NAME________________________

ENVI2030L - ALPINE AND CONTINENTAL GLACIATION

I. Introduction

Glaciers are slowly moving ice sheets. They are very effective erosional agents and can drastically modify the landscapes over which they flow. Periods of glaciation are not common, but the last million years have been marked by several major periods of glacial advance and retreat. Therefore, many areas of the earth's surface are presently characterized by glacial landforms.

Glaciers originate in areas of thick snow accumulation. Layers of buried snow are slowly converted to ice because of compaction and recrystallization. If the ice reaches a critical thickness it will begin to flow as a glacier. A glacier will advance if the rate of accumulation in the source area exceeds the rate of wastage along the terminus of the glacier. A glacier will retreat if wastage exceeds accumulation. It is important to realize that regardless of changes in a glacier's terminal position, glacial ice is continually flowing.

Glaciers may be divided into two categories on the basis of their size and shape:

1. *Alpine* glaciers which flow within preexisting stream valleys in mountainous terrains.

2. *Continental* glaciers which are more extensive ice sheets whose flow is not confined to pre-existing valleys.

II. Alpine Glaciation

Permanent snowfields form in mountainous areas where annual snowfall exceeds annual snowmelt. As snow accumulates the bottom layers pack to form granular ice known as ***firn*** or ***neve***. The firn consolidates under further compression to form ***glacial*** ice. When the ice thickness approaches 50 m the pressure of the overlying ice exceeds the bearing strength of the ice on the bottom, and this lowermost ice begins to flow plastically out of the ***zone of accumulation***. Gradually a "river" of ice forms (Fig. 1), flowing slowly down the mountainside following preexisting stream valleys or other natural depressions.

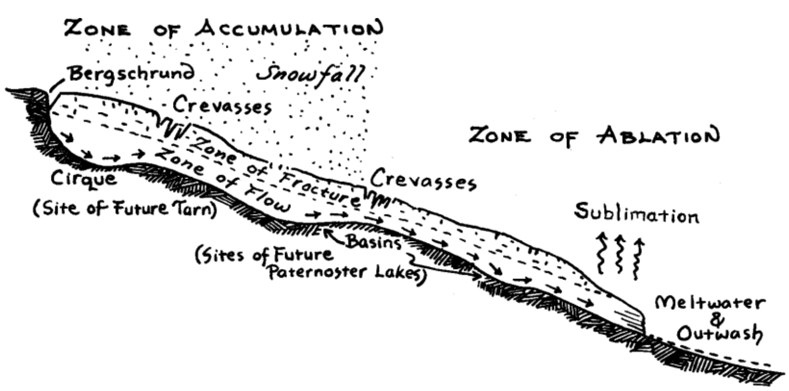

Figure 1. Longitudinal profile of an Alpine glacier. From Finch et al., 1980. *Lab Studies in Physical Geology, 2nd Ed.* Winston-Salem: Hunter Textbooks Inc., p.119.

Ice forming below the accumulated snow and firn freezes onto the bedrock surface of the mountainside. As the ice begins to move, it will literally pluck, or pull out, pieces of the bedrock and carry them away. The result of this plucking is the creation of a ***cirque*** (Fig. 1), an amphitheatre-like rock basin partially surrounded by glacially eroded cliffs. After the glacier has melted away the cirque may be partially occupied by a meltwater lake known as a ***tarn*** (Fig. 1).

Where several glaciers flow away from a ridge or mountain peak several cirques may form. ***Headward erosion*** by plucking in the cirques will cause the ridge to be narrowed. The peaks may become faceted by cliffs forming abrupt, jagged ***horns*** (Fig. 2 & 3). Low spots, called ***cols***, between the horns occur where two cirques begin to intersect due to headward erosion. Cirques eroding headward from two sides may form a narrow jagged ridge of rocky peaks and spires called an ***arete***.

