dicates that the igneous rock continues to flow after it has begun to cool and crystallize, and that the fissure is gradually narrowed by the formation on either wall of successive layers of solid trap.

One of the most interesting and important structures of plutonic rocks is that illustrated by the two large and seemingly stratified masses of syenite from Marblehead (**62–63**). The syenite, which is the coarsely crystalline, feldspathic rock (light-colored), is eruptive here through the finely crystalline diorite (dark-colored). The diorite is itself an older eruptive rock in which, as the result of enormous pressure, possibly during its original solidification, an imperfect cleavage or foliation had been developed. This structure, which resembles stratification, causes the diorite to split easily in parallel vertical planes; and the liquid syenite instead of forming and filling one wide fissure in the fissile diorite, has, under great pressure, been injected in thin layers along all these planes of weakness, thus giving rise to a very perfect interlamination of the two rocks; although, as the specimens show, the syenite sometimes breaks across the diorite, forming ordinary dikes. When the diorite is less fissile, the relations of the two rocks are represented by the smaller specimen (**66**) and by the other examples of enclosed fragments from Marblehead (**61, 81**), except that the injected rock is mainly granite instead of syenite.

Truly stratified rocks are also sometimes injected along the bedding-planes in this intimate way by igneous material; and there can be no doubt but that many of the so-called gneisses or crystalline stratified rocks are partly if not wholly of igneous origin.

Contact Phenomena. — Under this head are grouped the interesting and important phenomena observable along the contact between the dike and wall-rock. These throw light upon the conditions of formation of dikes, and are often depended upon to show whether a rock mass is a dike or not. We may notice here: —

1. *The detailed form of the contact.* It may be straight and simple as in the first model (**1**) and several of the specimens (**25–27, 51**) or exceeding irregular, the dike penetrating the wall, and enclosing fragments of it, as in the second model (**2**), which represents a typically igneous contact, and as in most of the specimens already noticed, and particularly in the contact of trap and marble from Lewiston, Me., (**43**)

2. *The alteration of the wall-rock by heat.* This may consist in: (*a*) *Coloration*, shales (**84**) and sandstone (**85**) being reddened in the same way as when clay is burnt for bricks, or whitened by the oxidation of the carbon in carbonaceous clays. (*b*) *Baking and induration*, sandstone being converted into quartzite (**85**) with the hardness and color of jasper; clay, slate, etc., being not only baked to a flinty hardness (**86–87**), but actually vitrified, as in porcelainite; and bituminous coal being converted into natural coke (**88**) or anthracite. (*c*) *Crystallization*, chalk (**89**) and other forms of limestone being changed to marble, and crystals of pyrite (**90**), calcite, quartz, etc., being developed in slate, sandstone and other rocks, through the direct action of the volcanic heat or of the thermal waters accompanying the eruption. The massive garnet and other minerals in the calcareous

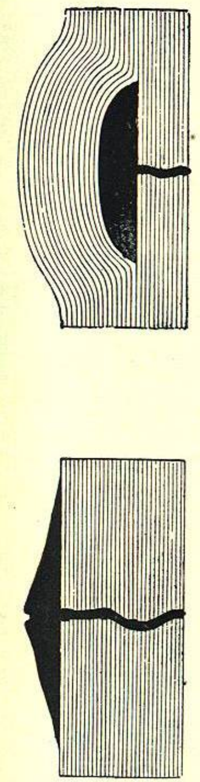
slates of Nahant (**91**), and Newbury (**92**), represent a large number of silicate species which owe their origin to contact metamorphism and crystallization.

3. *The alteration of the dike rock.* (*a*) By the more rapid cooling near the walls, as already explained (**41–42**), rendering it more compact in texture. (*b*) By the access of thermal or meteoric waters, which may decompose the eruptive rock, as in the case of the small branch dikes in the Somerville slate (**45, 47–50**).

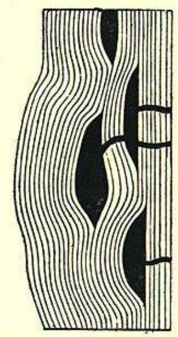
The alteration of the wall-rock may extend only a few inches or many yards from the dike, gradually diminishing with the distance; and the cases are very numerous where there is no perceptible alteration (**51**, etc.); and, again, as just explained, the alteration is usually mutual, the dike rock being altered in texture, color, and composition.

