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EARTH-CRUST MOVEMENTS AND THEIR CAUSES

Annual Address by the President, **Joseph Le Conte**

Contents

INTRODUCTION.

SOURCES OF ENERGY.

Nearly all the processes of nature visible to us—well nigh the whole drama of nature enacted here on the surface of the earth—derive their forces from the sun. Currents of air and water in their eternally recurring cycles are a circulation driven by the sun. Plants derive their forces directly, and those of animals indirectly through plants, from it. All our machinery, whether wind-driven , or water-driven, or steam-driven, or electricity-driven, and even all the phenomena of intellectual, moral, and social activity, have still this same source. There is one, and but one, exception to this almost universal law, namely, that class of phenomena which geologists group under the general head of *igneous agencies*, comprising volcanoes, earthquakes, and more gradual movements of the earth's crust.

Thus, then, all geological agencies are primarily divided into two groups. In the one group come atmospheric, aqueous, and organic agencies, together with all other terrestrial phenomena which constitute the material of science; in the other group, igneous agencies and their phenomena alone. The forces in the one group are exterior; in the other, interior; in the one, sun-derived; in the other, earth-derived. The one forms, the other sculptures, the earth's features; the one rough-hews, the other shapes. The general effect of the one is to increase the inequalities of the earth's surface, the other to decrease and finally to destroy them. The configuration of the earth's surface, the distribution of land and water—in a word, all that constitutes physical geography at any geological time is determined by the state of balance between these two elderly antagonistic forces.

PHENOMENA TO BE STUDIED.

Now the phenomena of the first group, lying as they do on the surface and subject to direct observation, are comparatively well understood as to their laws and their causes. While the causes of the phenomena of the second group, hidden forever from direct observation in the inaccessible depth of the earth's interior, are still very obscure; and yet partly on account of this very obscurity, but mainly on account of their fundamental importance, it is just these which are the most fascinating to the geologist. The former group constituting, as it does, the terrestrial drama enacted by the sun, its interest is shared by geology equally with other departments of science, such as physics, chemistry, and biology. The phenomena of the second group are more distinctively the field of geology.

If we compare the earth with an organism, then these interior forces constitute its life-force, while the other group may be likened to the physical environments against which it eternally struggles, and the outcome of this struggle determines the course of the evolution of the whole. Now in biological science nearly the whole advance has heretofore been by study of the external and more easily understood phenomena, thus clearing the ground and gathering material for attack on the interior fortress, and the next great advance must be through better knowledge of the vital forces themselves. The same is true of geology. Nearly all the progress has heretofore been by the study of the exterior phenomena, such as erosion, transportation, sedimentation, stratification, distribution of organic forms in space and their succession in time, etcetera. Many of the laws of these phenomena have already been outlined, and progress today is mainly in filling in and completing this outline; but the next great step must be through a better knowledge of the interior forces. This is just what geological science is waiting for today. Now the first step in this direction is a clear statement of the problems to be solved. The object of this address is to contribute something, however, small to such clear statement.

EFFECTS OF INTERIOR FORCES.

As the interior of the earth is inaccessible to direct observation, we can reason concerning interior forces only by observation of their effects on the surface. Now these effects, as usually treated, are of three main kinds: (1) Volcanoes, including all eruptions of material from the interior; (2) Earthquakes, including all sensible movements, great and small; (3) Gradual, slow movements affecting large areas, imperceptible to the senses, but accumulating through indefinite time.

It is certain that of these three the last is by far the most fundamental and important, being, indeed, the cause of the other two. Volcanoes and earthquakes, although so striking and conspicuous, are probably but occasional accidents in the slow march of these grander movements. It is only of these last, therefore, that we shall now speak.

KINDS AND GRADES OF EARTH-CRUST MOVEMENTS.

