95. Life History of a Volcano. — While a volcano is active the cone usually grows, because each eruption adds material to it. A dormant volcano may, however, break forth in so violent an explosive eruption that the cone is wrecked and its size and form changed (Figs. 199, 220). Or, by the opening of a new outlet, the lava may be drained from beneath the cone, causing it to collapse (Fig. 219). But these causes for changes in the form of volcanoes are accidental.

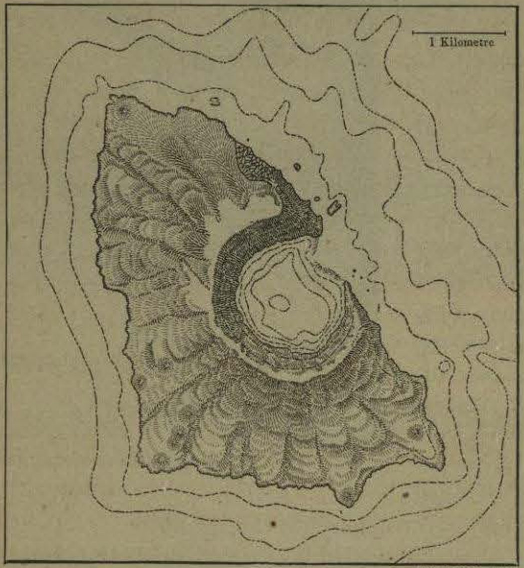

FIG. 234. — St. Paul, a volcanic island with the crater wall breached by the waves, forming a crater harbor.

Throughout the life of every volcano the agents of denudation are at work tearing it down; but so long as it is active, fresh supplies of lava or ash tend to repair the damage. When the volcano becomes extinct, however, denudation has full sway. At first the crater is occupied by a lake (Figs. 216, 225), but the rim is slowly destroyed and the lake drained. Streams gully the cone with deep ravines and gorges, until it bears little resemblance to a volcano. As the cone is slowly worn down, the hard core of lava in the volcanic neck resists denudation better than the looser beds of porous lava and ash. It therefore remains above the surface as a central divide for radiating streams (Figs. 227, 231, 237). In western United States there is every gradation from the perfect cone to the volcanic neck remnant.

If a volcano stands in the sea, the waves have a large share in its reduction (Fig. 234). At first, steep cliffs are cut, on which the waves beat with such force that no boat can land. As these cliffs are pushed back into the land, the crater may be reached and a crater harbor be opened (Fig. 234). Further wave cutting may entirely consume the volcano, leaving only a shoal to mark its site.

Summary. — *During activity a volcano grows by addition of lava or ash faster than denudation wears it away; but explosion or collapse may change its size or form. When extinct, however, volcanoes are slowly worn away, the last remnant being the hard volcanic neck. Waves aid in the destruction of cones in the sea.*

96. Importance of Volcanoes. — The most noticeable effect of volcanoes is the destruction of life, — human, plant, and animal. The ash, lava, steam, gases, hot water, mud flows, lightning, and earthquakes that accompany eruptions all contribute to this destruction. Nothing in nature is more terrible than a volcanic eruption.

Yet volcanoes have some beneficial effects. The burial of organic remains beneath ash and lava has preserved fossils that throw much light on the history of former life on the globe. The eruption of Vesuvius in 79 has preserved a record of Roman life that we could not in any other way have obtained. Lava flows have also covered and preserved deposits of precious metal, as in California, where some of the gold mining is carried on in ancient river gravels beneath old lava flows (Fig. 238).

Volcanoes have formed many lakes, like Nicaragua in the Isthmus of Panama. Volcanoes and lava floods have helped make grand scenery. There are few finer sights than a large, snow-capped volcanic cone, like Etna, Ranier, Hood, or Shasta.

Lava soils are usually very fertile; for example, one of the most productive wheat regions of the country is the Columbia valley, with its rich volcanic soil. Lava and ash have supplied much of the material of which the sedimentary strata are made; and igneous rocks have supplied underground water with much valuable mineral for deposit in veins. Lava also heats the water, thus giving it more power to dissolve minerals. The presence of lava in western United States has had a very important influence on the formation of the valuable mineral veins of that region.

Summary. — *Volcanoes are very destructive to life; but they have some beneficial effects. They preserve records of past life, and occasionally valuable minerals; they cause lakes; they aid in the making of scenery; their soils are usually fertile; they have helped supply material for the sedimentary strata; and they have aided in the formation of mineral veins.*

EARTHQUAKES.