Intrusive Beds. — We commonly think of dikes as cutting across the strata, but they often lie in planes parallel with them; and the same dike may run across the beds in some parts of its course and between them in others, as shown in the model (**1**); or the conformable dike may be simply a lateral branch of a main vertical dike, as may be seen in the same model; or, finally, a dike cutting across the strata may end abruptly at a particular plane of stratification and spread out between the strata. All dikes or portions of dikes lying conformably between the strata are called *intrusive beds* or *sheets*.

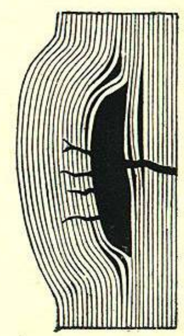
Intrusive beds are exposed at many points in the vicinity of Boston. The great mass of diabase forming the principal part of Nahant is an intrusive bed in the slate; but the clearest and most typical examples occur in the slate formations of the outer



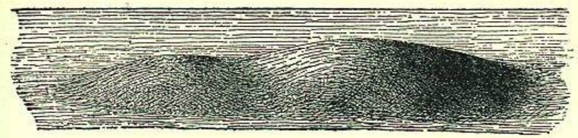
Ideal cross-sections of a volcano and a laccolite.



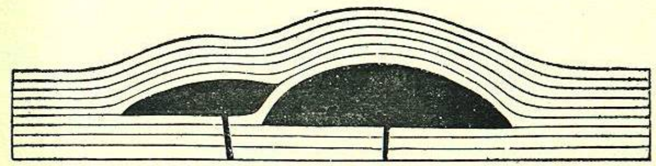
Ideal cross-section of a group of laccolites.



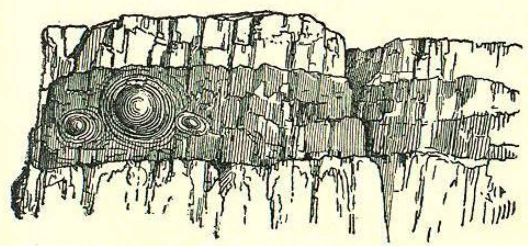
Ideal cross-section of a laccolite, with accompanying sheets and dikes.



Ideal restoration of the laccolites of Mt. Holmes.



Ideal cross-section of the laccolites of Mount Holmes, after restoration.



Dike of obsidian, San Luis District, Colorado.

islands of Boston Harbor. The picture (**64**) shows a natural section on the south side of Middle Brewster Island, the lighter color representing the slate and the darker the interbedded sheets of diabase.

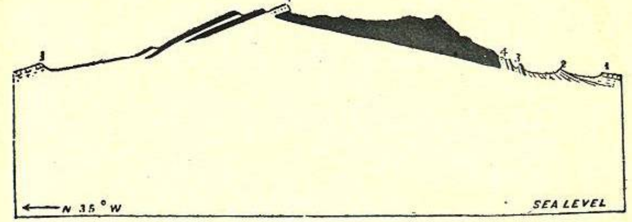
When a dike, failing to reach the surface, spreads out horizontally between the strata, forming a thick dome-shaped intrusive bed, *i.e.*, an intrusive bed of great thickness in proportion to its horizontal extent, it is called a *laccolite*. The model (**2**) gives the general idea of a laccolite, as seen in section and in relief; and also affords a comparison between a laccolite and a volcano. In the one case a large mound of eruptive material accumulates between the strata, the overlying beds being lifted into a dome; while in the other case the fissure or vent reaches the surface, and the mound of lava is built up on top of the ground. Laccolites are sometimes of immense volume, containing several cubic miles of igneous rock. The laccolites first described, and one of the largest and most typical groups yet discovered, are those forming the Henry Mountains, in Utah. These are well represented by the two relief maps in the middle window-space of this room. The first map shows the laccolites as they probably appeared when first formed. The overlying strata are lifted into smoothly rounded domes which completely conceal the igneous masses, and the uniform surface of the entire map, the complete absence of evidences of erosion, indicates that this region had not been elevated above the sea since the deposition of these Cretaceous beds. The companion map, on the other hand, shows the present appearance of the same area, after extensive erosion has removed a large part of the newer strata, developing the drainage systems, and exposing the summits of the laccolites.

The sedimentary beds (Cretaceous) can, however, still be seen arching up over the slopes of the igneous cores on every side. It is, in fact, this circumstance that most clearly distinguishes a laccolite from a true volcano; for even if the latter were submerged and covered by sedimentary deposits, they would rest horizontally and unconformably against its slopes, and not arch regularly and conformably over it. Laccolites are more numerous than they were formerly supposed to be, many eruptive masses which were once classed as volcanoes being now regarded as laccolites.

