GLACIAL GEOLOGY

An abundance of landscape features provide evidence of the great ice sheets that covered New York State during the Pleistocene Epoch (the period 10,000 to 1.6 million years ago). Most of the landscape in New York State is directly related to the glaciers that covered the state to depths of 1-2 kilometers. A **glacier** is a large, long lasting mass of ice which forms on the land and moves downslope because of gravity. It forms due to the compaction and recrystallization of snow where more snow accumulates than melts away over a period of time.

Our lives and environment today have been strongly influenced by glaciers. The Finger Lakes, Lake Ontario, the Hudson Valley, and Long Island all owe their existence to the scouring, gouging and deposition of glacial ice. Nationally, the fertile soils of the Great Plains and the spectacular scenic beauty of some of our national parks such as Yosemite Valley in California are all due to the activities of glaciers.

WHAT ARE GLACIERS

Glaciers are found in the polar regions or in mountain areas at lower latitudes, where there is little melting of snow during the summer. At present, about 10% of the Earth's surface is covered by glaciers (compared to about one/third during the peak of glacial activity). Today, 85% of all glaciers are in Antartica and 10% in Greenland. If all the ice in Antartica were to melt, sea level would rise about 60 meters (200 feet). This would flood the world's greatest cities.

Types of Glaciers. There are two types of glaciers that have covered the Earth's surface. A **valley glacier** (or **Alpine glacier**) is a glacier that is confined to a valley and flows from higher to lower elevations. Most present day glaciers in the United States and Canada are of the valley type. A thick mass of ice that covers a large area of land (over 50,000 square kilometers) is an **ice sheet.** Only two ice sheets exist today – in Antartica and Greenland. The glacier that covered Eastern North America during the Ice Ages was called the **Laurentide Ice Sheet** (see Figure D-1).

Snow changes to glacier ice in a manner similar to the way sediments turn into sedimentary rocks and then metamorphic rocks.

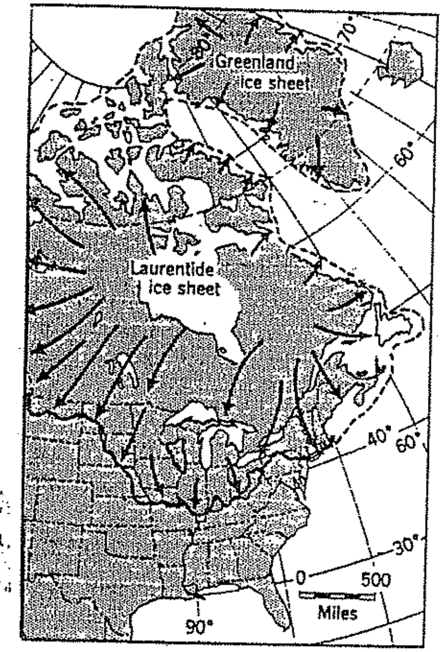


Figure D-1. Pleistocene ice sheets of North America at their maximum spread reached as far south as the present Ohio and Missouri rivers.

After enough snow falls, the snowflakes settle by compaction under their own weight. The sharp points of the snowflakes are destroyed as the flakes reform into granular snow (the "corn snow" of spring skiing) called **firn** or **neve** (see Figure D-2). As more snow covers the firn and the pressure increases, the grains recrystallize, developing a texture similar to that of quartzite, a metamorphic rock. The force of gravity causes glaciers to flow slowly downhill and outward. If a glacier reaches a body of water, blocks of ice called **icebergs** may break off and float free.

The **Zone of Accumulation** is the upper part of a glacier where more snow falls than melts. In the lower part of the glacier, more snow melts than falls (see Figure D-3). The boundary between these two zones is the **snow line,** the lower limit the permanent snows reach in summer. During summer, the ice melts below the snow line, producing large amounts of **meltwater,** water from the melting snow.

