such a height that actually trees 40 feet in height are sometimes buried to the tops. An analysis of the sand shows that it is very fertile when sufficiently irrigated, but the high winds absorb so much moisture that it is impossible for vegetation to take root in the dry season.

In fighting the sand sea, several methods of checking the movement of the sand have been tried, some of them with notable success. The first and most extensively used is the "sand panel." A panel consists of two boards, 1 inch thick by 12 inches wide, and about 20 feet long, nailed to sharp stakes at each end. The stakes are driven into the sand, so as to make the panel stand up with its length oblique to the wind, and the leeward end away from the track. The wind is thus made to carry the sand along the face of the boards and away from the track. While the wind is blowing hard, the panels must be closely watched, as they soon become undermined and fall down, or if not properly placed, are covered up. The second method can be used only where there is a considerable level space on the leeward side of the track. A vertical wall of inch boards from 10 feet to 20 feet high is built a few feet to windward of the track, with an opening of 3 feet or 4 feet at the bottom. The wind striking the wall is turned down, and passes with increased velocity through the opening at the bottom, carrying the sand with it, but soon loses its force on the lee side of the wall, and deposits the sand just across the track. From there it must be occasionally removed by teams or some other means.

A third method, invented by Mr. J. P. Newell, is a modification of the panel plan, but is intended to be of permanent construction. A tight wall from 10 feet to 16 feet high, composed of two planes, the upper inclined toward the wind and the lower away from it, it built between the track and the approaching sand drift. The upper plane deflects the air current strongly downward, and the lower one throws it out so that it cannot undermine the walls, but is turned against the sand bank. The wind is thus made to carry the sand along the wall to the end, which is located at some point where the natural features will prevent the sand from doing any harm. Such a wall has protected one of the worst places on the road for three years. The movement of the sand has also been partly obstructed by the planting of trees at right angles to the direction of the waves. The trees, which are of a variety which will take root in the formation, are usually set out in two rows separated by a bank of sand, but the formation about them must be artificially moistened to keep them from dying.

As the photographs show, however, there are places where apparently no protection is sufficient to keep the sand from covering the right-of-way. At one point where the track passes close to the wall of rock forming one side of the valley, a force of men and teams is almost constantly employed with shovels and scrapers as illustrated.

As far back as 1832 the people of Massachusetts realized the necessity of preventing the movement of sand dunes near some of the coast towns, to prevent the latter from being literally overwhelmed. The principal form of protection has been the planting of beach grass in places where the wind currents are not too violent to check its growth, keeping the dunes from forming. Some of the dunes have also been "fixed" after formation by planting the grass, then protecting it from the wind by covering the windward side of the hill with brushwood. On a fixed dune certain kinds of trees will grow to maturity. This is illustrated by the forests in New Jersey and Virginia, some of which extend almost to the water's edge. In these States, however, are places where the dunes have reached a height of over 100 feet, and have literally buried growths of large timber to such an extent, that only a few feet of the trees can be seen projecting from the sand here and there.

Near Cape Henry there are shifting dunes, which are gradually engulfing pine woodland in their rear, since this section of the coast is exposed to the severest

gales which sweep over the Atlantic in winter. One of the most notable illustrations of shifting dunes, however, is to be seen at Cape Henlopen, Delaware. Here the lighthouse, one of the highest towers on the seaboard, is nearly surrounded by a ridge of sand, which already reaches more than half way to the top.

and maintains it unchanged as long as the load does not change. The piece returns to its original length promptly when the load is removed. The piece is a competent structure under these loads.

As soon as a load is applied which is slightly beyond the elastic limit, the behavior of the piece is very

RAILROAD MEN FIGHTING THE SAND SEA IN OREGON. THE TRACK CAN BE SEEN TO THE LEFT PARTLY BURIED.

The resistance to the wind, however, has caused eddies, which have prevented the sand from closing in around the structure, except on one side. From Delaware Bay the size and height of the building can be appreciated, but looking at it from the southeast, from which come the principal winds, the tower appears to be only about 20 or 25 feet above the shore.

THE EARTH A FAILING STRUCTURE.*

By JOHN F. HAYFORD.

THE earth is a failing structure. Stresses are set up within it by many forces. It is yielding to those forces and is being deformed beyond its elastic limit. The yielding certainly occurs every year, and probably every day and every hour.