The movements of the earth's crust determined by interior forces are of four orders of greatness: (1) Those greatest, most extensive, and probably primitive movements by which oceanic basins and continental masses were first differentiated and afterward developed to their present condition; (2) Those movements by lateral thrust by which mountain ranges were formed and continued to grow until balanced by exterior erosive forces; (3) Certain movements, often over large areas, but not continuous in one direction, and therefore not indefinitely cumulative like the two preceding, but oscillatory, first in one direction, then in another, now upward and then downward; (4) Movements by gravitative readjustment, determined by transfer of load from one place to another. Perhaps this last does not belong strictly to pure interior or earth-derived forces. Nevertheless they are so important as modifying the effects of other movements and have so important a bearing on the interior condition of the earth that they cannot be omitted in this connection.

Now of these four kinds and grades of movement the first two are primary and continuous in the same direction, and therefore cumulative, until balanced by leveling agencies. The other two, on the contrary, are not necessarily continuous in the same direction, but oscillatory. They are, moreover, secondary, and are imposed on the other two or primary movements as modifying, obscuring, and often completely masking their effects. This important point will be brought out as we proceed. We will take up these movements successively in the order indicated above.

1. OCEAN BASIN-MAKING MOVEMENTS.

I have already given my views on this most fundamental question very briefly in my "Elements of Geology," a little more fully in my first paper, "Origin of Earth Features,"* and in my memoire of Dana.† I give it still more fully now.

We may assume that the earth was at one time an incandescent, fused spheroid of much greater dimensions than now, and that it gradually cooled, solidified, and contracted to its present form, condition, and size. Now if at the time of its solidification it had been perfectly homogeneous in composition, in density, and in conductivity in every part, then the cooling and contraction would have been equal on every radius, and it would have retained its perfect, evenly spheroidal form; but such absolute homogeneity in all parts of so large a body would be in the last degree improbable. If, then, over some large areas the matter of the earth were denser and more conductive than over other large areas, the former areas, by reason of their greater density alone, would sink below mean level and form hollows; for even in a solid—much more in a semi-liquid, as the earth was at that time—there must have been static equilibrium (*isostasy*) between such large areas. This would be the beginning of oceanic basins;

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*Am. Jour. Sci., 1872.

† Bull. Geol. Soc. Am., vol. 7, 1895, pp. 461–474.

but the inequalities from this cause alone would probably be very small but for the concurrence of another and much greater cause, viz, the greater conductivity of the same areas. Conductivity is not, indeed, strictly proportional to density; but in a general way it is so. It is certain, therefore, that the denser areas would be also the more conductive, and therefore the more rapidly cooling and contracting areas. This would again increase, and in this case progressively increase the depression of these areas. The two causes—density and conductivity, isostasy and contraction—would concur, but the latter would be far the greater, because indefinitely cumulative. The originally evenly spheroidal lithosphere would thus be deformed or distorted, and the distortion, fixed by solidification, would be continually increased until now. When the earth cooled sufficiently to precipitate atmospheric vapor the watery envelope thus formed would accumulate in the basins of the lithosphere and form oceans. It is possible and even probable that the depressions were at first so shallow that the primeval ocean may have been universal, but the process of greater downward contraction continuing, the ocean basins would have become deeper and the less contracted portions of the lithosphere would appear as land. The process still continuing, the land would grow higher and more extensive and the ocean basins deeper and less extended throughout all geological time. On the whole, in spite of many oscillations, with increase and decrease of land, to be spoken of later, and in spite, too, of exterior agencies by erosion and sedimentation tending constantly to counteract these effects, such has been, I believe, the fact throughout all geological history.

It is evident, also, that on this view, since the same causes which originally formed the ocean basins have continued to operate in the same places, the positions of these greatest inequalities of the lithosphere have not substantially changed. This is the doctrine of the permanency of oceanic basins and continental masses, first announced by Dana. Some modification of this idea will come up under another head.

