moving sheets of water. In China there is an extensive deposit of loess brought by the wind.

Summary. — *Loess is a fine-textured clay, in some cases wind-deposited, in others brought by slowly moving sheets of water.*

112. The Till Sheet. — The principal soil of a glaciated country is *till* or *bowlder clay*, which occupies the region between the moraines, wherever the surface is not covered by stratified drift. Till is a compact clay, usually unstratified, with bowlders and pebbles mixed through it (Fig. 283). It is the ground moraine left when the ice melted.

The till sheet varies greatly in thickness, being usually thin where the rock is hard, and thick where it is soft and easily ground up. In Labrador, and in hilly New England, there are large areas with little or no till; but in the Mississippi valley, where the land is more level and the rock softer, the till sheet is sometimes 100 or 200 feet thick.

There is also much difference in composition. In some places it is made of clay with only occasional bowlders; in others it is so full of bowlders that farming is almost impossible (Fig. 284). An abundance of bowlders is likely to be found just south of mountain areas of hard rock, as in New England, and south of the Adirondacks. They sometimes form trails, or *bowlder trains*, from the place of origin, growing less common and smaller as the distance from the source increases, because of the erosion to which they have been subjected. In central New York, where the bowlders are largely hard rock from the north, farmers call them "hardheads."

Summary. — *Till or bowlder clay, the most widespread glacial deposit, is the ground moraine. It is a sheet of mixed clay and bowlders varying in thickness and in the proportion of bowlders.*

113. Drumlins. — In many sections the till sheet is smooth and regular, covering the surface to a fairly even depth; in other places it is ridged and irregular. One peculiar irregularity of till is the *drumlin* (Figs. 286–288). Drumlins vary from 100 feet to

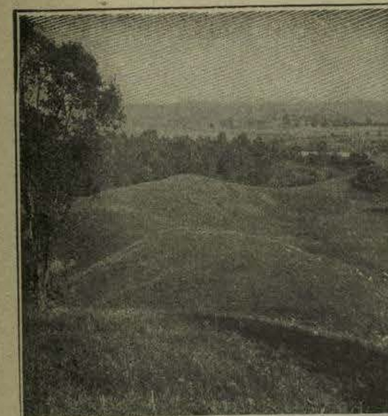

FIG. 282. — An esker ridge near Ithaca, N.Y. This is a stream deposit made in a tunnel underneath the glacier.

FIG. 283. — A section in till in which there are not many bowlders.

FIG. 284. — A bowlder-strewn, glacial soil in Maine.

FIG. 285. — Large glacial bowlders brought by the ice.

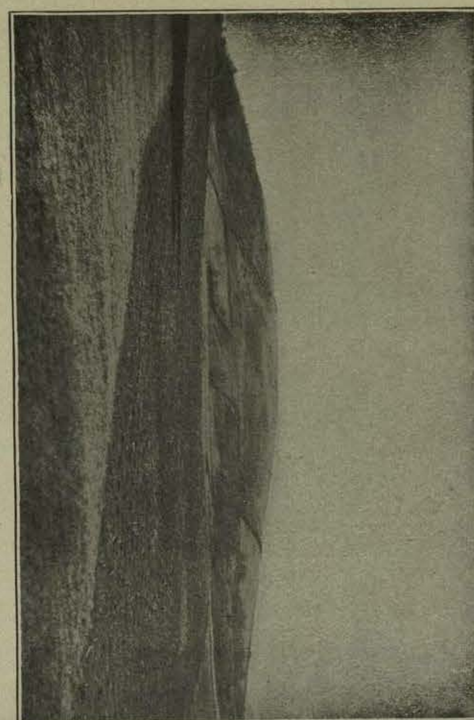

FIG. 286.—A drumlin at Ipswich, Mass.

