main shelf, the mechanically formed sedimentary rocks (**21–29**) and the chemically and organically formed sedimentary rocks (**31–39**); followed, on the third shelf, by the metamorphic or crystalline stratified rocks, including the schists (**41–47**) and the gneisses (**51–57**). From the gneisses the passage is natural to the plutonic division of the original or eruptive rocks on the fourth shelf, the acid types being placed on the left (**61–64**), and the basic on the right (**71–74**); and on the bottom shelf we come to the true volcanic rocks or lavas, which are arranged in the same way, the acid species on the left (**81–87**) and the basic species on the right (**91–97**).

DYNAMICAL GEOLOGY.

Dynamical Geology is that branch of the science which treats of the processes of geological change at present in progress; and it is essentially the foundation of geology, since we must work continually from the known to the unknown, finding in the causes of changes now taking place a key for the interpretation of those changes which have occurred in the past.

Unfortunately, however, it is also true that no other department of geology is so difficult to treat satisfactorily in a museum. The agencies themselves, in operation, cannot be shown; and they can be only very inadequately represented pictorially or by models. Hence our only resource in most cases is to illustrate the geological causes, so far as practicable, by examples of their recent effects, and leave the remainder to the imagination, aided by the descriptions of the standard authors, and, still better, by the visitor's recollections of personal observation on the seashore and mountains, or in the neighborhood of rivers, volcanoes, and glaciers.

The geological agencies are divided naturally into two great classes: (1) those operating below the earth's surface, the subterranean or igneous agencies, deriving their energy from the central heat of the earth; and (2) those operating upon the earth's surface, the superficial or aqueous agencies, deriving their energy from the solar heat.

In the earlier periods of geological time, when the outer portion of the earth had a much higher temperature than at present, so that the water of the globe could exist only in the form of vapor in the atmosphere, the chemical and mechanical changes taking place, even on the earth's surface, must have originated chiefly in the subterranean heat. But as the outer layers of the globe cooled, and the changes due to the internal heat gradually subsided, the influence of the solar heat must have become more marked, giving rise to that wide circle of superficial changes in which the circulation of air and water over the earth, due to variations of temperature, is such an important factor. It is thus apparent that we simply follow the natural or historical sequence in considering the subterranean before the superficial agencies.

The dynamical collection is in the two cases on the west side of the vestibule (right hand on entering), the illustrations of the subterranean agencies occupying the right hand case and the illustrations of the superficial agencies the left hand case.

SUBTERRANEAN OR IGNEOUS AGENCIES.

HORIZONTAL COMPRESSION AND CORRUGATION OF THE EARTH'S CRUST.

The principal reasons for believing that the temperature of the ground increases downwards, and that the earth's interior is very hot, a great reservoir of heat, have been stated in the introduction. The earth is not only a very hot body, but it is rotating through intensely cold space, and, therefore, must be a cooling body, the interior heat slowly passing out toward the surface and being radiated into space. Cooling means contraction, and consequently the heated interior of the earth, as it cools, must constantly tend to shrink away from the cold external crust. Of course no actual separation of the crust and interior can take place, but there is no doubt that the crust is left unsupported to a certain extent, and it must then behave like an arch with a radius of 4,000 miles, and the result is an enormous horizontal or tangential pressure.

It is now believed, however, that an entirely independent cause also tends to develop a powerful tangential strain in the earth's crust. It is well known that the centrifugal force arising from the earth's rotation is sufficient to change the otherwise spherical form of the earth to an oblate spheriod, with a difference of about twenty-six miles between the polar and equatorial diameters. It is also well known that while the earth turns from west to east on its axis, the tidal wave due to the attraction of the moon moves around the globe from east to west, thus acting like a powerful friction brake to stop the earth's rotation. Our day is consequently lengthening, and the earth's form as gradually approaching the perfect sphere. This means a very decided shortening and consequent crumpling of the equatorial circumference, and is equivalent to a marked shrinkage of the earth's interior, so far as the equatorial regions are concerned.

The subterranean agencies are chiefly various manifestations of this enormous horizontal pressure, which is one of the most important and generally accepted facts in geology. The principal and most direct result of the lateral thrust, whether due to cooling or tidal friction, is the corrugation or wrinkling of the crust; and the earth-wrinkles are, generally speaking, of three orders of magnitude,—continents, mountain-ranges, and rock-folds or arches.

That lateral or edgewise pressure does produce undulations or wrinkles, alternate elevations and depressions, in layer of flexible material is a matter of common experience, as with the folds and wrinkles of our clothing. This is shown by the thick layers of felt in the model (**25**). The layers were first spread out horizontally and then squeezed endwise by shoving the confining blocks toward each other. The next model (**24**) is a farther illustration of the same principle, showing in plaster the result of an experiment by Alphonse Favre made by spreading layers of plastic clay on a stretched sheet of India rubber and then allowing the rubber to contract, carrying the clay with it and forcing the layers into irregular folds or corrugations. In this experiment the contraction of the rubber represented the shrinkage of the earth's interior due to cooling.

