacial ice
 - Sea ice is up to 4 meters thick while glaciers are hundreds to thousands of meters thick
 - Sea ice expands and contracts with the seasons
 - Glaciers form on land (*continental ice sheets*)
 - Greenland (60° – 80° N. latitude)
 - » Ice sheet covers 1.7 square million kilometers, avg. ~1500 meters thick
 - Antarctica in the southern hemisphere
 - » Ice sheet covers 13.9 square million kilometers
 - Ice flows out in all directions from one or more snow accumulation centers

10  **Glaciers: A Part of Two Basic Cycles**

- Ice shelves
 - Along parts of Antarctica, glacial ice flows into the sea, creating ice shelves
 - In shallow water, the ice touches bottom and is *grounded*
 - In deep water, the ice shelf floats
 - Thickest on landward side and thin seaward
 - Sustained by ice flow from the adjacent ice sheet
 - Some ice shelves are unstable and starting to break apart
 - Breakup of ice shelves attributed to the trend related to accelerated climate change

11  **Ice Shelves**12  **Ice Shelves**

13  **Glaciers: A Part of Two Basic Cycles**

- Other Types of Glaciers
 - Ice caps cover some uplands and plateaus
 - Ice caps and ice sheets feed outlet glaciers, which are tongues of ice extending outward from the large masses
 - Essentially these are valley glaciers connecting ice caps/sheets to the sea
 - Piedmont glaciers form when one or more alpine glacier emerges from the valley and spreads out in a broad lobe, occupying broad lowlands at the base of steep mountains


14  **Iceland's Vatnajökull Ice Cap**

15 

16  **Piedmont Glacier**

17  **Formation and Movement of Glacial Ice**

- Glaciers form in areas where more snow falls in winter than melts during the summer
 - Snow above the snowline does not melt in the summer
- Glacial Ice Formation
 - Air infiltrates snow
 - Extremities of crystals evaporate
 - Snowflakes become smaller, thicker, and more spherical
 - Air is forced out
 - Snow is recrystallized into a much denser mass of small grains called firn
 - Once the thickness of the ice and snow exceeds 50 meters, firn fuses into a solid mass of interlocking ice crystals—glacial ice

18  **Transformation of snow to glacial ice**

19  **Formation and Movement of Glacial Ice**

- Movement of a Glacier
 - Glacial ice moves as a *flow*
 - The solid flows in two ways:
 - Plastic flow involves movement *within* the ice
 - Under pressure, ice behaves as a plastic material
 - Along the ground, the entire ice mass slides along the ground as basal slip
 - Meltwater acts as lubricant

20  **Movement of a Glacier**

21  **Formation and Movement of Glacial Ice**

- Movement of a Glacier
 - Ice behaves as a brittle solid until subjected to pressure due to the weight of at least 50 meter of overlying ice
 - In contrast with the lower plastic portion, the upper 50 meter of a glacier is brittle and called the zone of fracture
 - Crevasses (cracks in the ice) are present in the zone of fracture but sealed off by plastic flow at depth

22  **Crevasses**


23 

24  **Formation and Movement of Glacial Ice**


- Rates of Glacial Movement
 - Movement of glacial ice is not obvious
 - Like a river, glacial ice does not all move at the same rate
 - Flow is fastest in the center of the glacier
 - Valley walls and floor slow the base and sides, causing drag
 - Glacial velocity ranges from extremely slow to several meters per day
 - Some glaciers exhibit extremely rapid movements called surges
 - Rates of movement have been measured using markers in the past, and time-lapse photography more recently

25  **Measuring Glacial Movement**26  **Movement of Antarctic Ice**27  **Formation and Movement of Glacial Ice**


- Budget of a Glacier
 - Glacial zones
 - The zone of accumulation is the area where a glacier forms
 - Is located above the snowline
 - The zone of wastage is the area where there is a net loss of glacial ice
 - Loss of ice by a glacier is called ablation
 - Melting
 - Calving
 - » the breaking off of large pieces of ice
 - » creates icebergs where the glacier has reached the sea

28  **Zones of a Glacier**29  **Glacial Ablation**30 31  **Iceberg**32  **Formation and Movement of Glacial Ice**

- Budget of a Glacier
 - Glacial budget
 - The glacial budget is the balance, or lack of balance, between accumulation and loss of ice
 - If accumulation exceeds loss, the glacial front advances
 - If ablation increases and/or accumulation decreases, the ice front will retreat
- Because glaciers are sensitive to changes in temperature and precipitation, they provide clues about changes in climate

33  **The glacial budget**34  **Retreating Glaciers**35  **Glacial Erosion**

- Glaciers are capable of great erosion and sediment transport
- Glaciers erode the land primarily in two ways:
 - As a glacier flows over a bedrock, it loosens and lifts blocks in a process called plucking
 - Occurs when meltwater penetrates the cracks and joints of bedrock beneath a glacier and freezes
 - Rocks in the glacier also act like sandpaper to smooth and polish a rock surface in a process called abrasion