Glacial Movement. Glaciers **advance,** move downslope, under the influence of gravity and their own weight (see Figure D-4). They move from less than a few millimeters a day to more than 15 meters a day. Glaciers move at different rates depending on the steepness

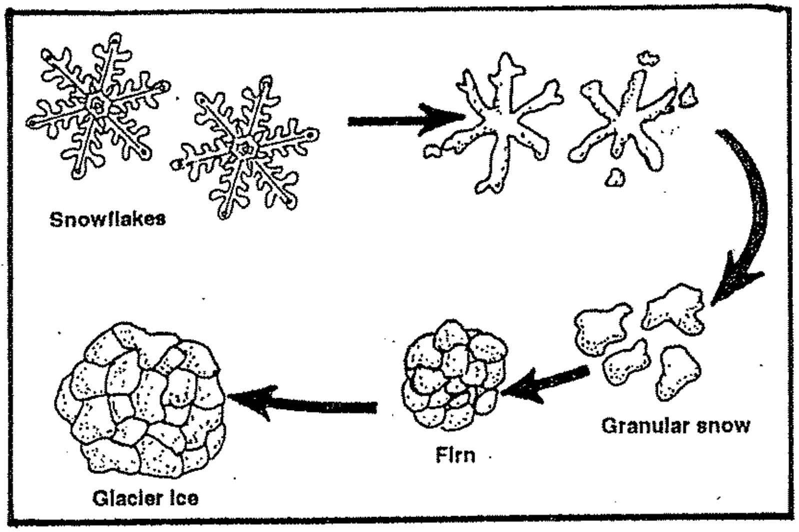


Figure D-2. Conversion of snow to glacier ice.

of the underlying material. Glaciers move more rapidly at the surface than at the deeper levels, and faster in the center than at the sides where there is less friction with the valley walls. The surface part of a glacier is brittle and nearly rigid. When the ice breaks while moving, it forms fissures or cracks called **crevasses,** across the width of the glacier. The deeper part of a glacier is more plastic due to the bendable nature of the ice itself.

When ice in a glacier melts back faster than the ice sheet moves downslope, the glacier **recedes**, or moves backward. Glaciers only appear to move backward, however. They are constantly moving downslope due to the pull of gravity, but the rapidly melting ice causes the leading edge of the glacier to appear to move backward.

Glacial Erosion. When a glacier slides over rock, the rock beneath the glacier is **abraded**, or scratched. As meltwater fills in cracks in the bedrock and refreezes, pieces of rock are broken loose and frozen into the base of the moving glacier. These rocks, while being dragged along by the glacier, grind the rock beneath it (see Figure D-5). The

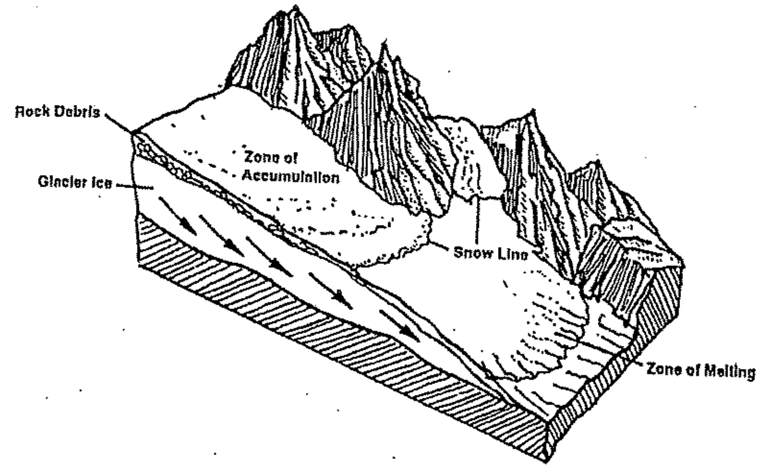


Figure D-3. A valley glacier as it would appear at the end of a warm season. Below the snow line, glacier ice and snow have been lost due to melting. In the zone of accumulation above that line, firn is added to the glacier from the winter snowfall.

