GLACIERS

Smith and Pun, Chapter 18

WHAT IS A GLACIER?

Glaciers are defined as an accumulation of snow and ice that is thick enough to flow under its own weight.

Valley glaciers are long, narrow glaciers confined within bedrock valleys (see Figure 18.3a, page 522). An example of a valley glacier is the Athabasca Glacier.

Ice sheets are broad glaciers not confined by topography (see Figure 18.3b, page 522).

Ice caps are smaller unconfined glaciers (see Figure 18.3c, page 522).

WHERE GLACIERS FORM

Glaciers form where snow persists year round. Heavy winter snowfall is essential for the formation of glaciers; more snow must fall during the winter than melts during summer.

The <u>snowline</u> is defined as the elevation above which new fallen snow persists throughout the year (see Figure 18.4, page 523).

Snowlines in the recent geologic past were much lower than today!

HOW GLACIAL ICE FORMS

The porosity of freshly fallen snow is high, because of the irregular shape of snowflakes. As the snowflakes are buried beneath more snow:

- **Ice molecules move from the edges to the center of the flakes**
- **Eventually the snow is transformed into rounded flakes**
- **Minor melting and refreezing during summer converts snow grains into ice grains, which pack even closer together (see Figure 18.5, page 524).**

HOW GLACIAL ICE FORMS (2)

When the ice grains are buried, the pressure eventually causes recrystallization into nonporous glacier ice.

Glacial ice forms either by metamorphic recrystallization of snow or by freezing of meltwater that soaks into the glacier.

HOW ICE FLOWS

Glacial ice flows because it is much weaker than the common rocks in the Earth's crust. When ice is stressed, the ice crystals slide on mineral cleavage planes, resulting in plastic deformation of the whole mass (see Figure 18.6, page 525). The critical pressure for plastic ice deformation is equal to a depth of only a few tens of meters. In contrast, the plastic flow of granite in the continental crust requires depths of about 10 km.

Crevasses are cracks in the brittle upper part of a glacier caused by motion of the lower, plastically deforming part. Crevasses generally do not extend below a depth of about 50 m.

HOW ICE FLOWS (2)

Addition of snow and ice at high elevation causes glaciers to flow downslope in response to gravity. Therefore, a growing glacier eventually descends to lower, warmer elevations where summer melting exceeds accumulation during winter (see Figure 18.7, page 525).

Zone of accumulation – The high elevation zone where winter snow accumulation exceeds summer melting.

Zone of wastage – The low elevation zone where summer melting exceeds the winter snow accumulation. This zone is also called the zone of ablation.

HOW ICE FLOWS (3)

The relative amount of accumulation and/or wastage determines whether a glacier is advancing, retreating, or remaining stationary (see Figure 18.8, page 526).

The highest velocity is always in the center of the glacier, because of friction along the valley walls.

HOW ICE FLOWS (4)

The temperature at the bottom of the ice determines whether the glacier is sliding or not. If the bottom of a glacier is frozen onto the underlying rock, then no sliding occurs. When liquid water is present below the ice, sliding occurs.

1. **Water acts as a lubricant between the ice and the underlying regolith or rock by reducing friction and cohesion.**
2. **Water is pressurized by the weight of the overlying ice. Water pressure at the base of some glaciers is nearly equal to the weight of the ice; this significantly reduces the friction.**

SPEED OF GLACIAL MOVEMENTS

Measurements have revealed significant variation in the velocity of glaciers. Some glaciers may move at rates up to 80 m per day; others move at rates less than 2 m per year.

The velocity decreases downward through the glacier and toward the valley margins (in a valley glacier).

Variability in velocity causes different parts of the glacier to experience tensional and compressional stresses.

Tension causes brittle fracturing indicated by crevasses; compression causes crevasses to close and may result in thickening and thrust faulting in the ice (see Figure 18.10, page 527).

GLACIAL EROSION

Some glacial erosion occurs through abrasion. Although ice is too soft to scratch the surfaces of many rocks, transported rocks and mineral debris act as abrasive tools (see Figure 18.12, page 530).

The presence of <u>striations</u> indicates that abrasion at the base of the glacier by rocks has occurred.

Abrasion may generate a significant volume of very fine-grained rock dust, called <u>glacial</u> <u>flour</u>.