A competent structure may be defined as one which bears the stresses brought to bear upon it without permanent injury to itself. When a competent structure is unloaded it returns to its original shape and size by virtue of its elasticity. Its deformation while loaded is fixed by the elastic constants of the material. A steel bridge under normal conditions carrying safe loads is a good illustration of a competent structure. Under every additional pound of load applied it moves to a new position. It responds to every shifting of the loads upon it. Every motion is governed by the laws of elasticity. When the loads are removed, the bridge goes back accurately to its former shape and position, and is without any discoverable difference in any respect from its state before being loaded.

The characteristics of a failing structure may be best illustrated by the well-known behavior of a piece of bridge steel being tested to destruction, under tension, in a testing machine. Suppose that successively larger loads are applied and removed. In the earlier stages of the test, as long as the loads are within the elastic limit for that material, the elongation of the piece is proportional to the load and independent of the duration of the application of the load. Under each new load the piece takes a new length promptly

different. The elongation is no longer proportional to the load. It increases with the lapse of time under the load as long as the load is maintained. When the load is removed, the piece returns only part way to its original length. It has acquired a permanent set, a permanent deformation.

When a load much in excess of the elastic limit is applied, the stretching under the load is more rapid, and a new feature of the failure begins to appear. When the piece was a competent structure, the elastic elongation was distributed throughout the piece, following a perfectly regular law. When the piece is failing under loads slightly beyond the elastic limit, the stretching is somewhat irregularly distributed through the piece. When the loads are long-continued and much beyond the elastic limit, the stretching concentrates gradually at the immediate vicinity of the weakest point of the piece. The degree of concentration of the damage increases until, just before the complete failure occurs, practically all of the distortion is taking place in the immediate vicinity of the point at which the rupture is to take place.

There are two contrasts which it is important to keep in mind between the behavior of this failing test-piece and of failing structures generally, on the one hand, and the behavior of an elastic competent structure, on the other hand.

First, the yielding of an elastic competent structure is independent of the length of time the stresses are in action. It depends solely upon the elastic constants and the inertia of the material. The bridge engineer in designing his competent structure does not consider the length of time the loads are to be applied. On the other hand, the yielding of a failing structure increases with the lapse of time; it is very slow if the stresses are but little in excess of the elastic limit, and is faster the greater the excess of stress beyond the elastic limit. To predict the behavior of a failing structure, it is necessary to know how much the stresses exceed the elastic limit of the material and how long they continue to be beyond that point.

Second, in a competent structure the distribution of

* Read before the Philosophical Society of Washington.

SHIFTING DUNES BURYING A FOREST.

WOODLAND DESTROYED BY SAND.
SAND WAVES AND THEIR WORK

HOUSE BURIED IN THE SAND SEA.

the yielding or distortion does not change with increase of load or lapse of time. With double the load applied at a given point, every part of a competent bridge yields by a double amount. On the other hand, the distribution of the permanent yielding or distortion in a failing structure is continually changing. The damage tends more and more strongly to concentrate at the weakest point or points as failure progresses.

G. H. Darwin, in his classic paper entitled "On the Stresses Caused in the Interior of the Earth by the Weight of Continents and Mountains,"* has furnished a very good way of approaching the question, "Is the earth a failing structure?" He assumes that the earth is a competent elastic structure, and upon that assumption proceeds to compute the stresses which must exist in it, due to the weight of the continents and mountains. He assumes the earth to be homogeneous in its elastic properties from surface to center. The material forming and underlying the continents is assumed to be of the same density as the material beneath the oceans. The computation is made under a sufficiently complete theory of elastic deformation to take account of the support which each portion of the material in the earth obtains from all the surrounding material. It takes into account the transmission of stress, by compression and shear, through the solid sphere in every direction from the points of application of the forces.

The computation shows that continents of such dimensions and form as those which are now in existence would produce stress-differences as great as four tons per square inch at depths of from 600 to 1,000 miles. The stress-differences due to the weight of the continents would, according to the computation, decrease both downward and upward from a maximum value at a depth of from 600 to 1,000 miles, becoming zero at the center and approaching zero at the surface. The stress-difference at 70 miles below the surface, according to the computation, is about one ton per square inch.† The computation, based on the assumption stated, also shows that parallel mountain ranges of density 2.8, rising 13,000 feet above the intermediate valley-bottoms, would produce stress-differences of 2.6 tons per square inch.