97. (A) *Cause.* — During mountain growth a jar, or earthquake, is sent through the rocks when they slip along fault planes. Sometimes, as in Japan, in 1891, the surface of the ground on one side of a fault plane is raised during the shock (Fig. 239). Volcanic explosions, and the rush of lava into fissures, forming dikes, also cause earthquakes. In fact, any jar to the rocks, as an explosion of gunpowder, the falling in of caverns, or an avalanche, will cause an earthquake. The jar may be so slight that it can be detected only by delicate instruments; or it may be so violent as to cause widespread destruction.

(B) *Occurrence.* — Since earthquakes are so commonly caused by the breaking of rocks and by the movements of lava, volcanic regions are especially liable to them. Indeed

FIG. 235. — Cinder Cone and the lava flow which dammed Snag Lake near Lassen Peak, Cal.

FIG. 236. — A volcanic bomb on the slopes of Vesuvius.

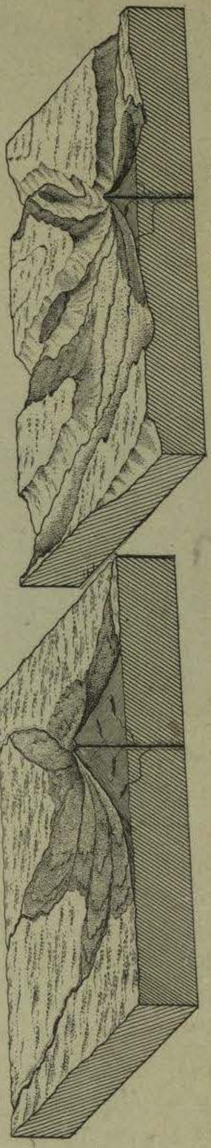

FIG. 237. — To illustrate the destruction of a volcano. On the left the cone is shown with its lava flows; on the right the cone has been mostly worn away, and streams have deeply carved the land. Small areas between the streams are left capped with lava, forming buttes, and the volcanic neck rises above the general surface.

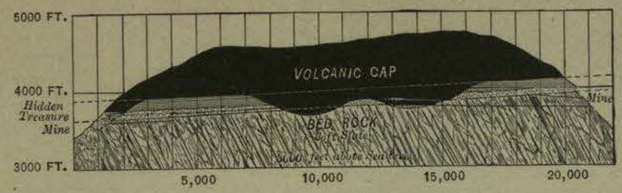

FIG. 238. — Section of a gold mine in California, beneath an ancient lava flow (volcanic cap). The circles indicate old river gravels, containing gold, which the lava flows covered.

FIG. 239. — Fault which caused the earthquake shock of 1891 in Japan. By this fault the road in the middle of the picture was raised several feet on the farther side of the fault plane. (See Figs. 241, 242.)

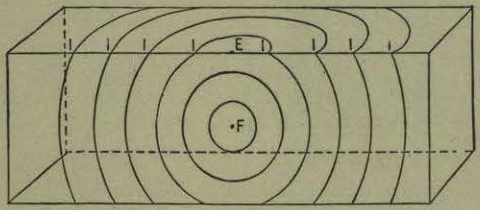

FIG. 240. — A drawing to illustrate the movement of an earthquake wave outward in all directions from the focus, *F*. The shock reaches the surface first at *E*, the epicentrum, and at later and later periods on the circles marked *I*.

a map of the distribution of volcanoes might also serve as a map of frequent earthquakes. To be sure, there have been violent earthquake shocks far from volcanoes; for example, those of Lisbon, Portugal, in 1755, southern Arkansas in 1812, and Charleston, S.C., in 1886. Such shocks are usually due to the slipping of rocks along a fault plane.

(C) *Characteristics.* — The center, or *focus* (Fig. 240), of an earthquake may be thousands of feet beneath the surface. From it the jar passes through the rocks in all directions (Fig. 240), in much the same way as a shock passes through a table when it is struck a heavy blow. The point above the focus, where the shock is first felt at the surface, is called the *epicentrum.*

At the epicentrum the movement of the earth is vertical, and the shock is most violent. As the distance from the epicentrum increases, the shock is felt with less and less violence. The Charleston earthquake was detected by delicate instruments as far away as Ontario, Canada.