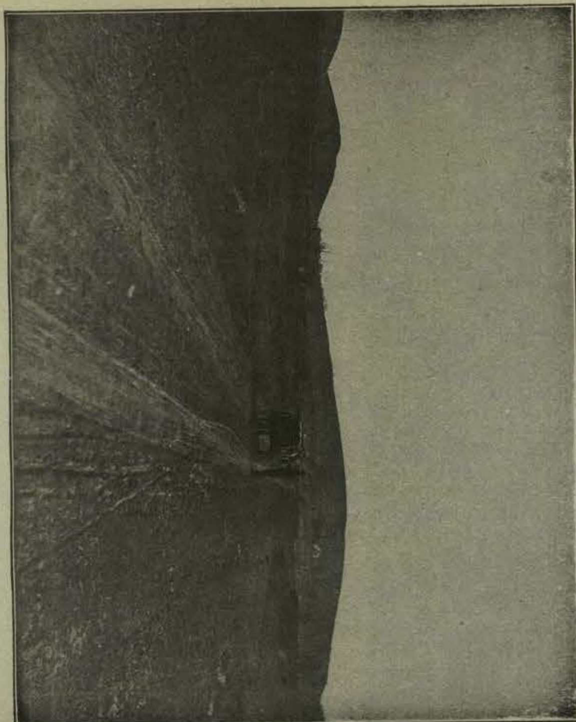

FIG. 287.—A drumlin north of Auburn, N.Y.

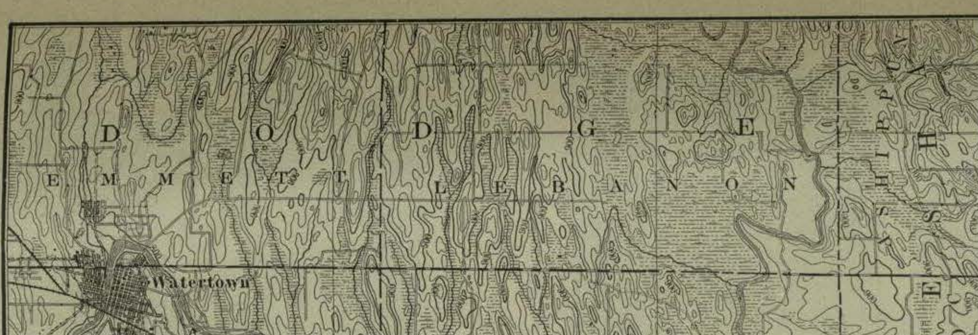

FIG. 288.—A part of the United States Geological Survey Topographic Map (Watertown, Wis., Sheet), showing a large number of drumlins. Also notice how the drift has embarrassed the streams, causing them to take long, roundabout courses, and transforming their valleys to swamps in many places.

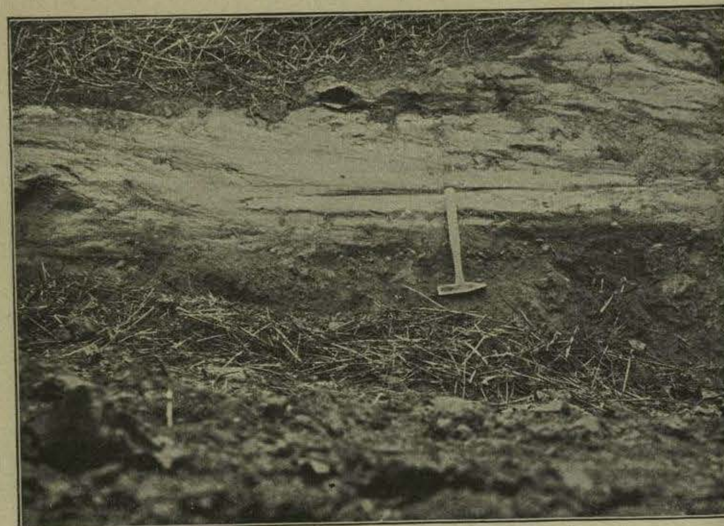

Fig. 289.—The end of the hammer handle rests on a glacial scratch or groove on a ledge of shale rock.

Fig. 290.—A pebble with glacial scratches; taken from the Greenland ice sheet at the place shown in Fig. 271.

Fig. 291.—A pebble with glacial scratches; taken from a till bed at Ithaca, N.Y.

a mile or more in length, and from 20 to 100 or 200 feet in height. Some are long and ridge-like; some short and lumpy; but the most typical drumlins are oval, having the shape of a half-submerged egg (Fig. 286), with the long direction parallel to the water surface. They are masses of till ridged up under the ice.

Drumlins usually occur in clusters. There is one group in Wisconsin, near Madison (Fig. 288); another in central New York between Rochester and Syracuse, and northward to Lake Ontario (Fig. 273, 287); another in the Connecticut valley; another in and near Boston (Fig. 286). Boston is built on drumlins, of which Bunker Hill is one.