The statement that the stress-difference is four tons per square inch at a given point within the earth means that at that point the compressive stress is four tons per square inch greater in the direction of maximum compressive stress at that point than it is at that point in the direction of minimum compressive stress. This form of statement eliminates any reference to the actual compressive stress in either direction. It is stress-difference which tends to deform and rupture the material, not hydrostatic pressure. A stress-difference of four tons per square inch corresponds in its effect to a compression of four tons per square inch applied to two faces of a cube in a testing machine while the other four faces of the cube are left free from pressure.

Darwin's conclusion, as stated in his paper, is that since such continents exist, since they do not sink down, or the sea bed rise up, the materials composing the earth are strong enough to bear the computed stresses. For example, he writes: "From this discussion it appears that if the earth be solid throughout, then at a thousand miles from the surface the material must be as strong as granite." He states in a table the breaking stress-difference in granite to be from 2.45 to 4.91 tons per square inch.

Let us take Darwin's computations, and reason from them in another way. Instead of deducing from the computations the strength of the materials composing the earth, let us take some of the known facts as to the behavior of materials under stress at the surface of the earth, and endeavor to estimate whether the material composing the earth probably would bear, without permanent deformation, the stresses brought to bear upon it by the continents and mountain ranges.

When the subject is approached from this point of view, at least six reasons appear for believing that the material would undergo permanent deformation:

1. It may be doubted whether even granite will stand for geologic ages, without permanent deformation, a stress-difference as large as four tons per square inch. This is the breaking stress-difference of a good granite, according to the figure given by Darwin. All materials begin to suffer permanent deformation at an elastic limit considerably less than the stress-difference necessary to break them. The longer the period of application of the stresses, the farther the effective elastic limit falls below the breaking stress-difference. In the case in hand the stresses exist continuously for geologic ages. A standard authority on engineering practice gives the safe working load for granite masonry at 30 tons per square foot, or one-fifth of a ton per square inch, and states that this is about the maximum in existing structures. According to Darwin, the material within the earth must stand for geologic

ages a stress-difference of four tons per square inch—twenty times as great as the safe load prescribed by engineers for granite—or it must fail.

2. Granite is one of the strongest of the materials found abundantly in the accessible part of the earth's crust. One may well doubt whether the heterogeneous mixture composing the crust is as strong on an average as continuous good granite.

3. Failure—that is, permanent deformation—at any point tends to concentrate further failure at and near that point. The heterogeneous mixture of material composing the earth probably has many spots of weakness in it which will tend to cause failure long before the stronger material gives way. The stress-differences at which failure will commence therefore depend upon the strength at the exceptionally weak spots in the material rather than upon the average strength of the material.

4. The materials composing the earth's crust, except those near the surface, are subjected to high temperatures, which tend to reduce their strength. The temperature at 70 miles below the surface probably exceeds 1,900 deg. C.—above the melting point of iron and many other materials, under surface conditions.

5. It is stated in Darwin's paper that one at least of the assumptions is such as probably to make the computed stresses smaller than the fact.* The speaker believes that there are other implicit assumptions, to which no attention is clearly called in the paper, which also tend to make the stresses computed by Darwin too small. For example, Darwin has dealt with a hypothetical continent represented by a regular mathematical form. His hypothetical continent resembles, as he states, an actual continent after its irregularities have been supposed smoothed out by leveling down the mountains and filling in the valleys. The stresses due to such a hypothetical smoothed-out continent are less than those due to an actual irregular continent. He has also computed the stress-differences due to ranges of mountains not much greater than some of the actual ranges which exist on the continents and has found the stress-differences nearly two-thirds as large as those due to the smoothed-out continents. In nature the two sets of stresses, those due to smoothed-out continents as a whole and those due to separate mountain ranges, exist at the same time in combination. The stresses are not in general combined by a mere algebraic addition. Nevertheless the combined stress-difference due to both at any one point is in general larger than the stress-difference due to either one alone.

6. As stated in Darwin's paper itself, if the earth is not solid throughout, if the outer solid crust is less than two or three hundred miles thick, the stress-difference must be much greater at some points within the crust than the value computed by him, namely, four tons per square inch. Now, in so far as any effect on the stresses above that depth is concerned, the part of the earth below a given depth is an exact equivalent of a liquid, if at that depth hydrostatic equilibrium exists—that is, if the pressure in all three directions is the same at each point at that depth. Now, many different men, reasoning from various points of view, have each reached the conclusion that a liquid condition, or its equivalent in the sense just indicated, is reached at a depth less than 200 miles.