GLACIAL EROSION (2)

Glaciers also pluck rock apart along preexisting joints and cracks similar to stream plucking. The plucking process at the bottom of a glacier is more erosive than that of a stream bottom because:

1. **The higher shear stress of flowing ice disaggregates fractured rock more readily**
2. **Freezing and thawing at the bottom of the glacier produces new rock fractures and further pries existing fractures open.**

GLACIAL EROSION (3)

3. **The plastic ice squeezes into fractures and pries the rock apart.**

4. **Water pressurized at the base of the glacier by the weight of overlying ice dislodges blocks of rock (see Figure 18.12, page 530).**

GLACIAL EROSION (4)

Glacial erosion is most intense where the moving ice shoves against rock. Therefore, erosion is characteristic of the zone of accumulation where ice flow is downward against the underlying rock and regolith (see Figure 18.13, page 531).

Erosion is also intense along the valley walls.

GLACIAL EROSION (5)

Glaciers shove and drag sediment at the base of the ice, carry it frozen within the ice, and piggyback it along the top (see Figure 18.14, page 532).

Sediment eroded by plucking and abrasion is frozen into the ice. Some debris remains at the base of the glacier, but a lot of it eventually moves upward near rock obstacles and in the zone of wastage because of upward flow.

GLACIAL EROSION (6)

Debris that drops onto the ice litters the tops of valley glaciers and ice sheets moving past higher mountain peaks.

This debris may be transported by glaciers as a moving ridge of boulder-rich sediment along the glacial margin, and is called a <u>lateral</u> <u>moraine</u>.

Where two valley glaciers meet, the <u>lateral</u> <u>moraines</u> combine to form a ribbon of sediment within the glacier called a medial moraine (see Figure 18.15, page 532).

GLACIAL DEPOSITION

Geologists classify two types of sedimentary deposits near or beneath modern glaciers, and these deposits are common in previously glaciated landscapes (see Figure 18.16, page 533).

- **Sediment deposited directly by the glacier is called <u>till</u>. Till is a very poorly sorted mixture of gravel, sand, and mud and typically lacks bedding Moraines consist of till.**
- **Sediment primarily eroded by glaciers and subsequently carried away by meltwater streams is called outwash. Outwash is the sediment that washes out of the glacier.**

GLACIAL DEPOSITION (2)

Ice sheets can transport boulders, some weighing hundreds of metric tons, more than 1,000 km from where they originated (see Figure 18.17, page 534). Such rocks are called <u>erratics</u>.

Outwash is much better sorted and has more distinct bedding than till. The gravelly and sandy alluvium is commonly associated with thinly bedded mud deposited in lakes that form along the front of a glacier.

Till deposited beneath the glacier forms a bumpy sheet of sediment of irregular thickness, called <u>ground</u> <u>moraine</u> (see Figure 18.18a, page 534).

GLACIAL DEPOSTION (3)

Ground moraine may originate from the following three processes:

1. **A glacier drags and pushes a large volume of sediment at the bottom of the ice, which increases friction at the base of the glacier. The frictional resistance builds until the rocky debris lodges against the ground surface and is left behind as the ice continues to flow.**
2. **Rock fragments frozen into the ice move upward in the zone of wastage, but fragments dragging along the base of the glacier are left behind.**
3. **Melting at the base of the glacier releases rock fragments that previously were frozen into the base of the flowing ice.**

GLACIAL DEPOSITION (4)

Most glacier margins are flanked by high ridges of till called <u>lateral</u> <u>moraines</u> (see Figure 18.18b, page 534).

<u>End</u> <u>moraine</u>s form at the leading edge of the glacier. Most end moraines are directly deposited from the glacier (see Figure 18.19, page 535). Some end moraine till is unconsolidated regolith that is bulldozed along in front of the moving glacier.

GLACIAL DEPOSITION (5)

Melting glaciers may also deposit outwash (see Figure 18.20, page 535). The large sediment load and widely fluctuating discharge combine to favor the development of braided streams. The sediment loads are typically so large that they overwhelm the transporting ability of the streams, resulting in widespread deposition.

GLACIAL DEPOSITION (6)

Meltwater streams also deposit outwash downslope, beneath and alongside the glacier (see Figure 18.21, page 536).