Summary. — *Elongated ridges of till, usually in clusters, are called drumlins. They vary greatly in shape and size, the most perfect having the oval shape of a half egg.*

114. Glacial Erosion. — In a glaciated country wherever the rock is uncovered, its surface is likely to be polished, scratched, and grooved (Fig. 289). In eastern United States the striæ point toward Labrador. Striæ and erratics found on high mountains prove that the ice was thick enough to override the tops of mountains even a mile in height.

The northern slopes of hills and mountains over which the ice moved are often rounded by ice erosion; and ledges have the smoothed and rounded form of the roches moutonnées (p. 142). Pebbles and bowlders in the till are also smoothed and scratched (Fig. 291). It is evident that much work of erosion was done as the ice sheet moved onward, pressing down with enormous weight, and dragging its rock load over the land. It acted like a great rasp or sheet of sandpaper.

By this erosion some rock was removed from the hills, but more was worn from those valleys along which the ice moved freely. In this way many north-south valleys were so deepened that their tributaries now enter through hanging valleys (Fig. 293); and the same is true of bays and fiords on the coasts of Maine, Labrador, Alaska, and Norway. By such erosion the valleys of the larger Finger Lakes of central New York (Cayuga and Seneca) were deepened; and part of the depth of Lake Ontario, and others of the Great Lakes, is also due to ice erosion. During this erosion, rock basins, in which lakes and ponds now stand, were scoured out. Thus the land surface was decidedly modified by erosion.

Summary. — *That the ice sheet did much erosion, is proved by striated pebbles, bowlders, and ledges ; by rounded north slopes ; by roches moutonnées ; by hanging valleys ; and by rock basins. The ice sheet acted like a great rasp, planing down the surface, especially in valleys through which it freely moved.*

FIG. 292. — To illustrate the effect of glacial deposits (dotted) in leveling a hilly country by filling the valleys, as in the prairie region of the Central States.

115. Effects of the Ice Sheet. — In some places the surface was roughened by the deposit of drumlins, eskers, kames, and moraines. Elsewhere the drift has smoothed the surface by making thicker deposits in the valleys than on the hills. This smoothing reaches its extreme in the prairie region of the Central States, where, in some cases, drift in the valleys has a depth of 500 feet. The level surface and fertile soil of the prairie are therefore due to the glacier (Fig. 292).

Throughout the glacial belt the drift soil shows many variations; for example, stony, clayey, sandy, gravelley, level, irregular. On a single farm there may be several kinds of soil. Sometimes this is better than the soil of rock decay that existed before the ice sheet came ; in other cases a barren, sandy, gravelly, or bowldery soil (Fig. 284) has been left in

