

GY325 Applied Geomorphology

Glacial Landforms Lab

Introduction

Glacial erosion is an important erosional process capable of producing a variety of landforms. Glacial systems can be separated into two types, *continental glaciers* and *valley (alpine) glaciers*. Continental glaciers cover a large proportion of an entire continent or microcontinent. Today there are only two existing continental glaciers, the Antarctic and Greenland continental ice sheets. During periods of our planet's recent geological history, continental glaciers covered significant portions of several continents that are free of ice today. In these regions landforms are predominantly glacial in origin even though glacial ice no longer exists in the region.

Valley or alpine glaciers occupy mountain valleys in much the same way as stream systems. Valley glaciers, however, fill a much greater proportion of the valley volume than do typical stream systems. In contrast to valley glaciers, continental glaciers grow in a radial fashion from a continental interior, therefore, they tend to have a roughly circular shape. Glaciers can erode to a base level that is below sea level- a fact which contrasts sharply with fluvial systems.

The basic difference between continental glacial and valley glacial systems are the differences in size and shape. The mechanism by which glaciers move is the same regardless of the type of glacier. The landforms produced by each type of glacial process are distinctive because of the difference in size and shape of each. The landforms produced are distinct and allow determination of whether or not a glacial system has produced a landform, and if so, whether it was a continental or valley glacier.

Glacial Flow

Glaciers, especially valley glaciers, can be thought of as "rivers" of ice. In many ways the rules governing streamflow also govern the flow mechanism of glacial ice. For example, just as flowing water will naturally seek out the lowest elevation, so will glaciers. The rate of movement for glacial systems is several order of magnitudes less than that of streamflow velocities. Most glacial systems flow at the imperceptibly slow rate of less than one meter per day.

Glaciers will grow in any environment where the annual accumulation of winter snow is larger than that of the amount of snow that melts during warmer months. Note that more than just cold temperatures are required for the accumulation of glacial ice; there must also be ample moisture in the environment in the form of snow. If a snowpack develops that is more than several meters thick the delicate ice crystals of snow will be crushed into more dense spherical ice pellets termed *firn*. This layer is also termed the "snowbase" upon which the uncompacted snow (powder) rests. As the layer of firn becomes thicker through

GY325 Applied Geomorphology

Glacial Landforms Lab

time the pressure on the firn increases. This leads to dramatic changes in the behavior of the firn ice. When a layer of snow and firn builds to more than approximately 50 meters thickness, the firn is compacted into a solid ice devoid of any void space. More importantly, however, is that the ice is under sufficient pressure to allow *viscous flow* in the solid state—similar to the behavior the asthenosphere relative to the lithosphere. In this state the glacial ice will begin to flow in the downslope direction under the influence of gravity. In addition to the ability to flow, the glacial ice at the base of the glacier may actually become liquid water because of the increased pressure of the building glacier. This effect can be understood from the Figure 12 phase diagram of water. Note that at the freezing point, if pressure is increased that the water will convert to the liquid state because that is the more dense arrangement for water molecule. This thin film of water will allow the glacier to move by sliding on a relatively frictionless surface.

The area that annually receives more snow in winter than melts during summer periods is termed the *zone of accumulation*. This area is marked on aerial photographs by very white areas covered with fresh snow. As the glacial ice flows downslope over time the fresh snow is taken to lower elevations where temperatures are warmer. This allows the delicate snow flakes on top of the glacial ice to melt revealing the surface of the firn or ice. This surface will appear distinctly different than the former snow because the glacial ice will reflect the blue sky if it is free of debris, or will appear "dirty" if it is covered by debris. The zone where the snow pack has melted is termed the *zone of wastage* or the *zone of ablation*. The line dividing the zone of accumulation and the zone of ablation is termed the *snowline*.

Valley Glaciers

Valley glaciers are the most common type of glaciers. They are usually found in the higher elevation parts of mountain ranges. The higher elevations have the lower temperatures and higher rates of precipitation that favor the growth of glacial ice. Valley glaciers may be found quite close to the equator if elevations are high— the Andes is but one example. Once the glacial ice of a valley glacier begins to flow downslope, the glacier normally occupies a valley that was formerly cut by stream erosion. Because the glacier is a more effective erosional agent than water the valley rapidly undergoes several dramatic changes:

- The formerly "V"-shaped valley becomes flat at the base but very steep along the valley walls to form a "U"-shape profile.
- The elevation of the base of the valley is rapidly lowered because the glacial ice will remove the entire regolith layer until bedrock is encountered. Because the solid ice

GY325 Applied Geomorphology

Glacial Landforms Lab

does not float in water until approximately 98% is submerged, glacial valleys can be eroded to a depth below sea level.