WHEN GLACIERS REACH THE OCEAN

Glaciers originate on land but may flow into the ocean or into large meltwater lakes. The interaction between glacial ice and water is complex because ice is slightly less dense than water.

<u>Tidewater</u> <u>glaciers</u> are glaciers that descend into the ocean from land and are in contact with the seafloor (see Figure 18.22, page 537).

Tidewater glaciers are common in southeastern Alaska, parts of northeastern Arctic Canada, and along the Greenland coast.

WHEN GLACIERS REACH THE OCEAN (2)

<u>Icebergs</u> are blocks of ice that detach from a glacier and float off into the ocean or a lake. Some icebergs break away from the front of a tidewater glacier because of oversteepening of the front of the glacier by wave erosion (see Figure 18.22, page 537).

The largest icebergs break away from ice shelves. Iceberg formation is an important wastage process for glaciers, particularly in cold climates with minimal melting (see Figure 18.23, page 538)..

Formation of icebergs along the Antarctic ice shelves accounts for 80 percent of the total glacier wastage for the entire continent (see Figure 18.24, page 538).

HOW VALLEY GLACIERS MODIFY LANDSCAPES

Landscape modification by moving glaciers is important because:

1. **Glaciers are not as common as streams, but they result in more erosion. In some places, glaciers are the dominant force in creating the landscape.**

2. **Ice age glaciers are responsible for formation of the primary landscape features over large areas of North America and northern Europe that are currently ice free.**

HOW VALLEY GLACIERS MODIFY LANDSCAPES (2)

Five landforms are particularly distinctive of the current or former action of valley glaciers:

1. **U-shaped valleys**
2. **Knife-edge ridges and pointed peaks**
3. **Places where erosion overdeepened valleys to form lakes**
4. **Hanging valleys**
5. **Moraine ridges**

Features 1 through 4 are erosional and number 5 is depositional (see Figure 18.25, page 539).

HOW VALLEY GLACIERS MODIFY LANDSCAPES (3)

U-Shaped Valleys

Glacial valleys eroded into bedrock have a distinctive, U-shaped, cross-valley profile with very steep walls and a broad valley floor (see Figure 18.27, page 540).

Bedrock stream valleys, in contrast, are usually narrow at the bottom and have a V-shaped cross-valley profile.

Fjords are U-shaped, glacier eroded valleys along coastlines that are now partially submerged beneath the ocean to form deep, elongate, steep-walled bays. Fjord is a Norwegian word, and the Norwegian coast has dozens of these landforms (see Figure 18.27, page 540).

HOW VALLEY GLACIERS MODIFY LANDSCAPES (4)

U-Shaped Valleys

Variation in the velocity of glaciers accounts for the erosion of U-shaped valleys (see Figure 18.28, page 541).

- **The greatest erosion occurs at the base of the glacier where the velocity is the highest.**
- **The highest sliding velocity at the base of a glacier in a V-shaped stream valley is not at the bottom of the valley, but is actually partway up the valley sides.**

  This means that erosion is more intense on the valley margins than at the valley center, so the valley floor widens into a U-shape.

HOW VALLEY GLACIERS MODIFY LANDSCAPES (5)

Overdeepened Valleys

The elevation of a stream valley floor always decreases continuously in the downvalley direction. The long profile of glacially eroded valleys, in contrast, commonly includes overdeepened areas where the valley floor actually slopes inward to make a bowl.

After the glacier melts, water accumulates within these eroded bowls and forms lakes (see Figure 18.29, page 542).

Deep erosion is especially common at the upslope end of glaciated valleys, where the steeply eroded valley walls partially enclose a natural ampitheatre called a cirque.

HOW VALLEY GLACIERS MODIFY LANDSCAPES (6)

Hanging Valleys

Another feature distinguishing stream and glacial valleys is the elevation where tributary valleys join the main valley. Streams generally join together at the same elevation. Tributary valleys in glaciated landscapes, in contrast, typically terminate high above the main valley.

Retreating glaciers in side valleys generally disconnect from the glaciers in the deeper main valleys. When the glacier melts completely, the tributary valley floor hangs hundreds of meters above the main valley, resulting in spectacular waterfalls.