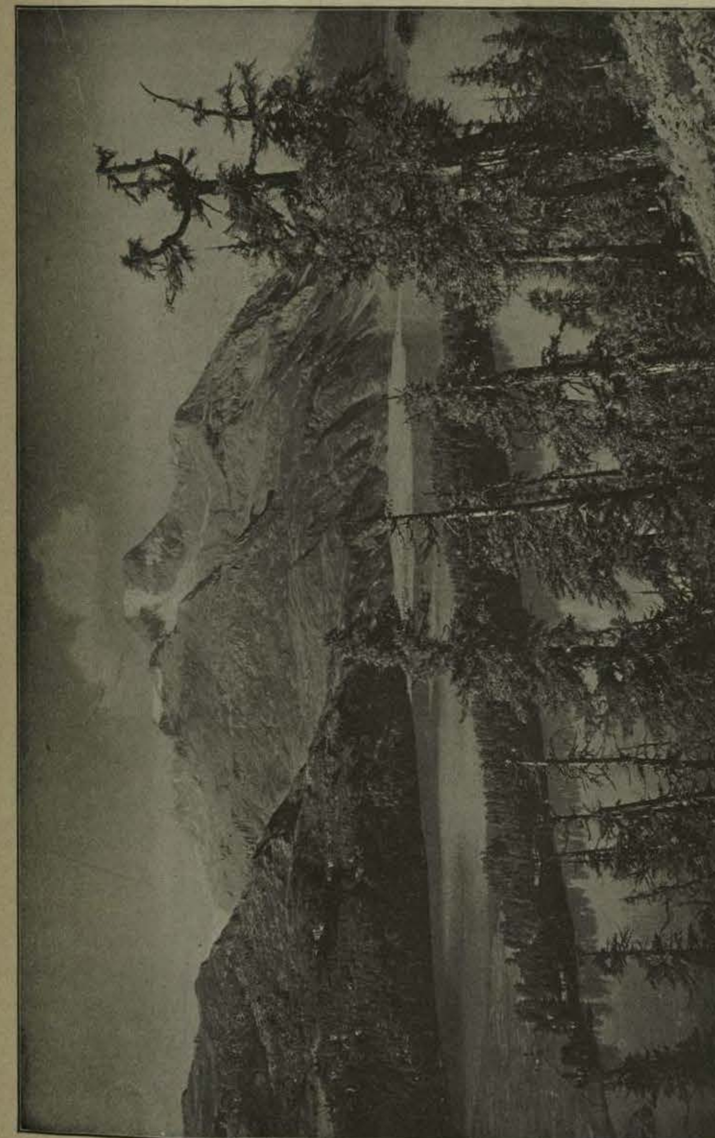

FIG. 293. — A hanging valley in the Engadine, Switzerland. The lake (the Silsersee) is in the Engadine valley. The rock bottom of the tributary valley, on the opposite side, is some distance above the main valley. It is, therefore, a hanging valley. The stream in the hanging valley has cut a gorge in its bottom and built a delta in the lake.

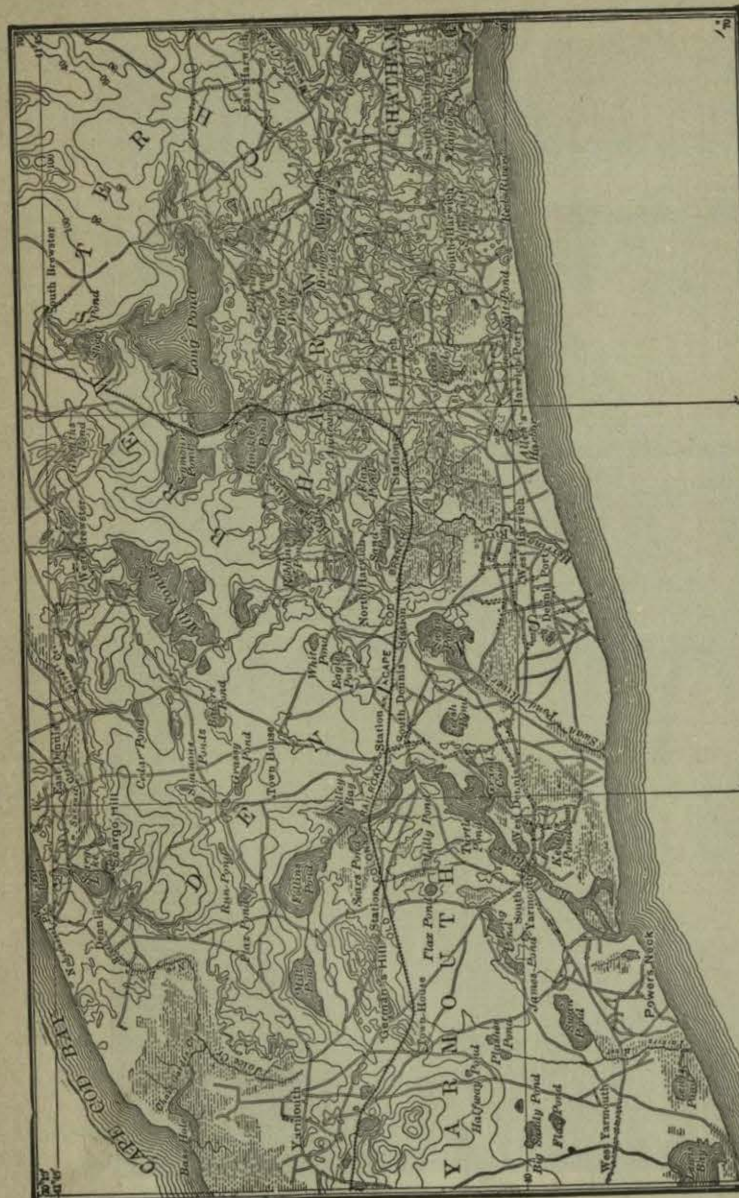

Fig. 294. — Large numbers of ponds in the Cape Cod terminal moraine. The contour lines show the hummocky nature of the moraine. (Yarmouth, Mass., Topographic Sheet, United States Geological Survey.)

place of a fertile residual soil. Usually the glacial soil is a strong one, because it consists of ground-up rock fragments, which are slowly decaying and releasing plant food.