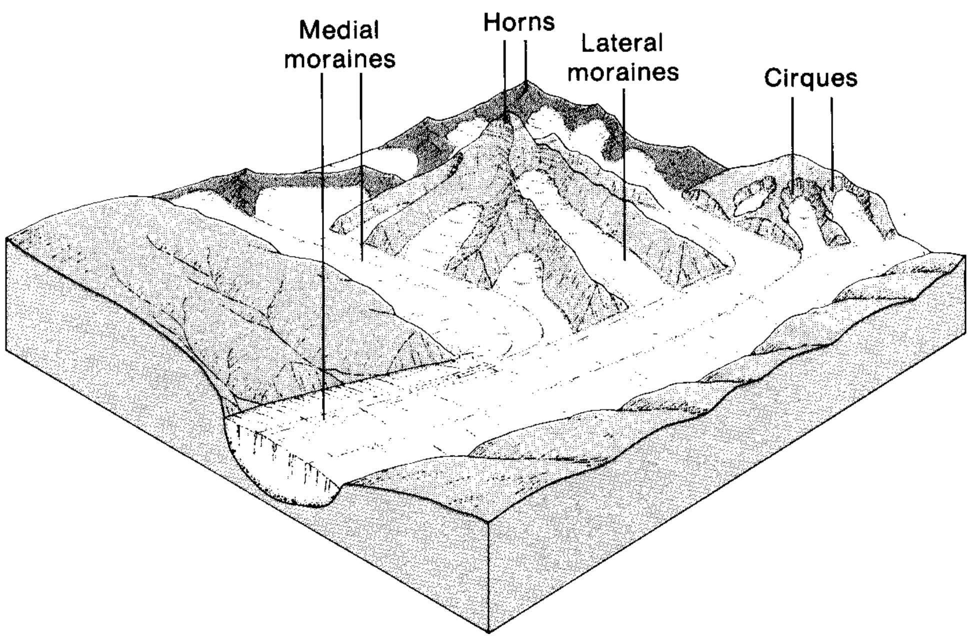

Figure 2. Area of Alpine glaciation showing master and tributary glaciers, moraines, cirques and horns. From Hamblin & Howard, 1980. *Exercises in Physical Geology, 5th Ed.* Minneapolis: Burgess Publishing Company, p. 119.

A glacier flowing down a valley carries large amounts of rock embedded in the ice. These rocks gouge and grind the bedrock underneath the glacier and in the valley walls. The result is a widening and deepening of the valley. Characteristically, glacially modified valleys are steep-walled, often rather deep, flat-bottomed and show a characteristic U-shape in cross section (Fig. 3). At various places along the valley floor rock basins may be formed where localized plucking and scouring occurs during glaciation. After the glacier has melted these basins, if separated by relatively abrupt drops in the valley floor, may have the appearance of giant steps, sometimes called ***cyclopean stairs***. The basins will be partially filled with a string of small lakes called ***pater noster lakes*** due to their resemblance (on a map) of a string of rosary beads. Because master glaciers carry a larger volume of ice then their tributaries, they erode their valleys to a greater depth. Following ice recession, tributary valleys are typically elevated above master glacier valleys and form ***hanging valleys*** (Fig. 3). Waterfalls frequently develop where streams flow from the floor of a hanging valley to the floor of a master valley (i.e. Bridalveil Falls in Yosemite Valley).

As the glacier scrapes along the valley walls rock debris accumulates on the surface of the ice near the margins of the glacier forming rock ridges known as ***lateral moraines*** (Fig. 2). Where two glaciers flow together the inside lateral moraines merge to form a ***medial moraine*** (Fig. 2). These rock deposits move with the ice and are seldom well preserved as topographic features after the ice has melted. At the snout of the glacier a larger morainal deposit may accumulate. This ***terminal moraine*** may make a distinctive topographic feature, but as it is composed of unconsolidated debris these moraines are easily destroyed by later stream erosion.