In an earthquake shock the ground may not rise and fall more than an inch, and yet do great damage. The earthquake is rarely a single shock, but usually a succession of jars, perhaps near enough together to give the appearance of a shaking of the ground. Very often one earthquake quickly follows another; for example, in 1783 nearly 1000 shocks were felt in Calabria, in southern Italy. In this case the rocks were probably slipping along a fault plane, and each slip sent out an earthquake. The many earthquakes that precede a volcanic explosion are no doubt due to the breaking of the rocks by the attempt of the steam-filled lava to escape.

(D) *Effects.* — Violent earthquakes are very destructive (Figs. 241, 242). They often cause avalanches, which dam streams and form lakes; and the shaking of the ground sometimes forms depressions, in which lakes and ponds gather. Trees are thrown down; cracks, in which plants and animals are swallowed up, are opened in the ground; and great destruction of life is caused by the overturning of houses

(Fig. 241). In consequence of the danger from falling houses, people who live in countries where earthquakes are frequent, build their houses so that they will withstand ordinary shocks. Even with this precaution, thousands of lives are sometimes lost in a single shock. If the shock is in the sea, a water wave may be started which causes much destruction on low coasts (p. 186).

Summary. — *Earthquakes are jars in the rocks, resulting from faulting, volcanic action, and other causes. They are most common in volcanic regions, but sometimes occur elsewhere. An earthquake, usually a series of shocks, is most violent at the epicentrum (point above the source, or focus, of the shock), diminishing in intensity in all directions from it. Earthquakes form lakes, open cracks in the ground, and throw down trees and houses, causing great destruction of life. If in the sea, a destructive water wave may be started.*

Cary

HOT SPRINGS AND GEYSERS.

98. Underground water is often heated by buried masses of lava or other causes. Where this heated water rises to the surface, usually through a fissure, it forms a *hot spring;* and if it occasionally gushes out, it is called a *geyser*.

The rising hot water always bears mineral substances in solution, some of which may be deposited near the spring. Such deposits are found around the hot springs (Figs. 243, 474) and geysers (Figs. 244, 473) of Yellowstone Park. Hot water is sometimes encountered in mines, and it is known that many veins of gold, silver, copper, and other valuable metals have been deposited by hot water on the walls of fissures.

There are geysers in New Zealand, Iceland, and the Yellowstone National Park — all volcanic regions. The mineral deposits made around these are often very beautiful in form and color, and they sometimes build a cone, through the crater of which the geyser erupts (Figs. 244, 473).

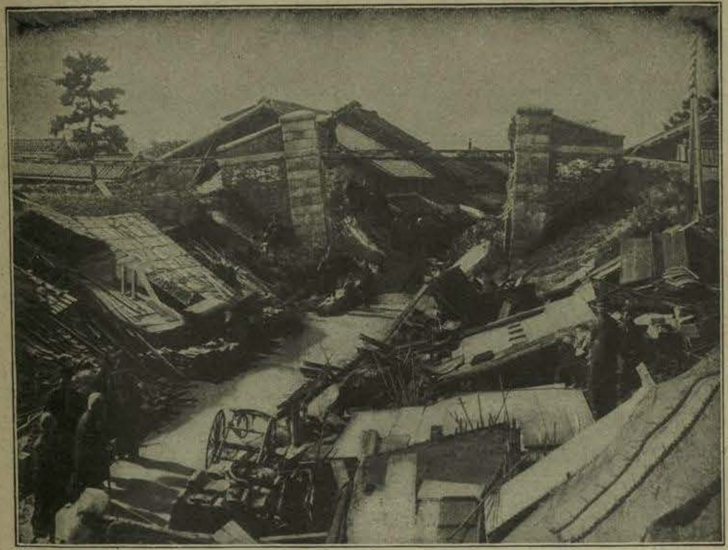

FIG. 241. — Destruction caused by the Japanese earthquake of 1891 (Fig. 239). All this damage was done to houses that were built very lightly and thus able to withstand ordinary earthquake shocks.

FIG. 242. — Damage to a railroad bridge by the Japanese earthquake of 1891. Note how the earth was shaken from beneath the track where it leaves the bridge.

FIG. 243. — Hot spring deposits in the Yellowstone Park. These deposits are carbonate of lime (calcareous tufa), and they build little basins in which the hot water stands, trickling over the edge and forming icicle-like deposits.

FIG. 244. — Giant Geyser, Yellowstone Park, in eruption. The deposits made around the geysers are of silica (siliceous sinter).