For all these reasons, then, it appears probable that under the stress-differences within the earth due to the weight of the continents and mountains, the material must slowly yield, the continents slowly sink downward, and the ocean bottoms rise.

One apparently invincible argument against this conclusion is thus stated in Darwin's paper: "The interior of the earth must be in a state of stress, and as the land does not sink in, nor the sea bed rise up, the materials of which the earth is made must be strong enough to bear this stress." But the premise of this argument ignores the overwhelming mass of evidence accumulated by the geologists, that large portions of the present surface of each continent have at some time been at or below sea-level. Changes in elevation in the material composing the continents are put in evidence everywhere by geologic structure and topographic forms. The continents are in the habit of sinking and rising. We must therefore draw the conclusion, apparently contradictory to Darwin's, that the materials of which the earth is made are not strong enough to bear the stresses to which they are subjected.

This conclusion is not necessarily contradictory to Darwin's conclusion, for the reason that the stresses which cause the continents to rise and fall may be due to some other cause than gravity.

The principal conclusion reached from Darwin's paper, as supplemented, is that if the material forming and underlying the continents is of the same density as the material beneath the oceans, the earth is probably a failing structure; that it is slowly yield-

ing under the stresses, the continents sinking and the ocean beds rising. Please note that, on this evidence alone, the yielding is stated to be a probability, not a certainty. Because of the uncertainty, it is desirable to examine all available lines of evidence.

The theory that there exists in the earth the state of approximate equilibrium called isostasy has an important bearing upon Darwin's paper. According to the theory of isostasy, the material forming and underlying the continents is less dense than that under the oceans, whereas in Darwin's computations the densities were assumed to be the same. Pendulum observations have long been known to indicate that isostasy exists. The originator of the word "isostasy," C. E. Dutton, based his belief in isostasy on geologic evidence and pendulum observations.* Other geologists have considered that the evidence before them indicates isostatic readjustment to have occurred. I have elsewhere presented some of the geodetic evidence which proves that, at least for the United States, there is a rather close approach to the isostatic conditions.†

To the extent that it is proved that isostasy exists, that the continents are lighter, and the ocean beds denser than assumed by Darwin, it is also proved that the stresses within the earth are less than his computations would make them. At first sight, apparently, it is also proved that there is decreased reason for supposing the earth to be a failing structure; but further consideration of the evidence in regard to isostasy, combined with geologic evidence, as indicated in the following paragraph, shows that, instead of concluding that the stresses are small, and that therefore the earth is not failing, we should conclude that the earth is failing under stresses even smaller than those we had believed to exist; that the earth is weaker than we had supposed.

The geologic evidence is overwhelming that within the interval of time covered by the geologic record many thousands of feet of thickness have been eroded from some parts of the earth and have been transported to and deposited upon other parts. If isostatic readjustment had not also been in progress during this interval, it would be impossible for the isostatic compensation to be so nearly complete as it is now known to be in and around the United States. By isostatic compensation is meant the compensation of the excess of matter at the surface (mountains, continents) by defect of density below, and of surface defect of matter (valleys, oceans) by excess of density below. Isostatic readjustment can only take place in two ways: It may take place by actual transfer of material beneath the surface. It may take place by change of density of matter without transfer of that particular matter—that is, by increase or decrease in volume of given masses. In either of these cases, or in any combination of them, there is permanent deformation of the material, a yielding to applied stresses, and we are led again to the idea that the earth is a failing structure.

If the earth is now and has long been a failing structure, the material accessible at its surface should bear the evidence of that fact in recognizable form, just as the twisted mass of steel on the bank of the St. Lawrence bears in itself easily recognizable evidence that a bridge has failed near Quebec. The material composing the earth's surface does bear the evidence, and the evidence has been described by thousands of men. If one consults the literature of geology, and especially that portion of it which sets forth directly the facts which have been observed, rather than the generalizations from them, he finds everywhere descriptions of faulting, of warping of strata, of folding of strata, of overthrusts, of intrusions, of vulcanism, of uplift, of subsidence. All these are evidence of past failure, of permanent non-elastic yielding to applied stresses. The only parts of the earth's outer crust where such evidence has not been found are apparently the parts of the land surface in which there has been little or no geological exploration, and the ocean bottom, where the evidence would be extremely difficult to detect.