Many features of the rocks composing the earth's crust indicate more or less plainly that they have been exposed to an enormous horizontal pressure. The most of these will be fully illustrated and explained in the petrographic collections in Room B; and it will suffice here to show only the plainest proofs of this tangential compression.

The fossil shell (**22**) was originally circular, but it has been compressed to a very flat form. The specimens on the next tablet (**21**) are pebbles from the Roxbury conglomerate whose forms have been distorted and indented by mutual compression, showing that this rock formation has experienced a powerful lateral squeezing. And the specimen of contorted shale (**23**) shows that when the rocks are composed of flexible layers they are wrinkled and plicated in the same manner as the layers of clay and felt in the artificial examples. These general illustrations, which are found in nearly all parts of the earth's crust, show that the lateral thrust required by the theories of internal cooling and tidal friction is an established fact.

ELEVATION AND SUBSIDENCE OF THE EARTH'S CRUST.

Relative changes of level of the land and sea are the most important of all subterranean phenomena, the influence which these vertical movements of the crust exert upon the forms, sizes and disposition of the continents and ocean-basins, and the general configuration of the earth's surface, far exceeding the combined effect of volcanoes and earthquakes; although these latter phenomena are far more obvious to the senses and more familiar to the mass of mankind.

Geologists now generally believe that the surface of the ocean is essentially stationary, and that any relative changes of level of land and sea are due to the movements of the former. The exact nature and cause of the movements are unknown in most cases; but it is probable that the lateral pressure in the earth's crust usually acts directly or indirectly. According to this view, continents and ocean-basins are great upward and downward bendings or undulations of the earth's crust resulting from the attempt of the crust to adapt itself to the shrunken interior. There are good reasons for believing, however, that some of the less important movements of the crust, especially in volcanic regions, are caused by expansion or contraction resulting from a gain or loss of heat in the part of the crust affected.

Slight movements of elevation or depression are sometimes accomplished suddenly and are accompanied by earthquakes; but all important oscillations of the crust take place with extreme slowness, a few inches or a few feet in a decade or in a century. Small changes of level are not easily detected except along the seashore, and even here the evidence is much more conclusive for elevation than for subsidence; since the land, in sinking beneath the sea, carries with it the evidence that it was once above the sea.

The principal proofs of vertical movements of the land are:—

(1) *Changes in position of works of man with respect to the sea-level.* The ruins of the Roman temple of Serapis at Pozzuoli, near Naples, shown in the picture (**1**), are a classic and perfect example of this kind of evidence. Only the floor and three columns of this structure still remain in their original positions; and when first discovered the floor and the lower part of the columns were covered with the debris of the temple and marine sediment. Above the part thus protected, the columns, as indicated in the picture, were perforated, to a hight of twenty feet, by numerous borings made by the bivalve mollusks called *Lithodomus* (lithos, a stone; and domus, a house), because they bore holes in the rocks near the water-line. The

floor of the temple was, of course, originally above the level of the sea. Then a subsidence, so gradual as to be unnoticed by the inhabitants, took place. Italian historians state that in 1530 the sea covered the site of the temple; and the lithodomus-borings on the columns show the extent of the subsidence, the floor of the temple being carried twenty feet below the level of the sea. The land then began to rise until, at the time the ruins were discovered, the base of the temple was several feet above the sea. The floor is now, as indicated in the picture, covered by a few inches of water at high tide, showing that a movement of depression is again in progress; and it is estimated that the land is now subsiding about one inch in four years. The upright position of the columns proves that these up and down movements of the temple have always been, like the present downward movement, gradual and quiet; and the neighboring volcanoes suggest that volcanic heat is the principal cause of the oscillations.

(2) *Sea-worn cliffs and caves above the reach of the waves at the present time.* The picture of Percé Rock, in the Gulf of St. Lawrence (**47**), shows, along the base of the cliff, the characteristic hollows and tunnels due to the action of the waves on the weaker portions of the rock; while precisely similar features are also clearly shown, especially near the right hand end of the picture, many feet above the present limit of wave action.

(3) *Elevated sea-margins or raised beaches.* When the elevation of the land is somewhat intermittent, beaches of sand and shingle, often with marine shells, and other traces of the shore-line, such as wave action, and corals

and shells sticking to the rocks, are left at different levels, and the beaches often appear as distinct terraces or level shelves fringing the coasts, as shown in the view on the coast of Labrador (**2**).