The sheet of drift has turned many streams aside, causing them to cut new valleys for a part of their course. In these the streams have often reached the rock and cut post-glacial gorges, in which there are rapids and falls (Figs. 60, 67, 71, 75). There are thousands of instances of this, and many of the falls are of great value for water power; for instance, the falls in the Mississippi at Minneapolis, Niagara, the falls at Rochester, and the rapids in the Merrimac where Manchester, Lawrence, and Lowell are situated. South of the glacial belt there are few places where there is water power; but in New England, New York, and other states in the glacial belt, it is this water power that has given rise to so much manufacturing.

Fig. 295. — Compare this map with one of the present drainage. For purpose of comparison, make a sketch map of the present drainage from a geography map.

In some cases streams have been turned into other river systems. Before the glacial period the upper Ohio, above Wheeling (Fig. 295), flowed into Lake Erie valley through the Grand River; and the Allegheny is made by the union of two streams, one of which entered the Lake Erie valley west of Erie, Pa., the other east of Dunkirk, N.Y. The present St. Lawrence system has also been made by the union of several independent parts.

Could we restore the pre-glacial drainage of the United States, it would, in thousands of cases, be found different from the present. Some of these changes have been of great importance; for example, how different would have been the history of Pittsburg if there had been a waterway to the north (Fig. 295) instead of to the southwest! How different would have been the history of Cincinnati if the Ohio flowed past it as a small stream without its great tributaries, the Allegheny and Monongahela! And what a contrast there would be where Buffalo and the other lake cities stand if glacial changes had not united streams and caused lakes in the valleys of the St. Lawrence system!

Of the tens of thousands of lakes in the glacial region, the great majority are due to some interference of drift deposits with drainage (Figs. 297–300). This is true of the small ponds and lakes, of which there are said to be 10,000 in Minnesota alone; and it is true of the many large lakes. Even the basins of the Great Lakes, caused in part by glacial erosion and changes in level of the land, owe a portion of their depth to dams of glacial drift. What an important difference it would make in the cities and industries of northern United States if glacial action had not caused the lakes which dot the surface!

Summary. — *The ice sheet caused many changes, making some regions rougher than before, others smoother; it changed the soil, causing it to differ greatly from place to place; by turning streams aside, it led to the formation of many gorges and waterfalls; it has even turned streams into other systems; and it has made thousands of lakes, great and small.*

Topical Outline, Questions, and Suggestions.

Topical Outline. — 99. **Valley Glaciers.** — (*a*) Formation: snow field; movement of snow; névé; formation of ice; extension of ice tongue. (*b*) Movement: nature; rate; glacial erosion. (*c*) Moraines: lateral; medial; crevasses; ice falls; movement of materials to bottom; ground moraine; terminal moraine. (*d*) Wash deposits: source of water; of sediment; rock flour; nature of deposit.

100. **Glaciers of Alaska.** — (*a*) Muir; tributaries; front; withdrawal. (*b*) Malaspina: form; size; movement; surface condition.

101. **Distribution of Valley Glaciers.** — Europe; North America, — Mexico, United States, Canada, Alaska; Arctic; southern hemisphere.

102. **Former Extension of Valley Glaciers.** — (*a*) Instances. (*b*) Evidence: erratics; striæ; moraines; till; wash deposits. (*c*) Ice erosion: roches moutonnées; rock basins; cirques; hanging valleys.

103. **The Greenland Ice Sheet.** — (*a*) General condition: topography; coast; valley glaciers; area of ice; meaning of ice sheet. (*b*) The ice sheet: interior condition; outward motion; nunataks; valley tongues; size; movement; icebergs. (*c*) Rock materials: on the surface; at the base; erosion; deposits at margin. (*d*) Former extension.

104. **Other Ice Sheets.** — Antarctic; islands of Arctic.

105. **Formation of Icebergs.** — Causes; effects; outward movement.

106. **Former Ice Sheets in Europe and America.** — (*a*) Extent: Europe; America; continental glaciers. (*b*) Proofs: striæ; erratics; ice erosion; glacial deposits; glacial drift. (*c*) Agassiz's explanation.

107. **Cause of the Glacial Period.** — Land formerly higher; probable result; retreat of ice; time since ice withdrawal.

108. **Terminal Moraines.** — Cause; form, size, kettles; composition; lobate moraines; moraines of recession.

109. **Stratified Drift.** — Nature of stratified drift; wash plains; kames; kettles; eskers; sand plains.