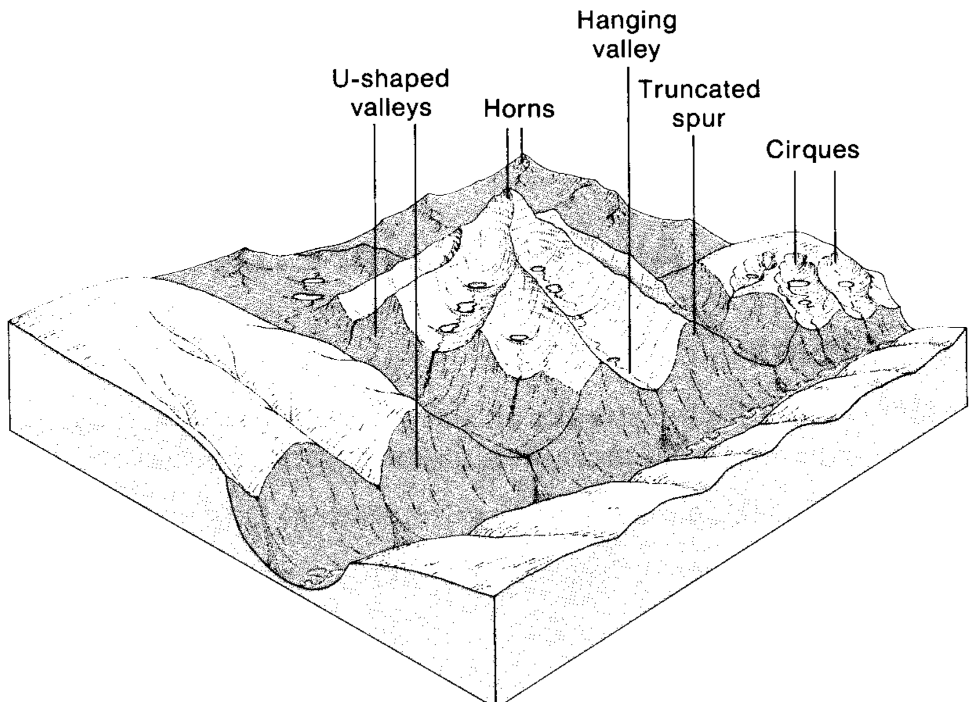

Figure 3. Erosional features left after the retreat of the Alpine glacier. From Hamblin & Howard, 1980. *Exercises in Physical Geology, 5th Ed*. Minneapolis: Burgess Publishing Company, p. 119.

When melting exceeds the flow rate the glacial front will retreat, leaving a cover of ***ground moraine*** on the valley floor. Large accumulations known as ***recessional moraines*** occur where the retreating ice front pauses temporarily.

Streams of meltwater issuing from glaciers are often milky colored due to the large amounts of finely ground ***rock flour*** in the water. These streams redistribute material from the terminal moraine, washing it out into a sloping plain of somewhat stratified and sorted sediments known as the ***outwash plain***. Because the melting glacier may release more sediments than the outwash streams are able to move, the stream channels downstream from the outwash plain often become clogged with sediments in the form of numerous channel bars. Thus ***braided streams*** result from this sedimentary overloading beyond the capacity and competency of the outwash streams.

Exercise 1. Use the map of the Rhone Glacier in Switzerland (Fig. 4) to answer the following questions.

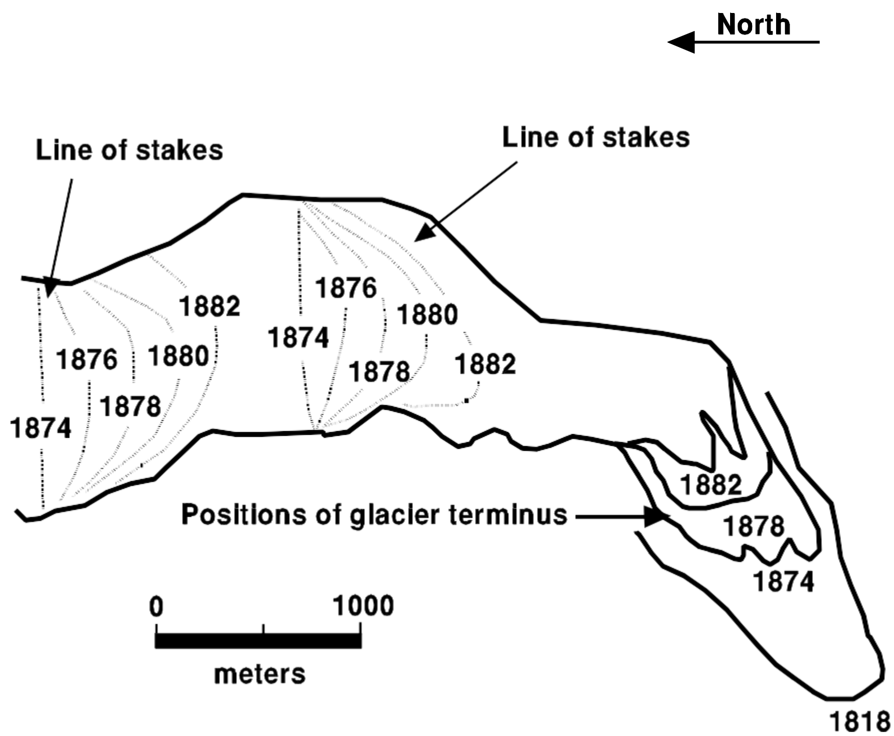

Figure 4. Map of Rhone Glacier, Switzerland, showing location of glacier termini and the positions of two lines of stakes placed on the glacier, as a function of time.

1. In what direction is the glacier moving?

2. Compare the positions of the stakes with the positions of the glacier termini. What happened during this 64 year period?

3. From the map determine the average annual rate of flow of the glacier near the center and along one edge.

4. Determine the average annual rate of retreat during the period of record.

Exercise 2. Radiocarbon analyses yield data which suggest that the margins of the continental ice sheets moved southward at a rate of 50 - 300 m yr^{-1}.