The objection which may be—which has been—raised against this view is that such heterogeneity as is here supposed, in a fused mass and therefore in a mass solidified from a state of fusion, is highly improbable, not to say impossible. This objection, I believe, will disappear when we remember the very small differences in conductivity, and therefore in contraction, that we are here dealing with; small, I mean, in comparison with the size of the earth. This is evident when we consider the inequalities of the earth's surface. The mean depth of the ocean is about two and one-half miles; the mean height of the land, about one-third of a mile. The mean inequality of the lithosphere, therefore, is less than three miles. This is 1/1300 of the radius of the earth—less than 1/100 of an inch (an almost imperceptible quantity) in a globe two feet in diameter. I believe that a perfectly spheroidal ball of plastic clay allowed to dry, or even a spheroidal ball of red-hot copper allowed to cool, would show more deformation by contraction than the lithosphere of the earth in its present condition. It is true the inequalities are more accentuated in some places, especially on the margins of the continental areas; but this is due to another cause, mountain-making, to be taken up later.

Another objection will doubtless occur to the thoughtful geologist. It would seem at first sight on this view that ocean areas cooling most rapidly ought to be the first to form a solid crust, and the crust (if there be any interior liquid still remaining) ought to be thickest, and therefore least subject to volcanic activity, there; but, on the contrary, we find that this is just in these areas that volcanoes are most abundant and active. It is for this reason that Dana believed that land areas were the first and ocean areas the last to crust over. This is probably true; but a little reflection will show that these two facts, namely, the earlier crusting of the land areas and the more rapid cooling and contraction of the ocean areas, are not inconsistent with one another; for the more conductive and rapidly cooling areas would really be the last to crust, because surface solidification would be delayed by the easy transference of heat from below, while the less conductive land areas would certainly be the first to crust, because the non-conductivity of these areas would prevent the access of heat from below. Observation of lavas proves this. The most vesicular and non-conductive lavas area the soonest to crust, but for that very reason the slowest to cool to great depths.

No doubt many other objections may be raised, especially if we attempt to carry out the idea into detail; for the physical principles involved, and especially the conditions under which they acted, are far too complex and imperfectly understood to admit of such detail. It is safest, therefore, to confine ourselves to the most general statement.

It may be well to stop a moment to compare with the above view that of Dana, as interpreted and clearly present by Gilbert in 1893.* (1) According to this view, the earth is supposed to have first solidified at the center. This, on the whole, seems most probable. (2) The investing liquid, say from 50 to 100 miles thick, might well be supposed to arrange itself in layers of increasing density from the surface to the solid nucleus. Now suppose for any cause, less conductivity or other, certain areas crusted on the surface. These crusts would, of course, consist of the lighter superficial portions; but since rocks contract in the act of solidification,† these solidified crusts would sink to the nucleus and be replaced by similar lighter material flowing in from the surrounding surface, which in turn would solidify and sink. Thus would be built up from the nucleus below a solid mass consisting only of the superficial, lighter materials to form the land, while the denser and less rapidly crusting material would form the ocean areas. As in my view, therefore, the oceanic areas are the denser and the land areas the lighter material.

It is evident that, according to either view, but especially according to mine, the material of the ocean basin areas down to the center of the earth must be as much denser than the material of the land areas down to the center as the subocean radii are shorter than the subcontinental radii, and therefore that the two areas must be in perfect static equilibrium with one another. Thus in the formation of continents the claims of isostasy are completely satisfied. I say completely because this is not a partial equilibrium resisted by rigidity but enforced by pressure; it is original and without stress.

* Bull. Geol. Soc. Am., vol. 4, 1893, p. 179.
† King and Barus. Am. Jour. Sci., vol. 45, 1893, p. 1.

2. MOUNTAIN-MAKING MOVEMENTS.

I have so recently discussed this subject* that I shall have little more to say now. Mountain ranges are of two types, namely, the anticlinal or typical and the monoclinal or exceptional. The one are mountains of folded structure, determined by lateral thrust, the other of simpler structure and determined by unequal settling of great crust blocks. It is only of the former that I shall speak now. The other or monoclinal type will come up under another head.