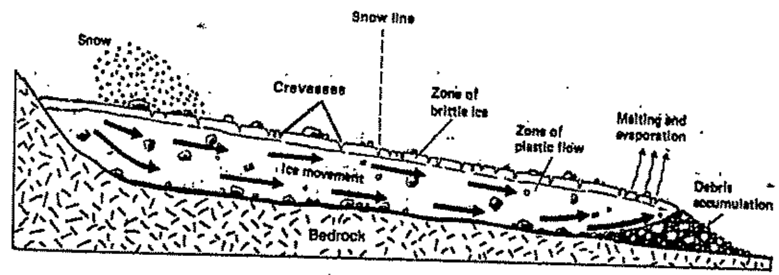


Figure D-4. The various zones within a glacier. The arrows indicate the path ice takes through the glacier.

thicker the glacier, the greater the pressure on the rocks resulting in increased grinding and crushing of the rocks.

Sharp corners of rocks dragged along make long scratches (**striations**) and grooves on the bedrock. Pebbles and boulders dragged along by the glacier are **faceted,** given a flat surface by abrasion. The bedrock as well as the rocks being carried by the ice are *polished* by the grinding. The grinding of rock across rock produces powder called **rock flour.**

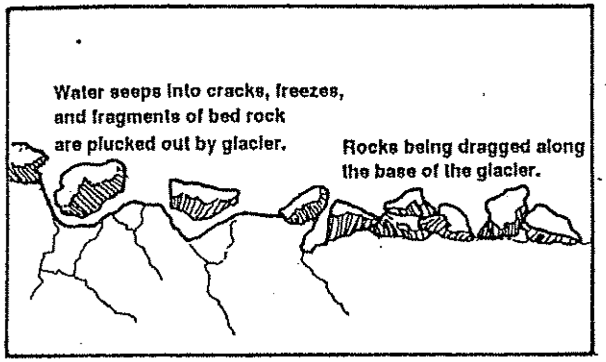


Figure D-5. Rock fragments and bedrock being plucked out and abraded by movement of a glacier.

Erosional Landscapes. Mountain ranges that have been covered by valley glaciers are noted for their rugged landscape and spectacular scenery. Glacially carved valleys are *U-shaped* (see Figure D-6). Valley glaciers tend to straighten the curves of valleys originally formed by streams. Erosional landscape features of glaciers are cirques, horns and aretes. A **cirque** is a bowl-shaped erosional scar on the side of a mountain formed by frost action and headword erosion of the glacier. The same processes that enlarge a cirque also create sharp peaks and ridges. A **horn** is the sharp peak that remains after cirques have cut back into a mountain on three or more sides. When two cirques "eat" into a ridge from both sides, a jagged, knife-edge ridge called an **aretes** is formed. Glaciers carve river valleys deeper than their smaller tributary valleys. After the glaciers melt, the tributaries remain as **hanging valleys** high above the main valley. Yosemite Valley in California has several hanging valleys which result in spectacular waterfalls. Glácial erosion of New York State's highest mountains show that the ice was close to two kilometers thick.

Glacial Sediment. Most glaciers push, carry and drag great quantities of sediment. Sediment carried by glaciers or the meltwater of glaciers is called **drift.** Most of the rock fragments carried by glaciers are angular, unsorted (all mixed together) and unlayered. Unsorted rock material deposited directly by glaciers is **till.** Glaciers carry rocks of mixed sizes, from clay to huge boulders. A large rock deposited by a glacier that is different from the type of rock beneath it is called an **erratic.** The great size of some erratics shows the tremendous power of a glacier. The rock type of some erratics is so