36  **Evidence of Glacial Erosion**37  **Glacial Erosion**

- Glacial abrasion produces:
 - Rock flour (pulverized rock)
 - Glacial striations (grooves in the bedrock)
- Glacial erosion is controlled by:
 - Rate of movement
 - Thickness of the ice
 - Types of rock fragments trapped in the ice
 - The erodibility of the surface below the glacier

38  **Glacial Abrasion**39 40 41 42  **Rock Flour**43  **Landforms Created By Glacial Erosion**

- Landforms created by valley glaciers and ice sheets are very different
 - While ice sheets subdue most topography, valley glaciers create sharp and angular topography
 - Valley glaciers widen and deepen valleys, creating U-shaped glacial troughs
 - Glaciers tend to straighten valleys, removing sharp curves and creating truncated spurs
 - Glaciers in a main (trunk) valley typically erode more than tributary glaciers, creating hanging valleys

44 **Erosional Landforms Created by Alpine Glaciers**

45 46 47 48 

49 **U-Shaped Glacial Trough**

50 **Landforms Created By Glacial Erosion**

- Glaciated Valleys
 - A pater noster lake forms after parts of the bedrock (lifted and plucked by the glacier) fill with water
 - A cirque (a bowl-shaped depression) is typically found at the head of a glacial valley
 - After the glacier has melted away, the cirque basin is sometimes occupied by a small lake called a tarn
 - When two glaciers exist on opposite sides of a mountain, the dividing ridge erodes away, creating a gap called a col

51 **Landforms Created By Glacial Erosion**

- Arêtes and Horns
 - Some features form from the continued glacial erosion of cirques
 - An arête is a sharp-edged ridge
 - A horn is a pyramid-like peak

52 **The Matterhorn (*in Switzerland, not Anaheim...*)**

53 **The Matterhorn**

54 55 56 

57 **Landforms Created By Glacial Erosion**

- Roches Moutonnées
 - An asymmetrical knob of bedrock produced by continued glacial erosion is called a roches moutonnées
 - Glacial abrasion smoothens the gentle slope facing the oncoming glacier and plucking steepens the opposite side as the ice sheet rides over it
- Fjords
 - Deep, steep-sided inlets of the sea
 - Drowned glacial troughs that form when sea level rises
 - Depths may exceed 1000 meters

58 **Roches Moutonnées**

59 **Fjords**

60 

61 **Glacial Deposits**


- As glaciers melt, the rocks and sediments in the glaciers are deposited
 - Glacial drift refers to all sediments of glacial origin
 - Two types of glacial drift
 - Till is material that is deposited directly by the ice
 - Sediments laid down by glacial meltwater are called *stratified drift*

62  **Glacial Till**63  **Glacial till is typically unstratified and unsorted**64  **Glacial Deposits**

- Glacial Till
 - Till is deposited as glacial ice melts and drops its load of rocks
 - Glacial erratics are boulders in the till or lying on the surface
- Stratified Drift
 - Sediment that is sorted by size and weight of the particles is called stratified drift
 - Deposited by glacial meltwater rather than the glacier itself

65  **Glacial Erratic**66 67  **Landforms Made of Till**



- Lateral and Medial Moraines
 - A moraine is a landform made of glacial till
 - A lateral moraine is an accumulation of debris on the side of the glacial till
 - A medial moraine is created when two alpine glaciers converge
 - The lateral moraines of each glacier converge in the center of the new glacier as a medial moraine

68  **Formation of a Medial Moraine**69  **Landforms Made of Till**

- End and Ground Moraines
 - A glacier is similar to a conveyor belt—regardless of the movement, sediments are constantly moved forward and dropped at the terminus
 - An end moraine is an accumulation of debris that forms at the terminus of a glacier
 - A glacier will retreat to a point where it is in balance, the ice front stabilizes, and a new end moraine forms
 - The very first end moraine signifies the farthest advance of the glacier and is called the *terminal end moraine*
 - End moraines that form as the ice front occasionally stabilizes are termed *recessional end moraines*
 - A ground moraine is a rock-strewn plain created as the glacier retreats

70  **Glacial depositional features**71  ***My favorite glacier:***

Athabaska Glacier, Alberta, 1976

72  ***“Geology Guy” on his favorite glacier in 1976***73 74 75 76  **End Moraines of the Great Lakes**77  **Two Significant End Moraines in the Northeast**78  **Landforms Made of Till**

- Drumlins
 - Drumlins are streamlined asymmetrical hills composed of till and formed from ice sheets
 - Range in height from about 15 to 50 meters and may be up to 1 kilometer long
 - The steep side of the hill faces the direction from which the ice advanced
 - The gentler, longer slope points in the direction the ice moved