It will not be questioned that mountain ranges of the first type are formed by lateral thrust, however much we may differ as to the cause of such thrust; nor will it be questioned that they are permanent features determined by continuous movement, however much they may be modified by other kinds of movement or reduced or even destroyed by subsequent erosion. I have placed them, therefore, among the effects of primary movements—that is, movements determined by causes affecting the whole earth. I have done so because until some more rational view shall be proposed I shall continue to hold that they are the effects of interior contraction concentrated upon certain lines of weakness of the crust and therefore of yielding to the lateral thrust thus generated. The reasons for, as well as the objections to, this view I have already on a previous occasion fully discussed. I wish now only to supplement what I have before said by some further criticisms of the most recent and, some think, the most potent objection to this contractional theory, namely, that derived from the supposed position of the "level of no strain."

It is admitted that the whole force of this objection is based on the extreme superficiality of this level, and that in its turn depends on the initial temperature of the incandescent earth and the time elapsed since it began to cool. Both these are admitted to be very uncertain. I have already discussed this in my previous paper and shall not repeat here; but, as recently shown by Davison,† there are still other elements, entirely left out of account in previous calculations, which must greatly affect the result, and these new elements all concur to place the level of no strain much deeper than previous calculations would make it.

* President's address, Am. Assoc. Adv. Sci., Madison meeting, 1893.
† Am. Jour. Sci., vol. 47, 1894, p. 480. Phil. Mag., vol. 41, 1896, p. 133.

These neglected elements are the following: (1) The earth increases in temperature as we go down. Now the coefficient of contraction increases with temperature. This would increase the depth of the level of no strain and also, of course, the amount of interior contraction and therefore the lateral thrust. (2) The conductivity increases with the temperature. This also would increase the rate of cooling and therefore of interior contraction. (3) The interior of the earth is more conductive not only on account of its greater temperature, but also on account of its greater density; and this would be true whether the greater density be due to increased pressure or to difference of material, as, for example, to greater abundance of unoxidized metals. (4) The materials of the interior, aside from greater temperature and density, have a higher coefficient of contraction. (5) The usual calculations go on the assumption that the initial temperature was uniform for all depths. It probably increased with the depth then as now. This would again increase in an important degree both the depth of the level of no strain and the amount of lateral thrust.

The final result reached by Davison is, that while according to the usual calculations the level of no strain may be only a little over two miles (2.17) below the surface, yet taking into account only the first element mentioned above, the depth of that level would be increased to nearly eight miles (7.79), and taking into account all the elements it would come out many times greater still. The general conclusion arrived at is that the objections to the contractional theory, based on the depth of the level of no strain, must be regarded as invalid.

3. OSCILLATORY MOVEMENTS.

The movements thus far considered are continuously progressive in one direction as long as they last. The resulting features are therefore permanent, except in so far as they may be modified by other movements or by degrading influences; but nothing is more certain that that besides these more steady movements there have been others of a more oscillatory character—that is, upward and downward—in the same place, affecting now smaller, now larger areas, and often many times repeated. These are the most common of all crust movements, and are shown everywhere and in all periods of the earth's history by unconformities of the stratified series. Every line of unconformity marks an old eroded land surface, and every conformable series of strata a sea bottom receiving sediments. We give but two striking examples of such oscillations.