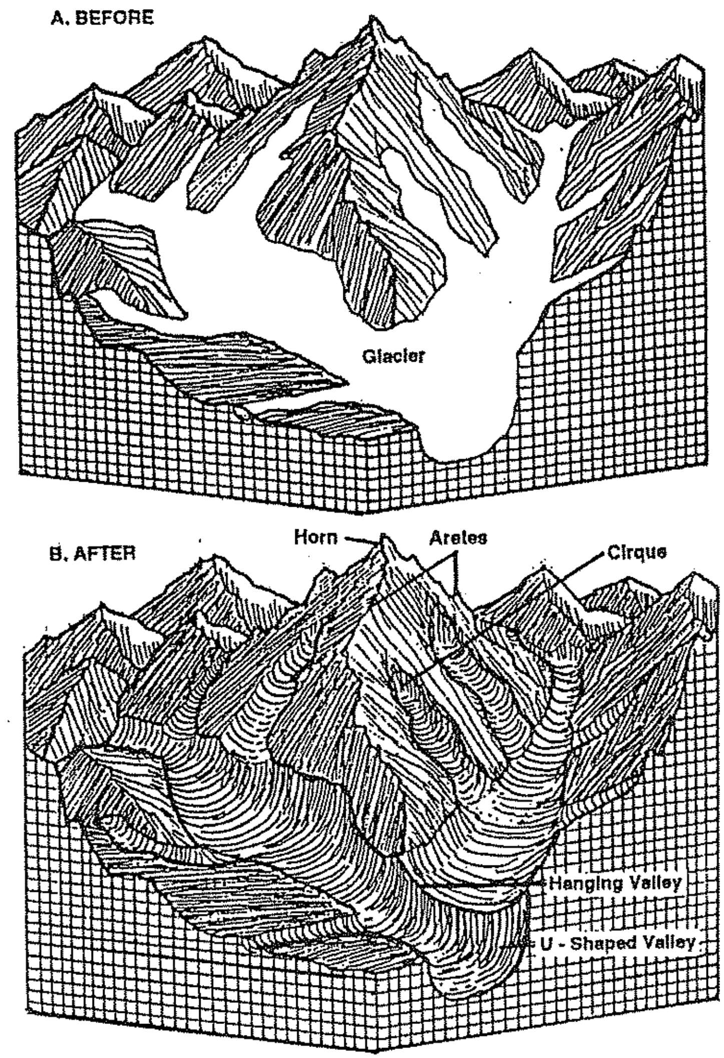


Figure D-6. Erosional landscapes. (A) Glaciers cover the area. (B) When the glaciers melt, erosional landscapes are visible.

distinct that their origins can easily be identified. The general direction of ice flow can be determined by tracing the bedrock exposure of the erratic to the north. Rock material deposited by the meltwater of a glacier is **outwash.** Long Island is composed of both till and outwash. The northern part of Long Island is essentially formed of till, while the southern part is primarily formed of outwash (see Figure D-7).

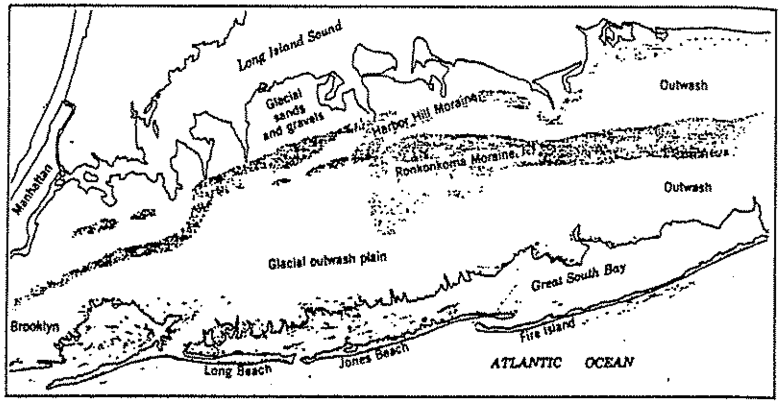


Figure D-7. Long Island's Surface. Long Island is composed of both glacial till which makes up moraines and glacial outwash.

Depositional Landscape Features. When a glacier melts, the rock debris (till) it carried is deposited in the same location as it was in the glacier (see Figure D-8). A **moraine** is a mass of glacial till left behind after a glacier has melted. A flowing glacier moves the till to the front edge of the glacier. If the front end of the glacier remains stationary for a period of years, the till piles up in a ridge along the front edge of the ice. This ridge of till is an **end moraine.** Two kinds of end moraines exist; a **terminal moraine** indicating the farthest advance of a glacier, and a **recessional moraine,** build up when the glacier recedes for awhile and then becomes stationary.