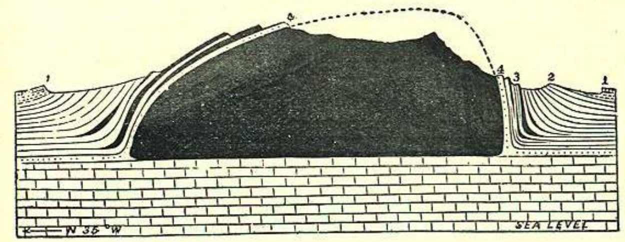
Ages of Dikes. — The ages of dikes may be estimated in several ways. They are necessarily newer than any rock formations which they intersect or of which they enclose fragments. But any sedimentary strata crossing the top of a dike must usually be regarded as newer than the dike, especially if they contain water-worn fragments of the dike rock.

The relative ages of different dikes are most easily and satisfactorily determined by their intersections, on the principle that when two dikes cross each other, the intersecting must be newer than the intersected dike. This principle is illustrated by several dikes in the model (**1**), some of the intersections showing in both the surface and sectional views; and it is apparent that it must sometimes be possible, in this way, to prove several distinct periods of eruption in the same limited district.

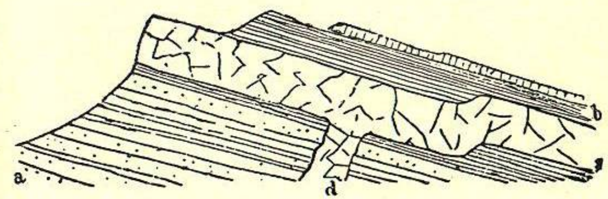
The textures of dikes also often afford reliable indications of their ages; for, as we have already seen, the upper part of a



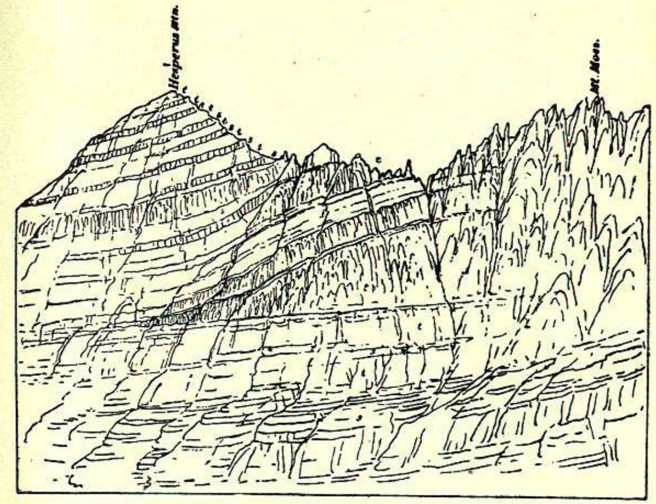
Cross-section of Mount Hillers.



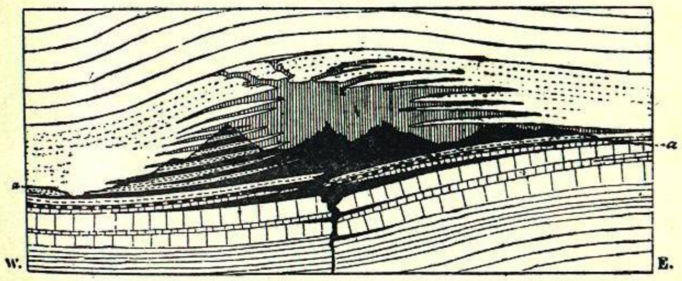
The same, with ideal representation of the underground structure. Scale, 1 inch = 6,000 feet.