Moreover, the geologic evidence shows that these yieldings have occurred at various epochs throughout the whole interval of time covered by the geologic record written in the rocks, and that the yielding, at least in some cases, has been gradual rather than sudden. In whatever area on any continent a geologist works he finds this evidence, and, so far as I am able to judge, it appears that the more a given area is studied, the more conclusive is the evidence that permanent deformation under stress has there taken place. Just as the geologist who studies cubic miles of the earth finds abundant evidence of past failure, so also does the geologist who studies cubic

* Philosophical Transactions of the Royal Society of London, vol. 173, 1882, pages 187-230.

† Scaled from Fig. 6, plate 20, of Darwin's paper.

* C. E. Dutton: "On Some of the Greater Problems of Geology." Bulletin of the Philosophical Society of Washington, vol. xi., pp. 51-64.

† John F. Hayford: "The Geodetic Evidence of Isostasy." Proceedings of Washington Academy of Sciences, vol. viii., 1906, pp. 25-40; and also "Geodetic Operations in the United States, 1903-06," a Report to the Fifteenth General Conference of the International Geodetic Association, by O. H. Tittmann and John F. Hayford.

millimeters of rock under the microscope find similar evidence in the structure of the rock.

One of the characteristics of a failing structure is that where failure begins, there later damage tends to concentrate. The point of initial failure in the Quebec Bridge was first located mainly by noting that two of the main members of the bridge had suffered much more distortion than the others. So, if the earth is a failing structure, we should expect to find indications that progressive and concentrated failure has occurred at some places rather than that the failure has been uniform in degree in all parts. Such indications exist and have frequently been recognized and commented upon. It is recognized by geologists generally that there are regions of excessive deformation, as if some incipient weakness had concentrated failure there, and that there are other regions in which the deformations have been moderate in amount, as if those were regions of more than average strength in a failing structure. Where mountain-building commences, there it tends to continue for a long time, though not, perhaps, for an indefinite time. Ocean bottoms and great plains apparently tend to remain ocean bottoms and plains.

The motions at the earth's surface due to earthquakes, which are detected by seismographs, are vibrations of small amplitude, having periods of a few seconds, as a rule. The fact that these vibrations persist for a considerable time, for minutes or hours, and that they not infrequently travel all the way around the earth, and at least part of a second trip, show that, under these particular applied forces, the earth acts as a highly elastic body. The observed rate of propagation of the wave, combined with the known density of the material through which the wave is propagated, enables one to compute the rigidity. Such computations have been made. But the rigidity is simply the relation between the applied force and the distortion produced. It is the stiffness. Such computations furnish no information in regard to strength. As soon as one considers the stresses involved, at points remote from the source of an earthquake, it is evident that they are insignificant as compared with the elastic limit of the material.

I conceive the earth to be a failing structure, slowly yielding to the forces acting upon it. I conceive that, at the source of an earthquake, stresses having accumulated to the breaking limit, a fracture occurs, and there is sudden movement, causing, as a rule, various other fractures at near points. From all these points of fracture elastic vibrations start out in every direction, and progress until they die out on account of internal friction; and this may not be until the vibrations have traversed the whole earth. This conception of elastic vibrations traversing a failing earth, which is at the same time slowly yielding in a non-elastic manner to other stresses, contains an apparent contradiction which is, however, not real.

It is not uncommon nor mysterious for a mass of material to respond with elastic vibrations to suddenly applied forces, while at the same instant it is yielding in a non-elastic manner to forces applied steadily without change of direction. A large mass of cold pitch will resist a light blow of a hammer, while at the same instant it is slowly yielding and flowing under the comparatively small stresses due to its own weight.