Piles of till along the sides of a glacier form **lateral moraines** (see Figure D-9). When two glaciers come together, the adjacent lateral moraines join and are carried as a single ridge of till in a **medial moraine.** As ice melts, rock material that has been carried by the glacier is deposited on the ground to form a **ground moraine,** a fairly thin layer of till. In some areas, ground moraine has been reshaped into streamlined hills of till called **drumlins.** A drumlin is shaped like an inverted bowl of a spoon, with the long axis parallel to the direction of ice movement (see Figure D-10). Drumlins were probably formed from a glacier passing over an older ground moraine.

Glacial outwash is carried by meltwater and dropped in **stratified** (layered), fairly well-sorted deposits. Bodies of stratified outwash are classified according to their shape (see Figure D-8). A body of out-

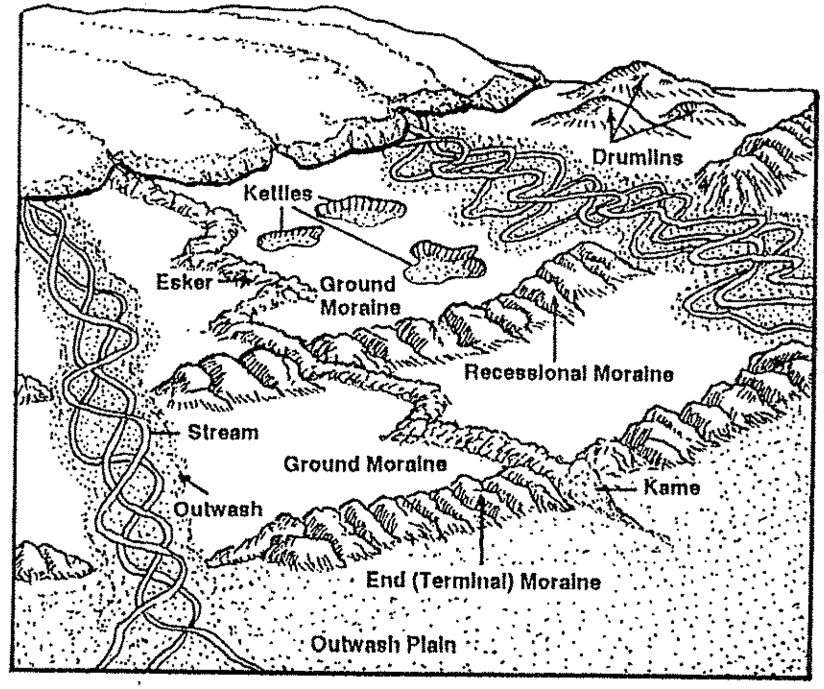


Figure D-8. Depositional features in front of a receding ice sheet.

wash that forms a broad plain beyond the moraine is an **outwash plain.** Short, steep sided hills of outwash that originated as meltwater stream or lake deposit are **kames.** When an ice block forms and then melts, it leaves a steep sided hole behind called a **kettle.** Many kettle holes are filled by small lakes. Kettles and kames are often found near each other. Meltwater rivers in glaciers often follow sinuous paths. When the glacier melts, the sinuous deposits from the rivers form an **esker.** In dry seasons, winds pick up the rock flour from these deposits and carry them long distances. These fine grained, wind-blown deposits of dust are called **loess.**

Causes of the Glacial Ages. The question "What caused the Ice Ages?" has been asked by scientists since the theory of glaciers originated. A number of hypotheses have been proposed to explain the Ice Ages, but none alone satisfactorily accounts for all of the data. The most accepted theory today says that the variations in our