The geysers are exceedingly interesting. Old Faithful erupts every 65 minutes, with such regularity that the time of each outburst can be accurately predicted. With each eruption a great mass of hot water and steam is thrown to a height of over 100 feet. The Minute Man geyser erupts a small column every few minutes to a height of only a few feet. Other geysers erupt very irregularly, and some have become extinct. The differences between the geysers suggest the probability of several explanations for their eruptions.

Those that erupt regularly, like Old Faithful, seem to be due to the following cause. There is hot water in a narrow tube; and this is heated, perhaps by an adjacent lava mass, until the boiling point is reached. The boiling point of water rises under pressure; therefore, it may be necessary to raise the temperature to 250° or more before boiling begins down in the tube. When the boiling point is reached steam forms, but the narrow tube prevents its easy escape. It then lifts the column of water and causes some of it to flow away from the geyser crater. This overflow removes some of the water column and therefore reduces the pressure on water that is already boiling at 250°. This removal of pressure at once lowers the boiling point; and, since a large mass of water has a temperature near 250°, it suddenly changes to steam. This expels the water with a rush. The time between eruptions depends upon the length of time required to heat the water down in the tube to the boiling point.

Summary. — *Hot water, rising from underground, forms hot springs; or, if it rises in eruption, geysers. It bears and deposits mineral substances, both at the surface and in the fissures through which it rises — in the latter case sometimes forming valuable mineral veins. Some geysers erupt regularly, others very irregularly.*

TOPICAL OUTLINE, QUESTIONS, AND SUGGESTIONS.

TOPICAL OUTLINE. — 80. **Graham Island.** — The eruption; materials erupted; the cone; its destruction; other volcanoes.

81. **Stromboli.** — Location; size of cone; nature of eruptions.

82. **Eruptions of 1902 in the West Indies.** — Destruction of St. Pierre; La Soufrière; previous eruptions; warnings; eruption of May 8; cause of destructiveness; effects of later eruptions; material erupted; distribution of ash; mud flows; probable future.

83. **Vesuvius.** — (*a*) Eruption of 79: previous condition; settlements on slopes; warnings; effect of eruption; our knowledge of the eruption; conditions accompanying eruption. (*b*) Pompeii: importance of its excavation. (*c*) Condition since 79: difference in eruptions; present condition; ordinary quiet; increase in activity; lava eruptions; observatory. (*d*) Other volcanoes of Bay of Naples.

84. **Etna.** — Position; eruptions; great height; decay of the lava.

85. **Krakatoa.** — Former eruption; eruption of 1883; ash on the sea; air wave; water wave; conditions since eruption; future.

86. **Hawaiian Volcanoes.** — (*a*) Island of Hawaii: its volcanoes; its height. (*b*) The craters: lava lakes; calderas. (*c*) Lava flows: rising in crater; draining through fissures; length of flows; nature of flow.

87. **Mt. Shasta and Lassen Peak.** — Shasta; ash cone; recent eruptions.

88. **Crater Lake.** — Size of lake; cause of caldera.

89. **Materials Erupted.** — Steam; other gases; meaning of "smoke" and "flame"; lava flows; effect of steam explosion on lava; bombs; mud flows.

90. **The Forms of Volcanic Cones.** — Ash cones; lava cones; ash and lava cones; calderas; wrecked cones.

91. **Distribution of Volcanoes.** — Number; general location; belt encircling Pacific, — South America, Antilles, western United States, Aleutian Islands, eastern Asia; other chains, — Pacific and Indian oceans, continents, Mediterranean, open Atlantic; areas free from volcanoes; areas of extinct volcanoes; association with mountains.

92. **Cause of Volcanoes.** — Immediate cause; effect of growing mountains; condition in western United States.

93. **Lava Floods.** — (*a*) Columbia valley: cause; area; lava plateau; thickness; later tilting. (*b*) Other areas. (*c*) Present condition: general absence of lava floods; Iceland; relation of fissures to volcanic cones.

94. **Lava Intrusions.** — Volcanic necks; dikes; how revealed; sheets or sills; illustrations: laccoliths; bosses.

95. **Life History of a Volcano.** — Normal growth; effects of explosion; of collapse; denudation; the volcanic neck; volcanoes in the sea.

96. **Importance of Volcanoes.** — Destruction of life; preservation of fossils; of human records; of mineral; formation of lakes; effect on scenery; on soils; on sedimentary rocks; on mineral veins.