(4) *The occurrence above sea-level of any rock which shows evidence of having been formed in the sea.* The Roxbury puddingstone (**41**), forming some of the higher hills about Boston, is essentially a consolidated gravel-beach, and proves a considerable elevation of the land in this vicinity. The same is true of the slate and sandstone (**42**) so abundant in and around Boston. They are hardened beaches and mud flats, and often show ripple-marks or other special indications of their marine origin. The evidence is still more striking when the rocks are filled with marine shells (**43**) or other organisms. In this way we learn that nearly all parts of the continents, including those having the greatest altitude and most remote from the shore, have been submerged beneath the waters of the ocean, not once, but many times.

(5) *Submerged forests, peat-beds, etc.* At various points along our coast, beds of peat, and the stumps or roots of trees are found below sea-level, and yet in the positions in which they grew, proving that the land is now subsiding. The piece of wood (**45**) is from such a submerged forest on Cape Cod.

(6) *The deltas of rivers* often afford unmistakable evidences of gradual depression. Thus, the delta of the Mississippi, for a depth of several hundred feet below the present level of the sea, consists of layers of soil with the stumps and roots of cypress trees in their original positions and containing fresh-water or land shells alternating with layers of clay and sand with marine shells. These facts prove that the bottom of the delta-deposit was once above sea-level, and that the subsidence has been gradual and somewhat intermittent. The valley of the Charles River, between Watertown and Charlestown, is an equally good illustration. The Charles, in this part of its course, flows over a considerable thickness of sediments which include, below the present level of Boston Harbor, layers of peat (**44**) with land shells and stumps of coniferous trees. And these phenomena are repeated in the valleys of the Mystic, Neponset and other streams of this region.

(7) *Fiords and drowned land-valleys generally.* The fiords of Scandinavia, Alaska, and other regions, are deep, narrow land-valleys which have been invaded by the sea. This is proved by their sides preserving nearly the same angle of slope below the surface of the water, and thus giving a great depth near the shore, the depth measuring the amount of subsidence. Soundings in the vicinity of New York (see map **46**) show that the channel of the Hudson can be traced more than one hundred miles beyond the present mouth of the river, and to a depth of more than twenty-eight hundred feet.

(8) *The development of coral-islands and reefs.* The reef-building corals are limited to a depth not exceeding twenty fathoms; and yet in the Pacific and other oceans the coral-limestone forming the islands and reefs often has a thickness very much greater than this; indicating, as will be more fully explained in a later section, that as the reefs gained in hight the sea-bottom on which they rest gradually subsided.

While the aqueous or sedimentary rocks of which the continents are chiefly composed, teach us that the oscillations of the earth's crust have been very extensive and wide-spread during the past geological ages, the map (**26**) shows that these movements of the land and sea-floor are still well-nigh universal. It is known that the land areas colored purple on the map are rising at the present time, and that those colored green are now subsiding. It will be observed that these areas embrace the greater part of the coast-lines of the globe, and the map may be regarded as fairly accurate for the coastal regions, but as almost entirely erroneous for the continental interiors and ocean-beds, since it is certain that the movements are not limited to the shore-lines, and probable that they are most important at the points farthest removed from the shore, which may be regarded, in many cases, as the axis or fulcrum of the oscillations.

FORMATION OF MOUNTAINS.

If the model of Favre's experiment (**24**) showing the plication of layers of clay by horizontal compression be regarded as representing a large tract or section of the earth's crust, it will not be difficult to understand how mountains may be formed by the yielding or mashing up of the crust under the tangential thrust, each irregular ridge on the model representing a mountain range. In other words, mountains are formed by the collapse and crushing up of the earth's crust along narrow but relatively weak zones, when the lateral pressure can no longer be resisted. The crust is shortened horizontally

and greatly thickened vertically, which explains the altitude of the mountains. It is in mountainous regions, almost exclusively, that the *reaction of the earth's interior upon its exterior* finally and permanently takes place. They are the culminating points of the play of the subterranean forces.

In considering the origin of mountains, we must distinguish carefully between mountain *forms* and mountain *structure*. Mountain-chains are the great theaters of erosion as they are of igneous action. "In all cases the erosion has been immense. In fact, as a rule, all that we see when we stand on a mountain-ridge — every peak and valley, every ridge and gorge, all that constitutes scenery, except the mere altitude — is wholly due to erosion."

A mountain-chain or system is produced solely, and the principal ranges of which it is composed, are produced chiefly, by the bulging of the crust by lateral pressure. But the minor longitudinal valleys and all the transverse valleys and cañons are always the work of erosion.

It follows from the foregoing that mountains when first elevated are much simpler externally than after they have been shaped by denudation. A recently elevated range would show its newness in its smoothly rounded outlines, unbroken crests, and general obtuseness. This contrast is well illustrated by the large relief maps in the west window space of Room B. We have reason to believe, however, that as a rule the elevation of mountains goes on so slowly that denudation destroys the original outlines as fast as they are formed.

The internal structure of mountains, it is almost unnecessary to add, is not influenced in any degree by the erosion; but is due