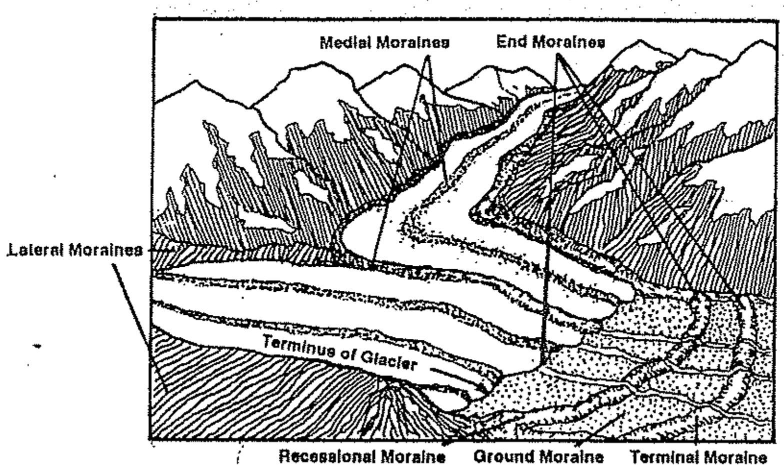


Figure D-9. Moraines associated with valley glaciers.

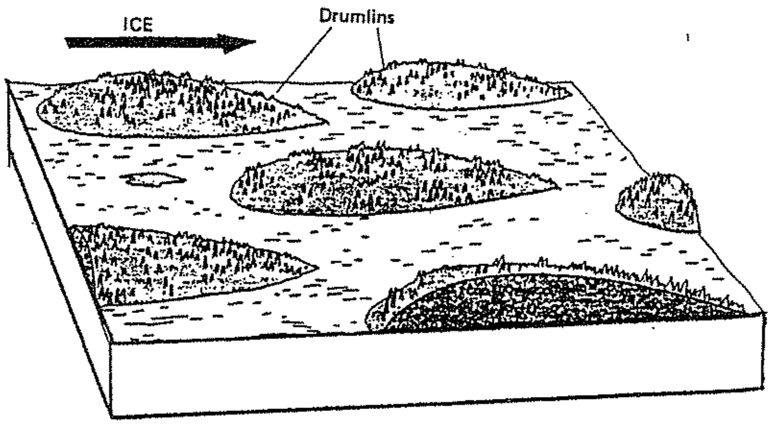


Figure D-10. The streamlined shape of drumlins. They are somewhat oval in shape, when viewed from above, with the steeper end usually toward the direction from which the ice came.

planetary orbit and the "wobble" of the Earth's axis cause cycles of cooling and warming that are largely responsible for the global changes necessary to produce glaciers. This theory, known as the *Milankovitch Theory,* has wide acceptance today, but it fails to explain the absence of glaciation over most of geologic time.

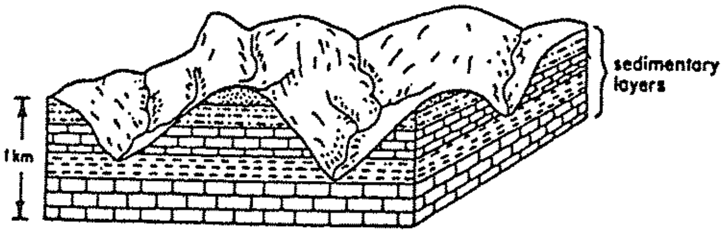
One hypothesis regards carbon dioxide as responsible for major climate changes. Solar energy which penetrates the Earth's atmosphere is trapped by carbon dioxide and the climate warms, accounting for the warm episodes between glaciers. Later, for some reason, the carbon dioxide content decreases, resulting in colder glacial periods. Another theory has to do with the positions of the continents during continental drift. Others believe that the circulation of sea water is a major contributor to glacial periods. Scientists do not completely understand what causes glacial periods and interim warm episodes, but the Milankovitch Theory is the most accepted for the moment because it seems best to explain what controls climate cycles.

Present Glaciers and the Past. Modern glaciers preserve samples of the atmosphere and dust from the time the ice formed. These samples include air, pollen, dust and meteorites. By studying these samples, it is hoped prehistoric conditions on our planet can be investigated.