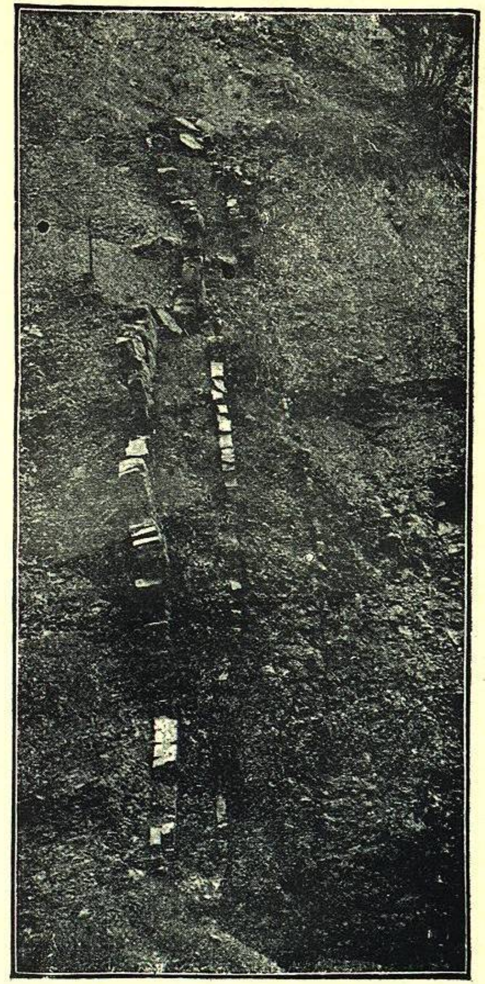
Intrusive sheet, with connecting dike.



Hesperus Mountain, showing wedges and sheets of trachyte intruded into the shales from the laccolite of Mt. Moss.



Ideal section of the La Plata Mountains, Colo., showing the supposed original form of the laccolite of Mt. Moss. *a. a.* Is the present profile, which cuts Hesperus Mtn. and Mt. Moss.



Group of sandstone dikes, the largest four inches thick. North Fork of Cottonwood Creek, California.

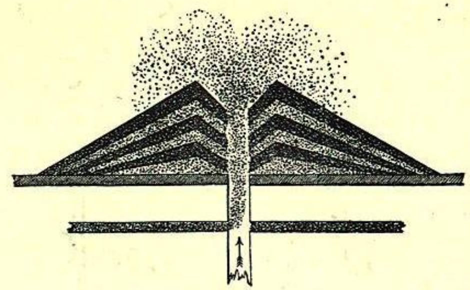
dike, cooling rapidly and under little pressure, must be less dense and crystalline than the deep-seated portion, which cools slowly and under great pressure. Now, the lower, coarsely crystalline part of a dike can usually be exposed on the surface only as the result of enormous erosion; and erosion is a slow process, requiring vast periods of time. Hence, when we see a coarse-grained dike outcropping on the surface, we are justified in regarding it as very old, for all the fine-grained upper part has been gradually worn away by the action of the rain, frost, etc. Other things being equal, coarse-grained must be older than fine-grained dikes; and the texture of a dike is at once a measure of its age and of the amount of erosion which the region has suffered since it was formed.

Eruptive Masses. — In striking contrast with the more or less wall-like dikes are the highly irregular, and even ragged, outlines of the eruptive masses; and it is worth while to notice the probable cause of this contrast. The true dikes are formed, for the most part, of comparatively fine-grained rocks — the typical "traps"; while the eruptive masses consist chiefly of the coarse-grained or granitic varieties. Now we have just seen that the coarse-grained rocks have been formed at great depths in the earth's crust, while the fine-grained are comparatively superficial. But we have good reason for believing that the joint-structure, upon which the forms of dikes so largely depend, is not well developed at great depths, where the rocks are toughened, if not softened, by the high temperature. In other words, trap dikes are formed in the jointed formations, which break regularly; while the granitic masses are formed where the absence of joint-structure and a high temperature combine to cause extremely irregular rifts and cavities when the crust is broken. And we may suppose that plutonic masses which are coarsely crystalline and extremely irregular in form at great depths in the earth often pass gradually upward into ordinary fine-grained, wall-like dikes.

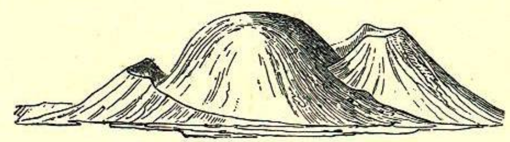
Volcanoes.

Volcanic eruptions, or the actual emission of lava at the earth's surface, are of two distinct types: (1) fissure eruptions, where the lava issues from a fissure or series of fissures, often in enormous volume, and forms broadly extended sheets and beds of lava, sometimes of great thickness, as in the northwestern part of the United States; (2) crater eruptions, where the lava issues from a more circumscribed vent or crater and builds up an ordinary volcanic cone. The fissure eruptions, although of vast importance in the structure of the earth, are evidently not adapted to museum illustration; but the remaining specimens and models under the general head of the eruptive rocks illustrate some of the varied structural features of crater eruptions.