In the deep copper mines of the northern peninsula of Michigan the behavior of the whole earth, with respect to earthquakes and stresses due to other causes, is well illustrated on a small scale. At certain times during each day blasts are set off in the solid rock at various places in each mine. Each battery of blasts is a miniature earthquake. In that particular spot, the earthquake center, the rock is fractured within a space limited by a radius of a few feet. Within a large space, limited by a radius of a few hundred feet, elastic vibrations are set up in the solid rock which are sufficiently violent to be perceptible to the touch and to the hearing. Within this larger space no fracture of the rock occurs. Feebler vibrations doubtless extend out for miles from the point of fracture, just as vibrations extend over the whole earth from an earthquake center. Now it also happens that in the lower levels of these deep mines, at a mile below the surface of the earth, the solid rock is slowly yielding, in a non-elastic manner, under the influence of the great weight above it, so that the larger openings are gradually closing up. This is so clearly recognized and progresses so rapidly that it is proposed as routine practice,* at the deep levels in these mines, to take out the ore at the distant end of each drift first. The miners will then work back slowly toward the shaft from which the drift is entered, while the spaces in which they have recently labored gradually close up behind them. The gradual collapse known to be in progress occurs apparently by imperceptible flow and by minor fracturing, but not, as a rule, by catastrophes which close up any opening suddenly. In this respect it is an epitome of what is

taking place every year in the failing earth as it yields under such stresses, due to gravity and other causes, as are applied for long periods without changes of sign. The solid rock near each large opening in the mine responds to every blast in the mine by elastic vibrations; and yet, at the same instant, that same rock is yielding in a non-elastic manner to the stresses due to gravity.

It is not necessary to go a mile below the surface of the earth to find non-elastic slow yielding. It is commonly known to miners working in mines of ordinary depth.

Each earthquake is evidence that at a particular point or region at that particular time the earth is failing. As the sensitive seismographs now in operation show that there are hundreds of earthquakes each year, the sum total of such failure is not small. But I repeat that the observations of earthquakes furnish little or no evidence of the absolute strength of the earth; for in or near each earthquake center, where the test of strength occurs, no accurate observations are ordinarily secured. Outside the region in which the test of strength takes place, seismographs secure a record of the elastic vibrations, and thus secure evidence as to the earth's rigidity—its stiffness, but not its strength. If the elastic vibrations were recorded by a seismograph so close to an earthquake center that the stresses during the vibration approached the breaking limit, then some information as to the strength might be secured; but such a fortunately located seismograph is so badly shaken that it furnishes no readable record.

If the earth is a failing structure; if throughout considerable portions of its mass the stress-differences are so great that the material is yielding in a non-elastic manner, or is about to yield in that way, if the sudden motions at earthquake centers are examples of such yielding, and if such stress-differences are due to the weight of the continents, or to other causes which act for geological ages with but little change, then we would find that earthquakes are more frequent at times when stresses due to other than these secular causes are greatest, and less frequent when the temporary stresses are least. According to the conception I have put before you, the earth is like a revolver with a hair-trigger. Just as a slight touch on the hair-trigger will discharge the revolver, so slightly unusual stresses in the earth should tend to produce earthquakes. This is apparently the fact. Omori, the Japanese earthquake expert, states that several such relations exist.* At times of high barometric pressure earthquakes of land origin are unusually numerous. Earthquakes are more frequent when the earth and moon are in certain relative positions than at other times, the unusual stresses being produced by the weight of the water concerned in tidal movements. More earthquakes occur in years when the range of variation of latitude is great than in years when the range is small, and Omori states that "all of the destructive earthquakes of recent years in Japan occurred exactly or very nearly when the latitude (at Tokyo) was at a maximum or minimum." The variation of the pole of the earth from its mean value—that is, the variation of the pole of the earth from its mean position—causes small unusual stresses in the earth.

Such relations of earthquakes to other phenomena indicate that the earth is now a failing structure.

It is important for various reasons to know whether the earth is a failing structure, and to what extent it is failing.

Curiously enough, in so far as our personal safety is concerned, the weaker the structure the safer we are. On a very weak earth continuously failing the changes in elevation are so slow that we have plenty of time, as a rule, to move back when the sea encroaches upon the land, and we are seldom shaken so severely by earthquakes as to disturb our comfort. If the earth were stronger the stresses would accumulate for a longer time and to a greater intensity before failure took place; but when failure took place it would be much more apt to bring disaster, by violent shocks and large changes of elevation; therefore the more firmly you are convinced that the earth is so weak as to be failing continuously, the safer you should feel.

It is important to know whether the earth is a failing structure or not, because such knowledge is necessary to a true understanding of many of the phenomena observed upon the earth. For example, it is a standard idea of the text-books, and indeed of many of the specialists in earth sciences, that the flattening of the earth at the poles, its ellipticity, indicates that it was formerly a liquid earth, or is now a liquid earth with a thin crust. If the solid earth is a failing structure in the sense and to the extent that I believe it to be, said standard idea is nonsense.