Topographic maps will display currently glaciated terranes as covered with a white color. In addition, the contour lines that are on top of glacial ice are colored blue. Since valley glaciers usually exist in high-relief mountainous areas, the contour lines will often have a close spacing giving an overall "bluish" tint to those areas covered by glacial ice.

As the glacier moves downslope through its valley, mass wasting processes, especially ice-wedging, shed debris onto the surface of the ice. The debris initially builds as mounds of material along the flanks of the glacier. These deposits of rock debris are termed *lateral moraines*. Lateral moraines are marked as a brown pattern of dots on the surface of the ice on topographic maps. A *moraine* is a generic term for any local deposit of unsorted glacial sediment. The abundant snow at higher elevations will often obscure the developing lateral moraine until the glacial flow transports the moraine to elevations below the snowline where the snow pack melts. These moraines will then be visible as linear patterns of brown dots on top of the ice. The higher elevation end of the lateral moraine will generally mark the snowline elevation on a topographic map. Note that many factors, such as the rate of glacial flow, control the elevation of the snowline for a particular glacier. Therefore glaciers on the same map may indicate a variety of snowline elevations.

If a glacier has tributary glaciers - and most large glaciers will - the confluence of lateral moraines produce a moraine that will be located in the middle of the glacier away from the sides of the channel. These moraines are termed *medial moraines*. The presence of each medial moraine indicates that a tributary glacier has merged with the larger glacial channel.

As the glacier moves downslope a mass of debris builds in the front of the glacial ice. The front or lower elevation end of the glacier is termed the *glacier terminus*. The mass of glacial till that builds up at the terminus is termed the *end moraine*. It is important to remember that, although the glacier may become stationary or retreat depending on the status of the *glacial budget*, the glacial ice is always flowing downslope. The continual flow of the ice delivers debris to the terminus of the glacier where it builds up as a large mound of till. This landform is the *end moraine*. Later, when the glacier retreats, the end moraine may act as a natural dam to create a lake. If the valley glacier is stationary several times over a period of retreat, each end moraine is likely to form a dam therefore creating a pattern of lakes termed *patter noster* (connected) lakes. The end moraines that lie above the lowest elevation end moraine are referred to as *recessional moraines*. Figure 13 displays several of the landform features common to alpine glaciation, such as *U-shaped* valleys, *aretes*, and *horns*, from a USGS topographic map. Aretes and horns are produced from the extreme down-cutting effect of glacial erosion, producing a rugged high-relief topography. The U-shaped valley is a product of this down-cutting effect along the flanks of the glacier, combined with the leveling effect of the ice directly under the glacier.

If a valley glacier develops near a coastline it may flow into the ocean. In this case

GY325 Applied Geomorphology

Glacial Landforms Lab

the glacier will actually continue to erode to a level far below sea level. This is because the glacial ice is not buoyant until about 98% of the mass is immersed in water. Since valley glaciers many hundreds of meters thick, the glacier will continue to erode far below sea level. If the glacier retreats in the future, a deep valley flooded by the sea will be left in place of the glacier. These narrow and deep inlets are termed *fiords*. The coastlines of Alaska and Norway are famous for their numerous fiords.

As a valley glacier flows into the sea, the ice is melted by warmer sea water and it is fractured by the action of storm waves. Eventually a large mass of ice will slump into the ocean forming an *iceberg*. This process is termed *calving*. All icebergs are produced by the calving of ice from valley or continental glaciers. The numerous icebergs in the North Atlantic that are navigation hazards are derived from the Greenland ice cap.

Landform Products of Valley Glaciation

When a valley glacier retreats fully from a valley it leaves behind distinctive landform features. The general effect of valley glaciation is to produce a very rugged terrain with extreme relief. If you determine that a topographic map has very high relief and a large contour interval, you should suspect that the area may have been recently affected by valley glaciation. Although it is a common misconception to attribute the rugged terrain of the European Alps and the Andes, for example, to tectonic forces, the high relief in these areas is for the most part attributable to glacial erosion.