1.How does this rate compare with that determined for the Rhone Glacier?

2. What are the maximum and minimum times that it would take for a glacier to advance from Hudson Bay (the continental ice sheet spread outward from this center) to Lowell - a distance of 400 kilometers?

Exercise 3. Use the air photos in *Aerial Stereo Photographs* to answer the following questions.

1. Plate 10 - Crillon Glacier, Alaska. What is the shape of the valley occupied by this glacier? What is happening at the lower end of the glacier? What might this form in the geologic record?

2. Plate 17 - Walker Lake, California. In the past a valley glacier extended down the side of the mountain. Name and describe the features which are indicative of the prior existence of this alpine glacier.

Exercise 4. Use the Mt. Tom, California topographic map to answer the following questions.

1. From the four existing glaciers determine the approximate elevation of the snowline.

2. What glacial features do these glaciers occupy?

3. Locate the positions of at least two heads of former glaciers. Give their location in terms of latitude and longitude.

4. What would account for the numerous lakes and what are they called?

5. Near the southern edge of the map lies McGee Lake. The lake and valley to the east (occupied by McGee Creek) were occupied by an alpine glacier. Note the change in valley shape 2 miles east of the lake. What is the change in shape and what might account for the change in shape?

III. Continental Glaciation

Continental glaciers are large ice sheets that cover substantial portions of the land area. In the region of accumulation these ice sheets may attain thicknesses of 3000m or more. Glacial ice flows outwards in all directions from the topographic high formed in the region of accumulation. Unlike alpine glaciers, the movement of continental glaciers is rarely confined by topographic features. As the ice moves across the land it gouges and scrapes away the underlying material. This material is carried in the glacial ice and eventually deposited in regions of melting. In places all soil and weathered rock are removed and the underlying bedrock is scoured by the glacier leaving behind grooves and striations in the bedrock.

If the ice sheet achieves a steady state in terms of accumulation and wastage, the terminus of the ice sheet will remain at a relatively fixed location. Material embedded in the ice sheet is deposited at the terminus to form a moraine. If this moraine marks the furthest advance of the ice sheet it is called a ***terminal moraine*** (Fig. 5). If the material represents a still stand during the retreat of the ice sheet it is called a ***recessional moraine***. Streams of meltwater running off or from under the glacier rework the sediment deposited at the terminus to form a partially sorted and layered ***outwash plain***. During the retreat of the glacier large blocks of ice may be left behind and partly or completely covered with sediment. When these blocks of ice melt they leave behind depressions called ***kettle holes***. The lakes that fill these depressions are referred to as ***kettle lakes***. Walden Pond is an example of a kettle lake.

A number of features also form under the ice sheet. ***Drumlins*** are streamlined hills of till (unstratified, unsorted glacial debris) that form asymmetrical hills elongated in the direction of ice movement. The steep side of the hill faces in the direction from which the ice came (i.e. the upstream direction). ***Rock drumlins*** (***roche moutonnee***) are streamlined asymmetrical bedrock hills elongate in the direction of glacial movement. In this case the steep side faces in the direction that the ice was going (i.e. the downstream direction). ***Eskers*** are long sinuous deposits which accumulate on the floors of ice tunnels created by meltwater streams flowing underneath the ice sheet.

As the glacier retreats material is randomly dropped forming a ***ground moraine*** which can cover vast areas. Ground moraine plus changes in topography due to glacial erosion may change the pre-glacial drainage patterns of a region resulting in very erratic stream courses. Such drainage patterns are referred to as ***aimless*** or ***derranged drainage***.