To those who are endeavoring to make progress in the study of the earth, it is especially important to

know the true answer to the question, "Is the earth a failing structure?"

If the answer is "No"; if the earth is, in the main, a competent elastic structure, subject only to minor and local failure, then future progress will be made largely by the elasticians, by those who study the earth as an elastic structure, as did Darwin, for example, in the investigation frequently referred to to-night.

On the other hand, if the true answer is "Yes"; if the earth as a whole is a failing structure, failing frequently or continuously, failing in many parts; if failure is the rule rather than the exception, then future progress in studying the earth is reasonably certain to be made mainly by investigating the manner of failure. These investigations cannot be effectively made by mathematics applied to the laws of elasticity. The elasticians may furnish rough guides, may indicate limits approached but not reached; but the real progress will be made by those who study the non-elastic behavior of the materials composing the earth; by those who study the behavior of the material at the regions of failure; who study its mode of fracture and of flow as it fails; who study the relations between stresses and microscopic structure; between pressure and density; between stresses and chemical condition; between stresses and solution and redeposition; between pressure and the change of state, as between the gaseous, liquid, and solid conditions; between possible stresses in the material and its temperature; between stresses and the growth of crystals.

ELECTRIC CULTURE OF PLANTS.*

At a recent meeting of the Royal Botanic Society, in London, Mr. B. H. Thwaite read a paper describing the new experimental installation which he has carried out at the Royal Botanic Gardens, Regent's Park. The author divided the early workers on this subject into those who utilized the effects of the arc light on the leaves of plants, and those who applied electrostatic stimuli to the plant and to the roots and stalks, in association with solar light; he then briefly summarized the results of their investigations, and explained the function of chlorophyll in the transformation of inorganic matter into organic products under the influence of light of suitable quality.

While it may be broadly suggested in the direction of restoring minerals back from their organic state or association to their mineral state, solar electric energy appears to be directed to the conversion of minerals into constituent elements, making up organic compounds necessary for the generation or creation of organic (animal and vegetable) activity summarized by the expression Life.

If a near imitation of natural forces is to be secured for the artificial cultivation of plants and independently of the sun or weather, the following agents must be assembled and harnessed for the common object: (a) An ample supply of violet or chemically active rays projected from powerful arc lights. (b) A supply of electrostatic current for atmospheric and root electrification. (c) The plant environment of an atmosphere containing moisture and CO₂ in the proportions common to the most fertile countries, and at temperatures within the limits of 70 deg. F. and 80 deg. F. (d) An ideal fertilizing agent. (e) An ample supply of water for the roots.

The system of electric culture about to be put to a practical test is designed to produce the condition specified, on a sufficiently large scale. The necessary heat and actinic light, as well as the carbon dioxide, moisture and nitrogen fertilizer in the form of ammonia sulphate, are to be derived from coal; "on the perfection of the combustion of the coal or fuel used depends the entire economy of the system," and this perfection can only be secured by converting the carbon into a gaseous condition.

These conditions are fulfilled by the employment of a suction gas producer and gas engine, whereby perfect combustion is attained simultaneously with the development of power, which is converted into electrical energy. The heat absorbed by the cooling water in the cylinder jacket is utilized for the purpose of heating the air in the glass house by means of circulating pipes, and the heat carried off in the exhaust gases is similarly employed by leading them, after purification, through earthenware junction pipes into the glass house, with outlets at suitable points, so that at the same time, carbon dioxide, water vapor, oxygen, and nitrogen are supplied in a heated condition to the plants, with suitable regulating devices at the points of outlet or discharge.

The author divides the heat energy of the coal as follows: 30 per cent to power production, 30 per cent to jacket water, and 30 per cent to waste gases for heating purposes, the balance of 10 per cent being absorbed in generating the gas and in dissociating the water introduced into the producer into hydrogen and oxygen, which afterward recombine and pass with the

* F. W. McNair: "Some Problems Connected with Deep Mining in the Lake Superior Copper District." *Science*, January 4, 1907, pp. 13-18.

* Publications of the Astronomical Society of the Pacific, vol. xviii., No. 109, August 10, 1906, pp. 235-241.

* Abstracted from the *Electrical Review*.