The Colorado plateau was a sea bottom, continuously or nearly so, from the beginning of the Carboniferous to the end of the Cretaceous, and during that time received about 12,000 or 15,000 feet in thickness of sediments. During the whole of this time the area of the earth's crust was slowly sinking, and thus continually renewing the conditions of sedimentation. Why did it subside? At the end of the Cretaceous the same area began to rise. What change of conditions caused it now to rise? It has continued to rise until the present time, and is still rising. The whole amount of rise cannot be less than 20,000 feet; for if all the strata which has been removed by erosion were again restored, the highest portion of the arch which was sea bottom at the end of the Cretaceous would now be 20,000 feet high. This, however, is only the last oscillation of this area, for beneath the Carboniferous there are several unconformities showing several oscillations of the same kind in earlier periods. During the Devonian the area was land, for the Carboniferous rests unconformably on the Silurian. During the Silurian it was sea bottom, receiving sediments at that time. Beneath the Silurian there are two other unconformities showing similar oscillations. These earlier oscillations were probably as great as the one now going on, but we cannot measure them as we can the last.

Another striking example, still more recent and widespread, is the enormous oscillations of the Glacial period. It cannot be doubted that over very wide areas—several millions of square miles—there were at the time upward and downward movements of several thousand feet, and therefore producing enormous changes in physical geography and climate. What was the cause of these movements? They were doubles modified, as will be shown later, by other movements superimposed on them; but the causes of the latter must not be confounded with the former.

We have given only two striking examples, but they are really the commonest of all crustal movements. They are everywhere marked by unconformities of the strata; they are everywhere going on at the present time. In some places the sea is advancing on a subsiding land, in others a rising land is advancing on the sea. These movements are more conspicuous along coastlines, because the sea is a datum-level by which to measure them, but they affect equally the interior of continonts [*sic*], as shown by the behavior of the rivers, which seek their base level by erosion in a rising and by sedimentation in a sinking country.

Many theories have been advanced to explain these movements, especially of certain very local shoreline movements. In volcanic regions they have been attributed to rise or recession of the volcanic heat and consequent columnar expansion or contraction of the crust. On non-volcanic sedimentary shorelines elevation has been attributed by some to the rise of the interior heat of the earth and consequent expansion of the crust produced by the blanketing effect of sedimentary deposit, while others with more reason think that regions of heavy sedimentation sink under the increasing load of accumulating sediments; but it is evident that, while such theories may explain some local examples in volcanic regions and along some shorelines, they cannot explain subsidences in the interior of continents, much less the wider and more extensive movements spoken of above. We must look for some more general cause. What is it?

It must be confessed that the cause of these oscillatory movements is the most inexplicable problem in geology. Not the slightest glimmer of light has yet been shed on it. I bring forward the problem here, not to solve it, for I confess my inability, but to differentiate it from other problems, and especially to draw attention to these movements as modifying the effects of movements of the first kind, and often so greatly modifying them as to obscure the principle of the permanency of oceanic basins and continental areas, and even to cause many to deny its truth. Nearly all the changes in physical geography in geological times, with their consequent changes in climate and in the character and distribution of organic forms—in fact, nearly all the details of the history of the earth—have been determined by these oscillatory movements; but amid all these oscillatory changes, sometimes of enormous amount and extent, it is believed that the places of deep oceanic basins and of the continental masses, being determined by other and more primary causes, have remained substantially the same.

4. MOVEMENTS BY GRAVITATIVE READJUSTMENTS—ISOSTASY.

This very important principle which, though partially recognized by Herschell, was first clearly enunciated by Major Dutton under the name isostasy.* The principle may be briefly stated thus: In so large a mass as the earth whether liquid within or solid throughout, it matters not excess or deficit of weight over large areas cannot exist permanently. The earth must gradually yield fluidally or plastically until static equilibrium is established or nearly so. Thus continuous transfer of material from one place to another by erosion and sedimentation must be attended with sinking of the crust in loaded and rising of the crust in the unloaded area. In this way we may account for the sinking of the crust at the mouths of great rivers and the correlative rising of interior plateaus and nearly all great mountain regions observable at the present time. The same seems to have been true in all geological times, for it is obviously impossible that 40,000 feet of sediments could have accumulated in the Appalachian region in preparation for the Appalachian's birth unless there were continuous *pari passu* subsidence ever renewing the conditions of sedimentation.