110. **Ice-dammed Lakes.** — Cause; Great Lakes, — early stages, changes in outflow, beaches, lake clays; changes of level, — evidence, effect on outflow, present changes.

111. **Loess.** — Nature; occurrence; cause.

112. **The Till Sheet.** — Distribution; nature of material; variation in thickness: variation in bowlders; reason for variation; bowlder trains.

113. **Drumlins.** — Size; shape; cause; occurrence.

114. **Glacial Erosion.** — Striæ; north slopes; roches moutonnées; scratched pebbles; nature of the ice erosion; effect in valleys; illustrations; rock basins.

115. **Effects of the Ice Sheet.** — (*a*) On the land surface: irregular surfaces; smooth surfaces; prairies. (*b*) On soil: differences; strength of glacial soils. (*c*) On streams: formation of gorges and falls; instances; effect on manufacturing; complete turning aside of streams; importance of this. (*d*) On lakes: cause; numbers; Great Lakes; importance.

Questions. — 99. What is the snow field? What is the nature and origin of the névé? What is a valley glacier? Why does it extend down the valley? How does the ice move? What is happening at its bottom? What are lateral moraines? Medial moraines? Crevasses? Ice falls? What descends through the crevasses? What is the ground moraine? Terminal moraine? Account for the wash deposits.

100. Describe the Muir glacier. The Malaspina glacier.

101. Where are the glaciers found? In what zones?

102. Where did valley glaciers formerly exist? What are erratics? What is till? Why is it unstratified? What work of erosion did ancient glaciers perform? What are roches moutonnées? Rock basins? Hanging valleys? State the evidences of former valley glaciers.

103. What is the condition of Greenland? What is an ice sheet? What is the condition in the interior? How does the ice sheet move? What is the condition at its margin? How are rock materials carried? What deposits are being made? State the evidence of former extension.

104. Where else are ice sheets found?

105. What are the causes for icebergs? Why do they drift away?

106. Where were there former great ice sheets? What evidence is there of former glaciation? Why are the deposits called glacial drift? Who proposed the theory of the Glacial Period? Why?

107. What is the most probable explanation of the glacial period? How did the ice advance? Why did it retreat?

108. What are the characteristics of terminal moraines? What are lobate moraines? Moraines of recession?

109. What is the cause of stratified drift? What are the following: wash plains, kames, kettles, eskers, sand plains?

110. What changes occurred as the ice melted from the Great Lakes? What deposits were made? What evidence is there of change in level of the land? State the past and possible future effects.

111. What is loess? How formed? Where found?

112. What is the principal soil of the glacial region? Where is it found? How does it vary? Why?

113. What are drumlins? How do they vary? Where found?

114. What proofs of glacial erosion are there? What were its effects on the valleys? Give illustrations.

115. What effects had the ice sheet on surface features of the land? On soil? On stream courses? Give instances of streams turned into other systems. What effect had the ice on lakes?

SUGGESTIONS. — (1) Cut out a square block of ice and float it in water. Measure it to see what proportion is above water. Place the same block in salt water and measure the proportion above water. (2) In a box, the end of which can be removed, place thin layers of snow interspersed with sheets of mixed gravel, sand, and clay, placing a much greater amount in the part from which the end of the box is to be removed. Compact it as tightly as possible, then allow it to freeze. Remove the end of the box, allow the ice to melt, and watch the result. Does a moraine-like accumulation form at the front? Does the surface of the ice eventually become covered with sand? A large number of glacial phenomena can be imitated by a little ingenuity, — for example, cutting crevasses, boring a tunnel at the bottom of the ice, and sprinkling the ice surface to supply water. The stream that issues from the tunnel may be made to build wash deposits on a moderate slope; or to build sand plains in temporary lakes along the ice margin, etc. (3) Imitate moraine topography by dumping small pailfuls of sand in piles close together. (4) Is your home in the glacial belt? If so, what effects of the glacier can you find in the neighborhood, either by a study of the topographic map or, better still, on a field excursion? Is the soil till or stratified drift? To answer this question look for cuts and study them carefully. If till, look for scratched stones. If stratified, why are the pebbles rounded and the scratches gone? Look for glacial scratches on recently uncovered exposures of bed rock. What is their direction? Are the bowlders and pebbles all of the same kind as the bed rock? Do you know if any of them could have come from ledges in the direction in which the striæ point? Can you find moraines, kames, eskers, or drumlins? If so, study them, — their form and the nature of the material.

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