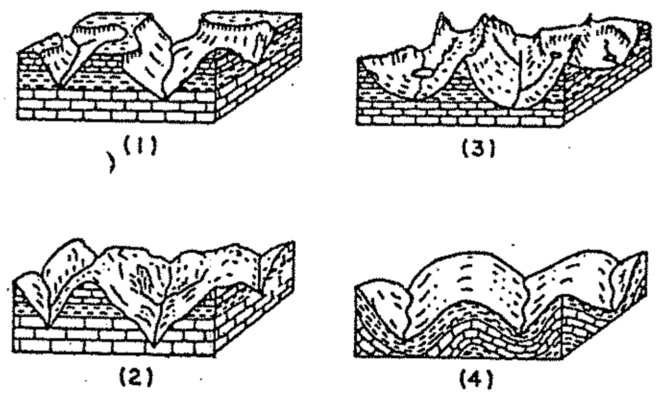
QUESTIONS

1. The basic difference between an ice sheet and a valley glacier is in their (1) temperature and density (2) size and shape (3) density and composition (4) size and direction of flow
2. A valley glacier moves faster (1) in summer than in winter (2) on mild slopes than steep slopes (3) at the top than at the bottom (4) at the sides than at the center
3. The front edge of a glacier is likely to be receding when it (1) stops moving (2) stops snowing (3) melts as fast as it moves (4) melts faster than it moves
4. Glacial depositional features deposited in tunnels that run beneath the ice are (1) moraines (2) kettles (3) kames (4) eskers

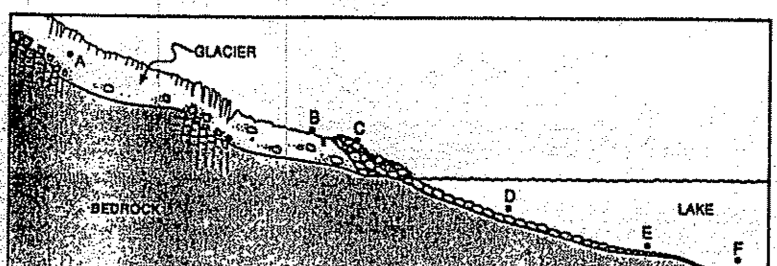
Base your answer to question 5 on the diagram below. The diagram shows the surface landscape features and the internal rock structure of a cross section of the Earth's crust.



5. How would this region most likely appear immediately after undergoing a period of glaciation?

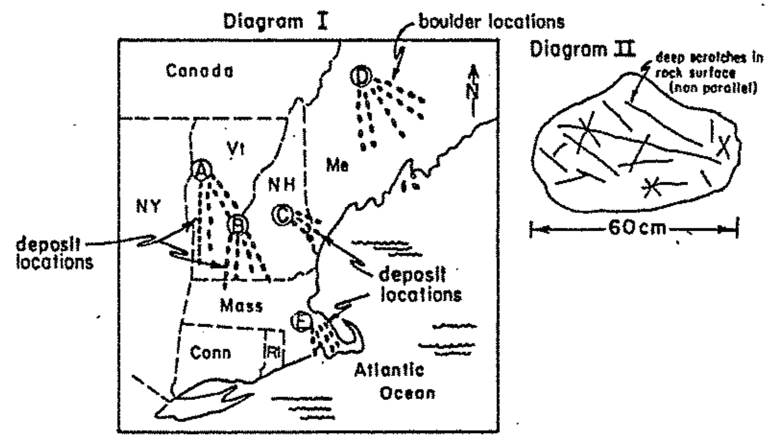


Base your answers to questions 6 through 8 on your knowledge of Earth Science, *Earth Science Reference Tables*, and the diagram below. The diagram represents a glacier moving out of a mountain valley. The water from the melting glacier is flowing into a lake. Letters *A* through *F* identify points within the erosional/depositional system.