The starting point of a valley glacier is an area where intense ice wedging causes rapid erosion of the bedrock. This area is marked topographically as a bowl-shaped depression near the peak of a mountain. These features are termed *cirques*. Cirques are marked on topographic maps by the arcuate contours that define the steep sides of the "bowl", with the flatter bottom of the "bowl" sometimes marked with closed hachured contours. The bottom of the cirque is often filled by water to form a lake. These are termed *tarns*. It is important to remember that, although the cirques represent locally low-lying depressions, they are found at the higher elevation portions of the map area near the summits of the mountains.

In many cases, two cirques will develop on opposite sides of a ridge. As the bowl-shaped depressions that define the cirque develop, a thin steep partition of rock will be left between the developing cirques. These knife-like ridges are termed *arêtes*, and are very characteristic of valley glacier landforms. Arêtes are easily recognized on topographic maps as very steep-sided ridges. Where three or more arêtes converge at the summit of a mountain, a steep-sided triangular peak is formed. These landform features are termed *horns*. The Matterhorn in the Swiss Alps is but one example of one of these landforms. Topographically these features are marked by steep triangular contours centered about a summit. Usually cirques are arrayed radially about the horn.

GY325 Applied Geomorphology

Glacial Landforms Lab

When a tributary glacier merges with a larger glacial channel, unlike a stream system, it will not enter the main channel at the same elevation but at a higher elevation. This is because the depth to which a glacier will erode its channel is primarily a function of its size. When the glacial ice retreats the tributary valley will be left overhanging the main glacial valley. These landform features are termed *glacial hanging valleys*. When streams occupy the valleys this situation will cause the formation of a waterfall. Because glacial valleys have flat bottoms and steep sides, a topographic profile constructed perpendicular to the valley produces a characteristic "U" shape.

Continental Glaciers

Continental glaciers are extremely large masses of glacial ice that may cover entire continents. Presently the continent of Antarctica is covered by Earth's largest continental glacier. During the past several million years portions of Eurasia and North America were also covered by large continental glaciers. The formation and movement of a continental glacier is governed by the same laws that control valley glaciers. If more snow falls on a continent in winter than can melt at the terminus of the continental glacier, the glacier will grow and advance. In the case of a continental glacier, however, the mass of ice may build up to a thickness of several miles. In addition, the continental glacier grows and flows in a radial fashion from the center or centers of snow accumulation. Therefore, a continental glacier will have a roughly circular shape that is thickest in the center and thins gradually to the margins. If the continental glacier continues to grow until it reaches the shoreline of the continent, it will then conform to the shape of the continent. The huge mass of ice on the continent will cause the lithosphere to become depressed into the asthenosphere, much like stepping on a floating piece of ice will cause it to float lower in the water.

The general topographic effect of continental glaciation is the opposite of valley glaciation- the landform left after a period of continental glaciation will have a subdued topography. This is because the huge size of the continental glacier acts like a "bulldozer" to level the land. In addition, formerly low-lying areas are often filled in by the abundant till and moraine left behind by the continental glacier. Lakes are common in recently glaciated area because during retreat the glacier may leave behind isolated blocks of ice that later melt to form lakes. Minnesota is termed "the land of a thousand lakes" for this reason.

Continental Glacier Landforms

As in the case of valley glaciation, if the glacial budget of a continental glacier dictates that the terminus of a glacier is stationary, an end moraine will form at the

GY325 Applied Geomorphology

Glacial Landforms Lab

terminus. Because of the scale of the continental glacier the end moraine may be hundreds of miles in length, and will dominate the topography of the region. The end moraine is often the most elevated portion of areas affected by continental glaciation. Continental glaciers typically have many cycles of advance and retreat. During a period of advance, a former end moraine may be encountered. When the glacial ice flows over the debris of the moraine, it will form numerous teardrop-shaped hills termed *drumlins*. The drumlins will be elongated parallel to the transport direction of the glacier. The steeper side of the drumlin faces the origin of the glacier, the side with the more gradual slope faces the terminus of the glacier. Therefore drumlins can indicate the movement history of a period of continental glaciation. Figure 14 is a portion of a USGS topographic quadrangle that contains several drumlin landform features. Note that the steep side of the drumlins is consistently the north slope, indicating a north-to-south transport direction.