Now there can be no doubt as to the value of this principle, but there is much doubt as to the extent of its application. The operation of exterior causes, such as transfer of load by erosion and sedimentation, are so comparatively simple and their effects so easily understood that we are tempted to push them beyond their legitimate domain, which in this case is to supplement and modify the more fundamental movements derived from interior causes. We are thus tempted to generalize too hastily and to conclude that all subsidence is due to weighting and all elevation to removal of weight. Probably this is a true cause, but not the main cause of such movements. Doubtless the proposition is true, but its converse is even much more so. It is certain that thick sediments may cause subsidence, but it is much more certain that subsidence, however determined, will cause continuous sedimentation by ever renewing the conditions of sedimentation. It is true that removal of weight by erosion will cause elevation, but it is more certain that elevation is the cause of removal of matter by erosion.

Take again the Plateau region as an example. We have seen that during the whole Carboniferous, Permian, Triassic, Jurassic, and Cretaceous times this region was subsiding, until at the end of the Cretaceous the earth's crust here had bent downward 12,000 or 15,000 feet. Shall we say it went down under the increasing load of sediments? Why, then, did it, from a previous land condition, ever commence to subside? And why, when the load was greatest, namely, at the end of the Cretaceous, did it begin to rise? Again, from that time to this it has risen 20,000 feet. Of this about 12,000 feet have been removed by erosion, leaving still 8,000 feet of elevation remaining. Now if this elevation be the result of removal of weight by erosion, how is it that a removal of 12,000 feet has caused an elevation of 20,000 feet? This result is natural enough, however, if elevation was the cause and erosion the effect, for the effect ought to lag behind the cause. It is evident, then, that we must look elsewhere—that is, in the interior of the earth—for the fundamental cause, although, indeed, the effects of this interior cause may be increased and continued by the addition and removal of weight.

But perhaps the best illustration of the distinctness of the two kinds of causes of these movements if found in the oscillations of the Quaternary period. I say best because in this case the effects of the two may be disentangled and viewed separately, and this in its turn is possible because the loading in this case is not by mere transfer from one place to another, and therefore is not correlated with unloading. In fact, the elevation in this case is associated with, and in spite of, loading. The elevation, as we all know, commenced in late Tertiary and culminated in early Glacial. This elevation was, at least, one cause, probably the main cause, of the cold and the ice accumulation, but the elevation continued in spite of the accumulating load of ice. Finally, however, the accumulating load prevailed over the elevating force and the previously rising area began to sink, but only because the interior elevator forces had commenced to die out. Then with the sinking commenced a moderation of the climate, melting of the ice, removal of the load, and consequent rising of the crust to the present condition, but far below the previous elevated condition, because the elevating forces, whatever these were, had in the meantime exhausted themselves. If it had not been for the interference of the ice-load, I suppose that instead of the double oscillation which actually occurred there would have been a simple curve of elevation coming down again to the present condition, but culminating a little later and rising a little higher than we actually find it did.

The question arises as to how great an area is necessary for the operation of the principle of isostasy? What extent and degree of inequality of surface may be upheld by earth rigidity alone?

The recent transcontinental gravitation-determinations by Putnam and their interpretation by Gilbert* seem to show a degree of rigidity greater than previously supposed. They seem to show that while the whole continental arch is certainly sustained by isostasy—that is, by deficiency of density below the sea level in that part, the continental area being lighter in proportion as it is higher—yet great mountain ranges like the Appalachian, Colorado, and Wasatch mountains show no such means of support, but are bodily upheld by earth rigidity; and even great plateaus like the Colorado plateau, 275 miles across, are largely though not entirely, sustained in the same way.

MONOCLINAL MOUNTAIN RANGES.