6. Deposits of unsorted sediments would probably be found at location (1) E (2) F (3) C (4) D
7. An interface between erosion and deposition by the ice is most likely located between points (1) A and B (2) B and C (3) C and D (4) D and E
8. Which characteristic would form as the glacier advances from point A to point B? (1) V-shaped valleys (2) a thick, well-sorted soil (3) layers of salt and other evaporites (4) scratched and polished bedrock
9. Which landscape features are primarily the result of erosion by continental glaciers? (1) U-shaped valleys with unsorted layers of soil (2) V-shaped valleys containing swiftly flowing streams (3) mountains with rugged slopes and shallow layers of soil (4) well-established stream drainage patterns with few lakes

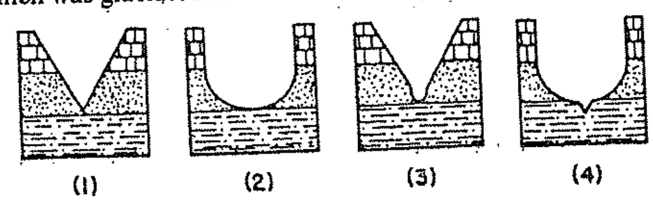
Directions: Base your answers to questions 10 through 14 on the diagrams below. Diagram I represents a section of the northeastern United States and Canada. Five different source regions, *A* through *E*, are shown along with the pattern of glacial deposits containing boulders which originated from each location. Diagram II represents the appearance of the surface of a typical boulder from any of the deposit locations.



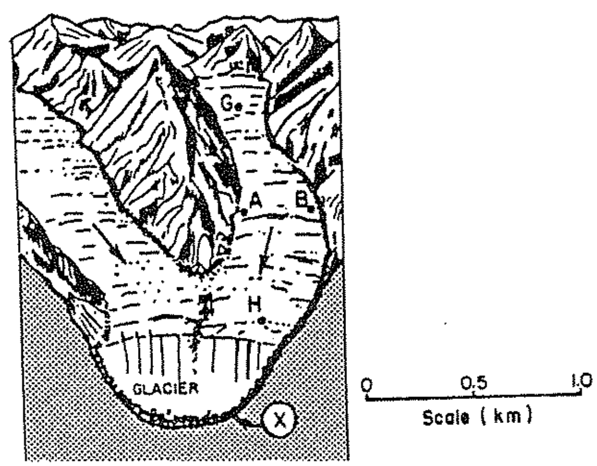
10. The force that caused the deposits to be distributed in the pattern shown in Diagram I most likely came from which general direction? (1) northwest (2) northeast (3) southwest (4) southeast
11. Which characteristic do all of the deposits most likely have in common? (1) The have the same chemical composition. (2) They were eroded from source region A. (3) They are

composed of unsorted sediments. (4) They are found at the ends of large rivers.

12. According to the *Earth Science Reference Tables,* during which geological epoch were deposits most likely transported to the locations shown in Diagram I? (1) Mesozoic (2) Pleistocene (3) Jurassic (4) Paleocene
13. The scratches in the boulder shown in Diagram II were most likely caused by the (1) internal arrangement of the minerals in the boulder (2) splitting of a large boulder into two smaller boulders (3) erosion of the boulder by running water (4) movement of the boulder over bedrock
14. About how many times larger is the actual boulder than the model shown in Diagram II? (1) 5 times (2) 14 times (3) 20 times (4) 60 times
15. Which diagram best represents a cross section of a valley which was glaciated and then eroded by a stream?



Base your answers to questions 16 through 20 on your knowledge of Earth Science, the *Earth Science Reference Tables,* and the diagram below. The diagram represent two branches of a valley glacier. Points *A, B, G,* and *H* are located on the surface of the glacier. Point *X* is located at the interface between the ice and the bedrock. The arrows indicate the general direction of ice movement.



16. Which type of weathering most likely is dominant in the area represented by the diagram? (1) biologic activity (2) frost action (3) acid reactions (4) chemical reactions
17. Which force is primarily responsible for the movement of the glacier? (1) ground water (2) running water (3) gravity (4) wind
18. The sediment deposited by the valley glacier at position *X* is best described as (1) sorted according to particle size (2) sorted according to particle size (3) sorted according to particle texture (4) unsorted
19. Metal stakes were placed on the surface of the glacier in a straight line from position *A* to position *B.* Which diagram best shows the position of the metal stakes several years later?