As a continental glacier migrates from colder to warmer regions large portions of the glacial ice melt. The meltwater of a continental glacier collects in cavities under the ice. There the meltwater more or less flows as a stream along the base of the glacier. These streams behave similar to normal stream systems in that they tend to meander, producing point bar deposits and sand bars within the stream channel. When the ice retreats from the area, an isolated ridge of material will often mark the position of the stream. These landform features are termed *eskers*. Eskers are different from landforms made of *till* because their material is made of sediment that has been sorted and deposited by running water. Meltwater may also collect in large ice caverns inside the glacial ice. If sediment-laden meltwater flows into these pools the sediment will collect at the bottom of the cavern. Later, when the glacier melts, the collecting sediment will be left a conical hill of sand and silt. As with the esker, the sediment will be sorted and stratified in contrast to deposits of till deposited directly by glacial ice. These conical hills are termed *kames*.

When the glacial meltwater reaches the terminus of the continental glacier the water will be laden with the abundant *rock flour* produced by the pulverizing action of the ice. When the water exits the ice and enters the stagnant lakes that build at the front of the glacier, this sediment is deposited to form the *outwash plain*. The outwash plain is essentially a series of merging deltas that build a large flat plain of sand and silt. The delta system is usually covered by many *distributary* channels. An esker may lead directly to one of these delta systems. One reason that the upper Midwest region of the United States is a rich agricultural area is because of the thick rich soil produced by the outwash plain of the *Pleistocene* glaciers.

As the end moraine builds through time, large tongues of ice may be forced on top of the moraine. When these melt they often leave behind depressions filled with water. A retreating glacier also commonly strands large ice blocks that are buried by ground moraine. The small circular depressions that are thus formed when the buried ice melts are termed *kettles*. If the depression is filled by water the landform is termed a *kettle lake*. Kettles may also be left in the outwash plain, but these are more rare. The pitted condition of the end moraine of the end moraine will appear similar to the landform produced by karst

GY325 Applied Geomorphology

Glacial Landforms Lab

erosion, however, other landform features should clearly distinguish between karstic and glacial processes.

As glacial ice flows over bedrock, several processes act to erode the rock. These include *glacial plucking* and *glacial abrasion*. The effect of these processes on erosionally resistant rock is to produce a subdued hill that has a shallow slope facing the origin of the glacier, and a steep slope facing the glacier terminus. Note that this is the opposite relationship demonstrated by a drumlin. These landforms are termed *roches moutanée*. The surface of *roches moutanée* is *striated* from the abrasion of the ice.

GY325 Applied Geomorphology

Glacial Landforms Lab

EXERCISE 5: GLACIAL SYSTEMS

Problem 1

Mt. Rainier, Washington 30' Quadrangle

- (a) Find the Cowlitz River valley in T13N, R9E. After inspecting the topography, describe the cross-sectional shape of the valley. Describe the process that probably created the valley.
- (b) What type of landform feature is Tumtum Peak (NW1/4, sec. 36, T15N, R7E)?
- (c) Several glaciers originate near the summit of Mt. Rainier and move downslope away from the peak in a radial fashion. What landform term would best describe the area where the glaciers originate?
- (d) There are several lakes that occur along the north flank of the Tatoosh Range (center of map, southeast of Mt. Rainier). What landform term best describes these features? Describe how they form.

Problem 2

Weedsport, N.Y. 15' Quadrangle

- (a) There are many hills that cover the area of this quadrangle. What landform term best describes these features?
- (b) A continental glacier has produced the landforms covering this area. In what direction did the glacier travel? Cite your evidence.
- (c) Is there any evidence that the terminus of the glacier was at one time located on this map? Why or why not?
- (d) There are several relatively small lakes in this area. Considering the process that created this landform, speculate on how these lakes may have formed.

Problem 3

Kingston, R.I. 7.5' Quadrangle

- (a) Great Neck ridge, located in the northwestern quarter of this quadrangle, is

GY325 Applied Geomorphology Glacial Landforms Lab

composed of abrasion-resistant granite. The surface of this hill is polished and displays glacial striations that are aligned north-south. From which direction did the continental glacier originate? Explain your answer.