97. **Earthquakes.** — (A) *Cause:* faults; volcanic action; other causes. (B) *Occurrence:* volcanic regions; other regions; illustrations. (C) *Characteristics:* focus; nature of shock; epicentrum; distance traveled; repeated shocks; explanation of repeated shocks. (D) *Effects:* avalanches; lakes; cracks in the ground; overturning houses; sea waves.

98. **Hot Springs and Geysers.** — Cause; nature of geysers; mineral deposit at surface; mineral veins; distribution of geysers; geyser deposits; eruption of geysers; explanation of geyser eruptions.

QUESTIONS. — 80. State the history of Graham Island. What causes ash and pumice? How do many volcanoes differ from this one?

81. Where is Stromboli? State its characteristics as a volcano.

82. What reasons were there for expecting an eruption? Why was the eruption so destructive at St. Pierre? What were its effects? What was the nature of the material erupted? What causes mud flows?

83. What was the condition of Vesuvius in 79? Tell about the eruption of 79. How has it been of importance? What has been the subsequent history of Vesuvius? What is its present condition? What other signs of volcanic activity are there near Vesuvius?

84. Describe Etna and its eruptions.

85. Describe the eruption of Krakatoa and its effects.

86. Describe the Hawaiian volcanoes and craters. Describe the eruptions. What is the nature of the lava flows?

87. What is the condition of Shasta? Near Lassen Peak?

88. What has been the history of Crater Lake?

89. What substances are erupted from volcanoes?

90. How do ash and lava cones differ? Why? What are calderas?

91. Trace (Fig. 222) the principal chains of volcanoes (named in text) in the belt which partly encircles the Pacific. Where else are volcanic chains found? Are volcanoes found everywhere?

92. What is the immediate cause for volcanic eruptions? What relation is there between growing mountains and volcanoes?

93. Describe the lava floods of the Columbia valley. Where else were lava floods formed? How may volcanic cones succeed fissure eruptions?

94. What are volcanic necks? Dikes? Sheets or sills? Give illustrations. What are laccoliths? Bosses? How are they brought to light?

95. What may affect the form of a volcano before its extinction? What is its history after extinction? What is the case in the sea?

96. State the important effects of volcanoes.

97. (A) What are the causes of earthquakes? (B) Where are they most frequent? Why? What explains violent earthquakes elsewhere? (C) What is the focus? The epicentrum? What is the nature of the shock? (D) What are the effects of earthquakes?

98. What are hot springs and geysers? What do the waters carry? Where are geysers found? How do they vary? Give the explanation of regularly erupting geysers.

End

Suggestions. — (1) Illustrate the formation of volcanoes. Take an ordinary wooden box, for example a soap or shoe box, remove the cover and turn it on its side with the bottom toward the class and the open side toward the teacher. Extend a glass tube through the top of the box and blow sand gently through it. A cone will be built with a crater in the center. The force of the eruption may be made to vary, and many phases of volcanic eruptions may be imitated. The sand is best blown through by means of foot bellows, and the result will be more satisfactory if the lower part of the tube is expanded into a bulb that is partly filled with sand. (2) In the same way, force melted wax up to form a volcano. Have a branch tube extend off, reaching an inch or two above the top of the box. Keep its end plugged until the wax covers it, then open it and plug the main tube, allowing the wax to escape through the side tube to illustrate the eruption of lava from the sides of a cone. If the wax solidifies in the tube and interferes with the experiment, warm the tube. (3) With a little ingenuity wax can be forced between layers of clay and cardboard, forming laccoliths; or into fissures cut through the layers, forming dikes. (4) Look for dikes. If your home is along the rocky coast of New England, they may easily be found. Study them and tell what you observe. (5) Students in the Connecticut valley, New York City, and east central New Jersey should be given an excursion for the study of the trap sheets. Look for jointing. Look for the rock strata above or below the lava. How do they differ from the trap? Make careful observations. (6) Earthquakes may be imitated and studied by jarring a slab or stone or a table top. (7) A geyser eruption may be made by constructing a long (two or three feet), narrow tube, filling it with water, and heating it near the bottom until steam is produced.