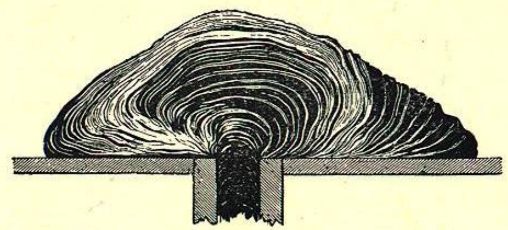
Volcanic Cones. — The crater eruptions, as explained on page 43, may be distinguished as (1) *quiet*, when the lava issues mainly in a liquid form; or (2) *explosive*, when it is largely blown out in the form of dust and fragments. The general forms of volcanic cones evidently depend largely upon the relative proportions of liquid and solid lava, the former making gentle and the latter steep slopes. This contrast may be observed in the large relief map of Mt. Vesuvius, in the Vestibule. The lower part of the mountain, built up largely of successive flows of liquid lava, is much less steep than the upper cone, in which the volcanic ashes and cinders largely predominate. The extreme examples are seen in some of the smaller cinder cones, such as Monte Nuovo, near



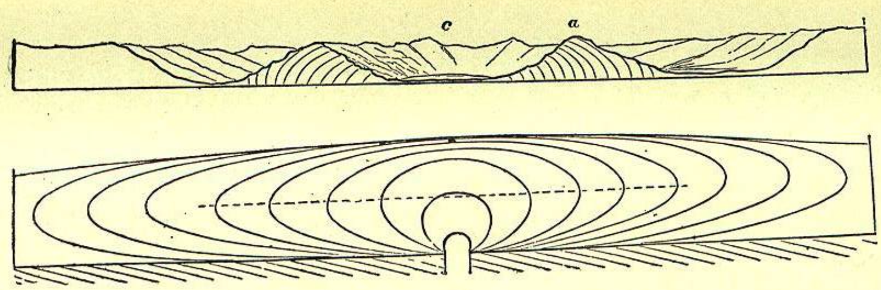
Experimental illustration of the mode of formation of volcanic cones composed of fragmental materials. (Judd.)



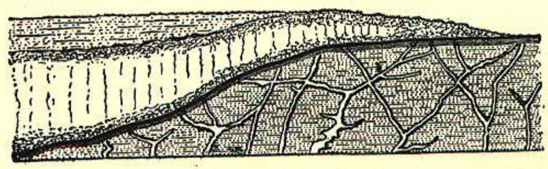
The Grand Puy of Sarcoui, composed of trachyte, rising between two breached scoria-cones. A typical example of a pustular cone formed of highly viscid lava (Auvergne).



Experimental illustration of the mode of formation of volcanic cones composed of viscid lavas.



The upper figure shows a section of a lava-flow exhibited in Meadow Creek Cañon, near Belmont, Nevada, the concentric curving lines representing cleavage planes. The base line is the level of the creek bed. The lower figure is an ideal section of the same flow. The dotted line indicates the level of the creek bed.



Natural section of a lava-stream in the Island of Vulcano, showing the compact central portion and the scoriaceous upper and under surfaces. (Judd.)

Section observed in the Val del Bove, Etna, showing a basaltic dike from which a lava-stream has flowed. (Judd.)

Naples, rising at angles of more than thirty degrees, and the great volcanoes of the Sandwich Islands, which, although in some cases more than 14,000 feet high, are so broad that the angle of slope is almost inappreciable. The relief map of Mt. Vesuvius, already referred to, shows, in Monte Somma, part of the wall of an older and larger crater, encircling the modern cone, and thus illustrates the concentric craters which are frequently developed when minor eruptions follow greater ones. The ideal section of a volcanic cone (**1**) shows outward sloping layers, representing the successive flows of lava in the history of a volcano; the lateral eruptions, with the dikes and monticules which they form; monticules which have been buried by subsequent eruptions from the main crater; the underlying sedimentary rocks on which the volcano stands; and the neck or pipe extending down through these to the original source of the lava.

In like manner, the sections on the next model (**2**) illustrate the different phases of extinct and fossil volcanoes, showing cones partially worn away; partially and completely buried by sedimentary deposits; cones that have been tilted by subsequent disturbance and folding of the strata; and the various appearances of the volcanic pipes or necks, where the cone itself, the surface accumulation of solid and fragmental lava, has been completely worn away. Some of the characteristic appearances of an extinct volcano are also well illustrated by the smaller models (**3–4**) and by the photographs (**5**); but no explanations are required beyond those given on the labels. The large relief map of the island of Oahu (section 7) shows, in the main mountain ridges, remnants only of