(b) There is an elevated ridge that parallels the shoreline in the southern half of the map. On this ridge are numerous small lakes. What is the term for the ridge assuming that it is made of glacial till.

(c) What is the landform term for the lakes on the ridge? How did they form?

Problem 4

Jackson, Michigan 15' Quadrangle

(a) There is a pronounced ridge that runs northeast to southwest across the map area. The ridge is made of well-sorted sand that has been deposited by a stream. What is the term for this landform feature? Describe how it formed.

(b) What type of glacier produced this landform?

GY325 Applied Geomorphology Glacial Landforms Lab

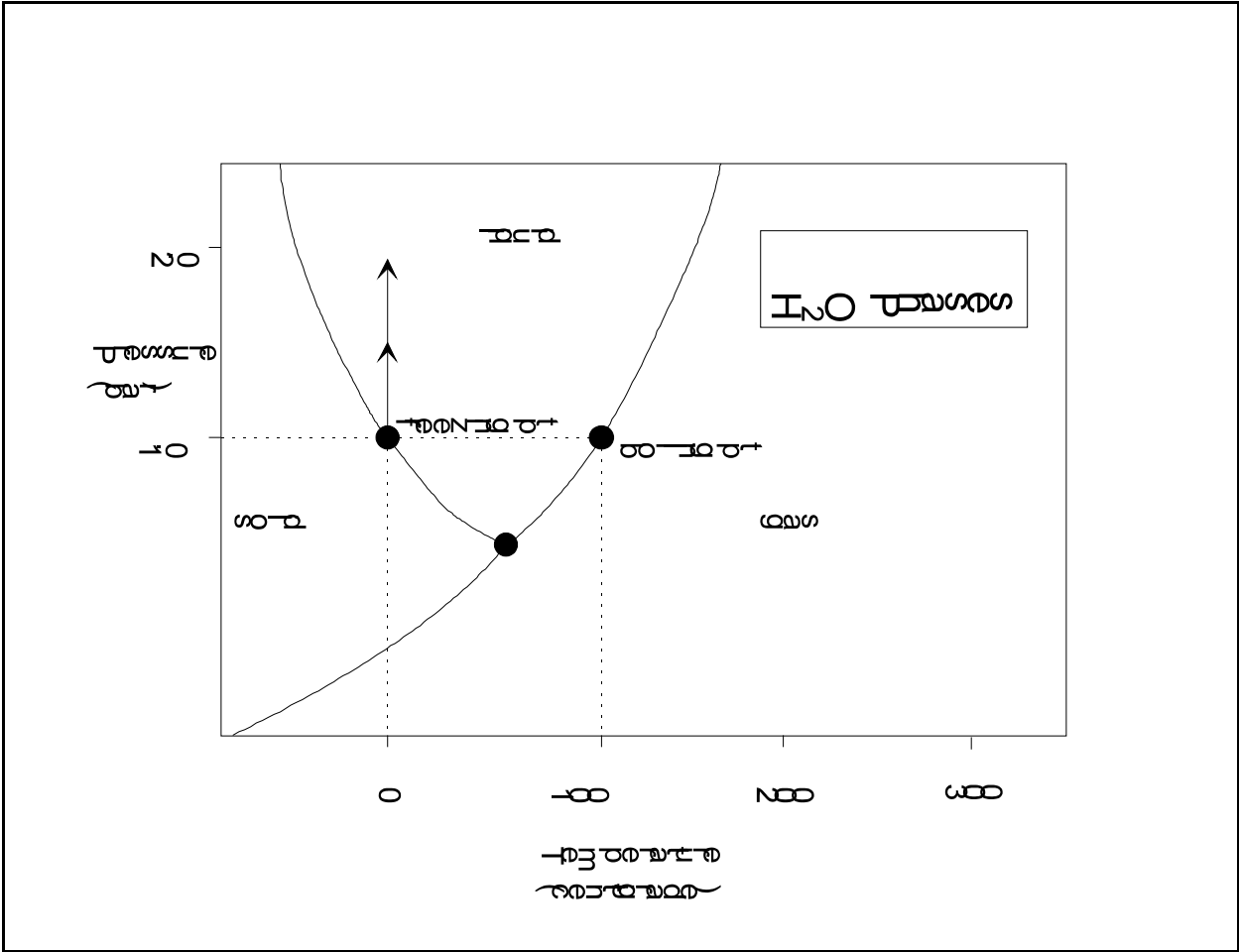


Figure 1-1: . Phase diagram of the 3 states of water.