Reference Books. — Russell, *Volcanoes of North America*, Macmillan Co., N.Y., 1897, $4.00; Heilprin, *Mt. Pelée and the Tragedy of Martinique*, Lippincott, Philadelphia, 1903, $3.00; Hull, *Volcanoes*, Scribner's Sons, N.Y., 1892, $1.50; Judd, *Volcanoes*, Appleton & Co., N.Y., 1881, $2.00; Dana, *Characteristics of Volcanoes*, Dodd, Mead & Co., N.Y., 1891, $5.00; Lyell, *Principles of Geology*, Chapters XXIII–XXV, Appleton & Co., N.Y., 1877, $8.00; Bonney, *Volcanoes*, Putnam's Sons, N.Y., 1899, $2.00; Geikie, *Ancient Volcanoes of Great Britain*, 2 vols., Macmillan Co., N.Y., 1897, $11.25; Dutton, *Hawaiian Volcanoes*, 4th Annual U. S. Geological Survey, p. 8; Gilbert, *Geology of the Henry Mountains*, Washington, 1877 (out of print); Diller, *Mt. Shasta, National Geographic Monographs*, American Book Co., N.Y., 1895, $2.50; Diller, *Crater Lake*, Annual Report, Smithsonian, Institution, 1897, p. 369; Milne, *Earthquakes*, Appleton & Co., N.Y., 1891, $1.75; Dutton, *Charleston Earthquake*, 9th Annual U. S. Geological Survey, p. 209; Weed, *Hot Springs*, 9th Annual U. S. Geological Survey, p. 619.

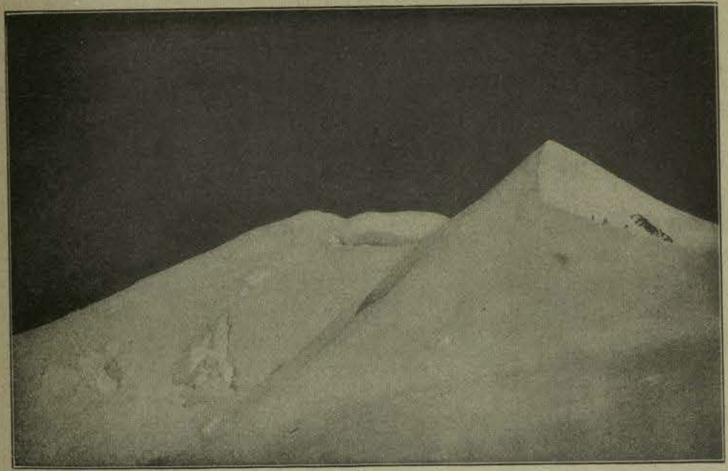

Fig. 245. — A snow field in the Alps — the top of Mt. Blanc.

Fig. 246. — A névé region in the Alps, showing the slope from which the snow slides, and, in the foreground, the crevassed névé.

FIG. 247. — The Mer de Glace, an Alpine glacier. A band of lateral moraine is seen on the left, and a talus, down which moraine material comes, on the right.

FIG. 248. — Crevasses in a Swiss glacier in the névé region.

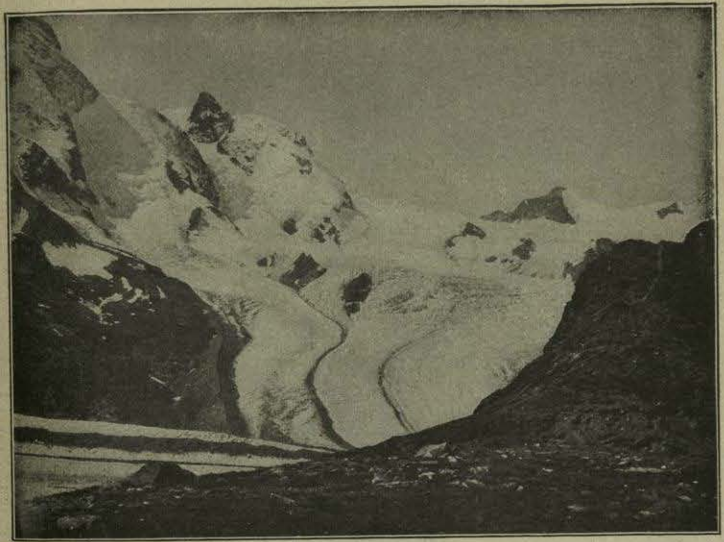

FIG. 249. — Snow field and glacier in the Alps with lateral and medial moraines.

FIG. 250. — A valley glacier in Alaska, showing well-defined medial moraine; also the snow field high up in the mountains.