79 80  **A drumlin in upstate New York**81 82  **Landforms Made of Stratified Drift**

- Two basic categories of features composed of *stratified drift*:
 - *Ice-contact deposits* accumulate on, within, or immediately adjacent to a glacier


– *Outwash sediment* is material deposited by meltwater streams

83  **Landforms Made of Stratified Drift**

- Outwash Plains and Valley Trains
 - Glacial melt water, choked with sediment, flows onto a flat surface, drops its load, builds a broad, ramp like surface, and creates braided streams
 - Outwash plains are associated with ice sheets
 - Valley trains are associated with mountain valleys
 - Often are pockmarked with basins or depressions known as kettles


84  **Landforms Made of Stratified Drift**

- Ice-Contact Deposits
 - Meltwater flows over, within, and at the base of motionless ice deposits, stratified drifts that remain once the ice melts away
 - A kame is steep-sided mound formed from ice-contact stratified drift
 - Kame terraces occur when glacial ice occupies a valley
 - An esker is a narrow, sinuous ridge composed largely of sand and gravel


85  **Common Depositional Landforms**


86 


87 

88  **Other Effects of Ice-Age Glaciers**

- Crustal Subsidence and Rebound
 - Ice sheets cause downwarping of the crust
 - After the glacier melts, the crust gradually rebounds
- Sea-Level Changes
 - During the last glacial maximum, sea level was 100 meters lower than present level
 - Atlantic coast of the United States lay more than 100 kilometers east of New York City!
 - If the Antarctic Ice Sheet melted, sea level would rise 60 or 70 meters


89  **Crustal Subsidence and Rebound**


90  **Changing Sea Level**

91  **Other Effects of Ice-Age Glaciers**

- Changes to Rivers and Valleys
 - The advance and retreat of the North American ice sheets changed the routes of rivers and modified the size and shape of many valleys
 - Upper Mississippi Drainage Basin
 - Prior to the Ice Age, a significant part of the Missouri River drained north toward Hudson Bay
 - New York's Finger Lakes
 - 11 long, narrow, roughly parallel water bodies oriented north-south
 - Prior to the Ice Age, they were a series of river valleys, glacial erosion transformed them into deep, steep-walled lakes

92  **Changing Rivers**


93  **New York's Finger Lakes**

94  **Other Effects of Ice-Age Glaciers**

- Ice Dams Create Proglacial Lakes
 - Ice sheets and alpine glaciers can act as dams to create proglacial lakes
 - Examples: Lake Agassiz, Lake Missoula
 - The failure of ice dams can release large volumes of water very quickly

95  **Glacial Lake Agassiz**

96  **Glacial Lake Missoula**

97  **Other Effects of Ice-Age Glaciers**

- Pluvial Lakes
 - The growth of ice sheets can cause the temperatures and evaporation to decrease in semi arid regions


- If precipitation occurs, pluvial lakes form
- Example: Lake Bonneville

98  **Pluvial Lakes**

99  **The Glacial Theory and *this* Ice Age**

- Glaciers were once more extensive than they are today
 - Looking at glacial deposits and using the principle of uniformitarianism
- Glacial/interglacial cycles occur every 100,000 years
 - The Northern Hemisphere Ice Ages began between 2 and 3 million years ago
 - ~20 of these cycles spanned the Ice Age
 - The Antarctic ice sheet formed at least 30 million years ago


100  **Where Was The Ice?**

101  **Maximum extent of ice during the Ice Age**

102  **Causes of Ice Ages**

- The Quaternary Ice Age is not the only ice age in Earth's history
 - Tillite is a sedimentary rock formed from glacial till
 - Rock evidence of earlier ice ages
- Any successful theory about the causes of ice ages must include:
 - Causes of the onset of glacial conditions
 - Causes of alteration between glacial and interglacial stages

103  **Tillite**

104  **Causes of Ice Ages**

- Plate Tectonics
 - Continents shift and move through geologic time
 - Change ocean circulation
 - Continents move toward or away from the poles
 - Climate change triggered by plate tectonics is extremely gradual
 - Happens on a scale of millions of years

105  **A Late Paleozoic Ice Age**

106  **Causes of Ice Ages**


- Variations in Earth's Orbit
 - Changes in Earth's orbit can vary the amount of solar radiation received
 - Variations in the shape of Earth's orbit around the Sun (*eccentricity*)
 - Changes in the angle of Earth's axis (*obliquity*)
 - The wobbling of Earth's axis (*precession*)

107  **Orbital Variations**

108  **Causes of Ice Ages**

- Other Factors
 - Changes in Earth's atmosphere
 - Changes in ocean circulation
 - Changes in the reflectivity of Earth's surface

109  **Ice Cores**

110  **End of Chapter 18**