Until recently mountain ranges were supposed to be all made in one way, namely, by lateral crushing and strata-folding and bulging along the line of yielding. To Gilbert is due the credit of having first drawn attention to another type, conspicuously represented only in the Plateau and

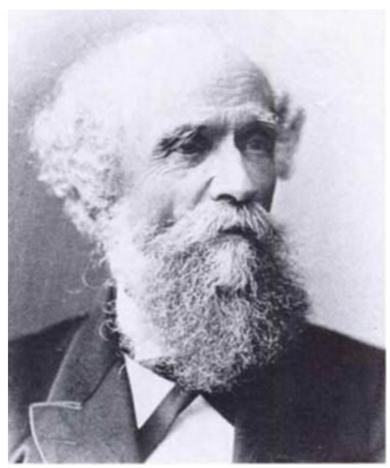
* Gilbert: Phil. Soc. Washington, vol. 13, 1895, p. 31. Gilbert: Jour. Geology, vol. 3, 1895, p. 331. O. Fisher: Nature, vol. 52, 1895, p. 433.

Basin region, especially the latter—that is, those produced by tilting and irregular settling of the crust blocks between great fissures. The two types of mountains are completely contrasted in all respects. As to form, the one is anticlinal, the other monoclinal. As to cause, the one is formed by lateral squeezing and strata folding, the other by lateral stretching, fracturing, block-tilting, and unequal settling. As to place of birth, the one is born of marginal sea bottoms, the other is formed in the land crust. Classified by form, we may regard the two types as belonging to the same grade of earth features, namely, mountain ranges; but classified by their generating forces, they belong to entirely different groups of earth movement. The one belongs to the second group mentioned above, the other to the third and fourth groups; for the plateau-lifting, crust-arching, and consequent tension and fracturing belong to the third group of oscillatory movements, but the mountain-making proper—that is, the subsequent block-tilting and unequal settling—belongs to the fourth group or isostasy, for that is wholly the result of isostatic readjustment and is one of the best illustrations of this principle. It shows on what comparatively small scale under favorable conditions (probably unstable foundation) the principle of isostasy may act.

It is evident, then, that it is impossible to exaggerate the distinction between these two types of mountains. They belong, as we have seen, to entirely different categories of interior forces, and, indeed, are not both mountains in the same sense at all. It was for this reason that in my paper on mountain structure* I put these latter in the category of mountain ridges instead of mountain ranges—of modification, not of formation. I now think it better to divide mountain ranges into two types, not forgetting, however, the very great distinction between them.

CONCLUSIONS.

To sum up, then, in a few words: There are two primary and permanent kinds of crust movements, namely, (*a*) those which give rise to those greatest inequalities of the earth surface—oceanic basins and continental surfaces; and (*b*) those which by interior contraction determine mountains of folded structure. These two are wholly determined by interior forces affecting the earth as a whole, the one by unequal radial contraction, the other by unequal concentric contraction—that is, contraction of the interior more than the exterior. There are also two secondary kinds of movement, which modify and often mask the effects of the other two and confuse our interpretation of them. These are (*c*) those oscillatory movements, often affecting large areas, which have been the commonest and most conspicuous of all movements in every geological period, and are, indeed, the only ones distinctly observable and measurable at the present time, but for which no adequate cause has been assigned and no tenable theory proposed; and (*d*) isostatic movements or gravitative readjustments, by transfer of load from place to place, by erosion and sedimentation, or else loading and unloading by ice accumulation and removal, and also by readjustment of great crust blocks. If the previous one (*c*) or oscillatory movements have masked and so obscured the effects of (*a*) continent and ocean basin-making, the last (*d*), isostasy, has concealed the effects and obscured the interpretation of all the others, but especially of (*b* and *c*) mountain making forces and the forces of oscillatory movements. In fact, in the minds of some recent writers it has well-nigh monopolized the whole field of crust movements. We shall not make secure progress until we keep these several kinds of movements and their causes distinct in our minds.



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* Am. Jour. Sci., vol. 16, 1878, p. 95.

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