GY325 Applied Geomorphology Glacial Landforms Lab

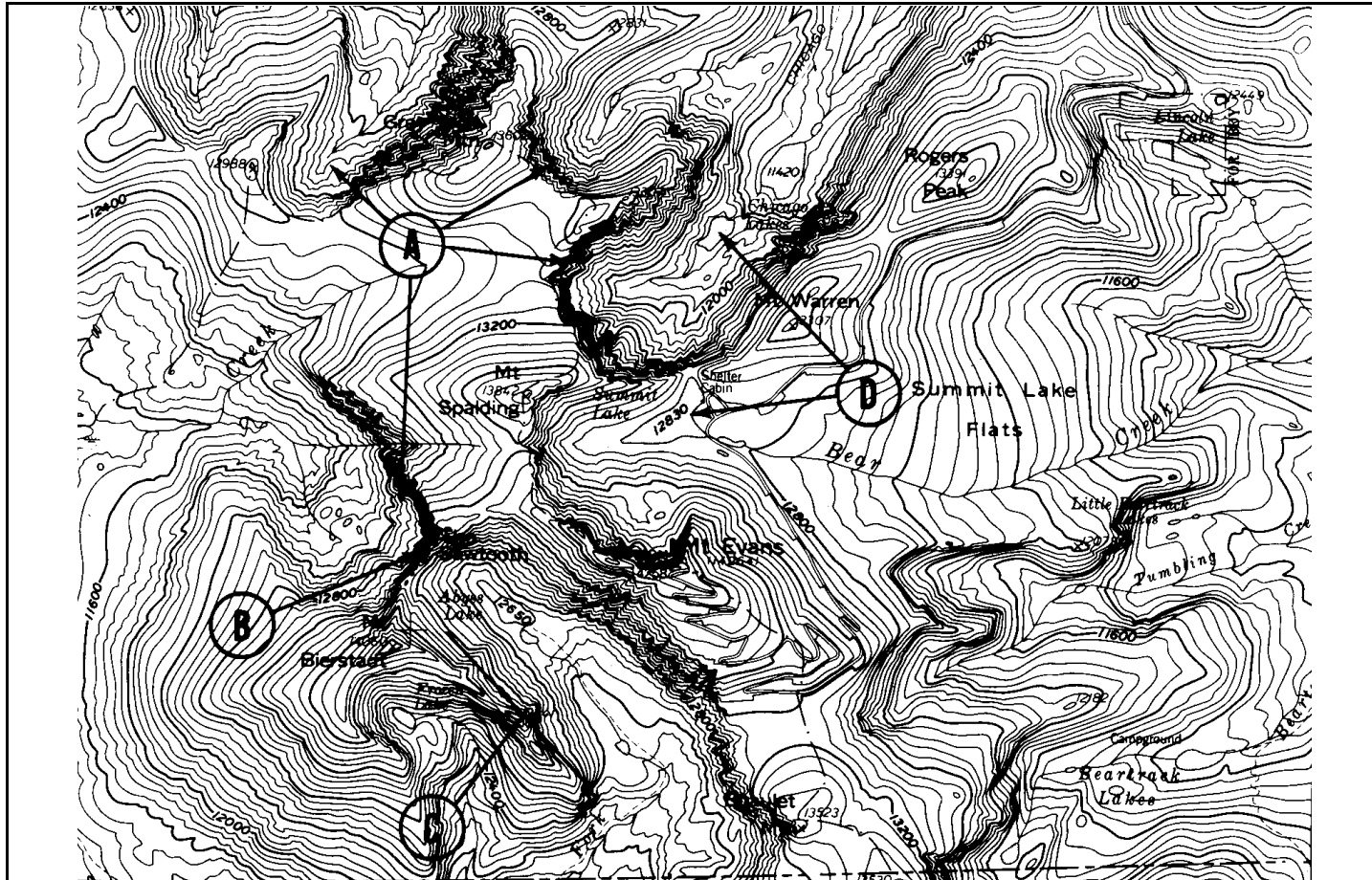


Figure 1-2: . Area affected by alpine glaciation. A=cirques; B=arête; C=horns; D=tarns.