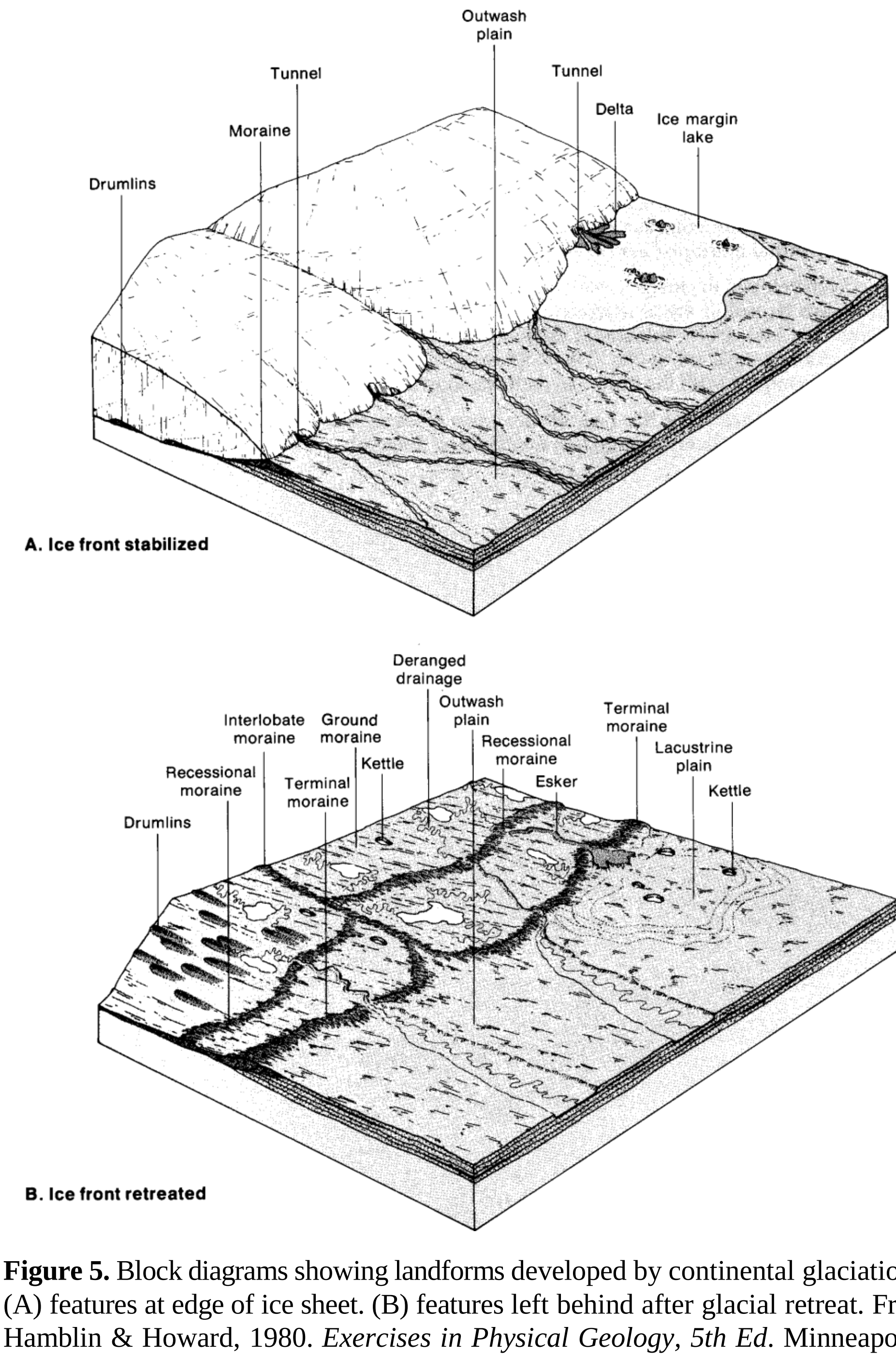

Figure 5. Block diagrams showing landforms developed by continental glaciation. (A) features at edge of ice sheet. (B) features left behind after glacial retreat. From Hamblin & Howard, 1980. *Exercises in Physical Geology, 5th Ed.* Minneapolis: Burgess Publishing Company, p. 127.

Exercise 5. Use the air photos in *Aerial Stereo Photographs* to answer the following questions.

1. Plate 19 - Knob and Kettle. Locate several kettle holes. Give their coordinates.

2. Plate 20 - Drumlins. Based on the shape of the drumlins, what was the direction of glacial movement? Give the location of a specific drumlin that you used to make this determination.

3. Plate 21 - Lake Kabetogama. Give the location of glacial grooves and striae and use these to determine the direction of glacial movement.

Exercise 6. Use the Kingston, R.I. topographic map to answer the following questions.

1. In the southern portion of the map there is an east-west belt of hills and depressions approximately one mile wide. Which of the plates in ***Exercise 5*** does this topography most closely resemble?

2. North of this belt the land is poorly drained and the hills are rounded. Several hills exhibit a north-south alignment. Does this alignment seem to be the result of glacial erosion or deposition? Why?

3. South of the belt mentioned in #1, the land slopes gently seaward. The general slope is broken by several hills, such as Green Hill, which stand above the sloping plain. The plain is composed of sand and gravel and was deposited by a broad sheet of water. In what direction did the water flow? How might you account for the depressions north of Trustom Pond?

4. Reconstruct the scene at the time of glaciation. Where was the edge of the ice and how were the various features formed?