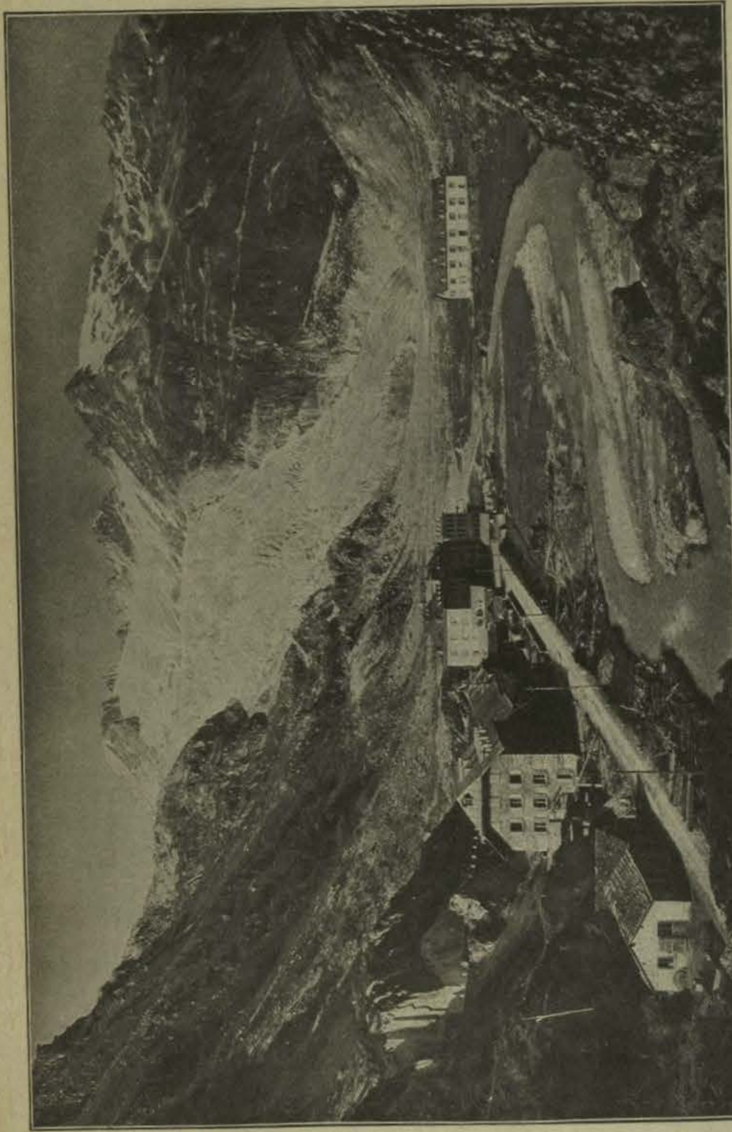

FIG. 251. — The Rhone glacier in Switzerland. This glacier formerly occupied the whole of the valley. Some of its deposits are seen on the left, and the ice-scoured cliffs on the right. The glacier-born stream (the Rhone) is here so embarrassed with sediment that it is aggrading its bed, building a wash deposit (see also Fig. 185).

CHAPTER VIII.

GLACIERS AND THE GLACIAL PERIOD.

99. Valley Glaciers. — The snow line in the Alps is about 9000 feet above sea level. Above this line is a great *snow field* (Fig. 245, 249), in which snow accumulates year after year, in some places reaching a depth of hundreds of feet. Some of the snow is whirled away by the wind, settling in valleys; some slides down the steeper slopes (Fig. 246), as snow slides from the roof of a house. There is so much snow falling into the valleys, both as small slides and great avalanches, that they would be completely filled if it could not in some way be removed.

The snow that accumulates in the valleys gradually changes to granular snow ice, resembling the snow banks of late winter. This change is partly due to the pressure of the overlying mass, and partly to alternate melting and freezing during summer days and nights. The granular ice, called the *névé* (Figs. 246, 248), moves slowly down the steep valleys.

As the mass moves, pressure and further melting and freezing gradually change it to pure, clear ice. The supply from the snow field causes the ice to move down the valley, much as a river extends beyond the place where the rain fell. Such an ice tongue, occupying a valley, is called a *valley glacier* (Figs. 157, 181, 185, 247–251). In the Alps some of the glaciers are 10 to 15 miles long, extending 4000 or 5000 feet below the snow line. They end where the warmth is sufficient to completely melt the ice, and the terminus may be below the timber line, even in the zone where grain will grow.

The glacier moves down grade, behaving much as a mass