HOW VALLEY GLACIERS MODIFY LANDSCAPES (7)

Knife-edged Ridges and Pointed Peaks

The ridges between widening glacial valleys become narrower, until they rise steeply to very narrow, almost knifelike ridges (also known as arêtes; see Figure 18.25).

Where several valleys slope radially away from a single mountain peak, the glaciers gouge and erode narrow troughs into the central mountain. This leaves behind a very pointy pyramid, also referred to as a horn.

Mt. Everest, Earth's highest peak, has the pointed pyramid shape that results from glacial erosion.

HOW VALLEY GLACIERS MODIFY LANDSCAPES (8)

Lateral and End Moraines

Lateral and end moraines are distinctive landforms in glaciated landscapes (see Figure 18.31, page 543).

- **Ridges of poorly sorted till parallel to valley margins mark the edges of former valley glaciers.**
- **The heights of the lateral moraine ridges above the valley floor provide a good estimate of the thickness of the former glacier.**
- **End moraines are ridges of till that cross the valley and, along with lateral moraines or the rock walls of the valley, may obstruct stream flow to produce a lake.**

HOW ICE SHEETS MODIFY LANDSCAPES

Four landscape characteristics are particularly indicative of past ice sheet glaciation:

1. **Large areas of scoured, plucked, and abraded rock surfaces**
2. **Large areas covered with great thicknesses of till**
3. **Streamlined ridges parallel to the direction of glacier movement**
4. **Landscapes with numerous lakes, ranging from small ponds to the largest lakes on Earth (see Table 18.2 and Figures 18.32 and 18.33).**

HOW ICE SHEETS MODIFY LANDSCAPES (2)

Thick Till and Long Moraines

Till in eastern North America is typically 30 to 60 m thick and is locally more than 200 m thick near and south of the Great Lakes. The till is so thick and extensive across the landscape that the bedrock geology over tens of thousands of square kilometers is only known from rocks uncovered in wells and outcrops in the bottoms of the deepest stream valleys.

Topography in these landscapes is very uneven because of irregular till thickness and depressions, called kettles.

HOW ICE SHEETS MODIFY LANDSCAPES (3)

Thick Till and Long Moraines

End moraine ridges continue across the landscape for hundreds of kilometers in the northeastern United States (see Figure 18.34, page 546).

Each glacier generates multiple end moraines. One end moraine forms at the farthest advance of the glacier. Other moraines form during glacial retreat, where the ice front was stationary for a while or where it temporarily began to advance again.

HOW ICE SHEETS MODIFY LANDSCAPES (4)

Streamlined Features in Rock and Till

Streamlined hills of till are tapered by the flowing ice (see Figure 18.33g). These ridges, sometimes called drumlins, provide evidence of past glaciation as well as the direction of glacier movement.

HOW ICE SHEETS MODIFY LANDSCAPES (5)

Glacially Formed Lakes

Lakes are very common features in glaciated landscapes.

- **Some mark locations where glaciers scooped out rock to leave a bowl that collected water (Figures 18.32 and 18.33a).**
- **Other lakes and ponds are kettles (Figures 18.32 and 18.33b). The irregular topography of till, especially within end moraines, often includes closed depressions that fill with water (Figures 18.32 and 18.33e).**
- **The Great Lakes are the most spectacular glacially eroded lakes on Earth (see Figure 18.35, page 547).**

NORTH AMERICA DURING THE LAST ICE AGE

The last ice age began about 120,000 years ago, late in the Pleistocene epoch. Spurts of glacial advance, alternating with minor retreats, continued over the next 100,000 years.

The continent scale ice sheets reached their largest extent approximately 21,000 years ago (see Figure 18.36, page 548).

The extent of the glaciers is determined by looking at the distribution of glacial till and the location of end moraines.

NORTH AMERICA DURING THE LAST ICE AGE (2)

The retreat of the great ice sheets is also linked to geologic features in North America (see Figure 18.41, page 552).

- **The northward retreat of the glaciers from the northern United States exposed freshly eroded bedrock, recently deposited till, and a new landscape for stream drainage.**

- **Glacial erosion and deposition completely rearranged the drainage basins of nearly a third of North America (see Figure 18.42, page 553).**