SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

FRIDAY, OCTOBER 25, 1907

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ADDRESS OF THE PRESIDENT OF THE MATHEMATICAL AND PHYSICAL SEC-TION OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE ¹

I PROPOSE to use the opportunity afforded by this address to explain a dynamical theory of the shape of the earth, or, in other words, of the origin of continents and oceans.

The theory which has for more than a century been associated with the phrase "the figure of the earth" is the theory of the shape of the surface of the ocean. Apart from waves and currents, this surface is determined by the condition that there is no up and down upon it. This condition does not mean that the surface is everywhere at the same distance from the center of the earth, or even that it is everywhere convex, but that a body moving upon it neither rises against, nor falls in the direction of, gravity (modified by the rotation). A surface which has this character is called an equipotential surface, and the surface of the ocean coincides with part of an equipotential surface under gravity modified by the rotation. This particular equipotential surface runs underground beneath the continents. It is named the "geoid." The height of a place above sealevel means its height above the geoid. If we knew the distribution of density of the matter within the earth it would be a mathematical problem to determine the form of the geoid. As we do not know this distri-

¹ Leicester, 1907.

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bution we have recourse to an indirect means of investigation, and the chief instrument of research is the pendulum. The time of vibration of a pendulum varies with the place where it is swung, and from the observed times we deduce the values of gravity at the various places, and it was shown many years ago by Stokes that the shape of the geoid can be inferred from the variation of gravity over the surface.

The question to which I wish to invite your attention is a different one. If the ocean could be dried up, the earth would still have a shape. What shape would it be? Why should the earth have that shape rather than some other? In order to describe the shape we may imagine that we try to make a model of it. If we could begin with a model of the geoid we should have to attach additional material over the parts representing land and to remove some material over the parts representing Our model would have to be as big sea. as a battleship if the elevations and depressions were to be as much as three or four inches. In thinking out the construction of such a model we could not fail to be impressed by certain general features of the distribution of continent and ocean, and we may examine a map to discover such fea-



tures. Fig. 1 is a rough map of the world drawn in such a way that to every degree of latitude or of longitude there corresponds the same distance on the map. Certain very prominent features have often

been remarked: the tapering of America and Africa towards the south, the disproportion between the land areas of the northern and southern hemispheres, the excess of the oceanic area above the continental area, which occupies but little more than one quarter of the surface: the wide extent of the Pacific Ocean, which with the adjoining parts of the Southern Ocean covers nearly two fifths of the surface. Another prominent feature is the antipodal position of continent and ocean. South America south of an irregular line which runs from a point near Lake Titicaca to Buenos Ayres is antipodal to a portion of Asia which lies in an irregular triangle with corners near Bangkok, Kiaochau and Lake Baikal; but no other considerable parts of the continental system have continental antipodes. The Antarctic continent is antipodal to the Arctic Ocean, Australia is antipodal to the central Atlantic, and so on. Another notable feature is the skew position of South America to the east of North America; South America lies to the east of the meridian 85° west of Greenwich; most of North America lies to the west of it. But, although we may observe prominent general features of the distribution, we should find it far from easy to attribute to the form of our imaginary model anything that could be called a regular geometrical figure. When we begin to think about the removal of material from the parts of the model which are to represent oceans and seas, we require a map which gives information about the depth of the sea in different places. Around all the coasts there is a margin of not very deep water. If some part of the sea could be dried up, so that more land was exposed around all the coasts, the area of the surface of the sea would be diminished; and it is known that the depth of water that would have to be removed in

order to make the area of the sea just half the total area, is about 1,400 fathoms. The contour-line at this depth would divide the surface into two regions of approximately equal area—the continental region and the oceanic region. Fig. 2 represents the con-



tour-line at 1,400 fathoms, or the line of separation of the continental and oceanic regions. The continental region is shaded. In drawing this map I have omitted a number of small islands, and I have also omitted a few enclosed patches of deep water. Two of these are in the Mediterranean, one in the Arctic Ocean, and others are in the Gulf of Mexico and the Carib-The Red Sea, the Mediterbean Sea. ranean, and the Arctic Ocean belong to the continental region, and so do the Gulf of Mexico and the Caribbean Sea. At this depth Asia and North America are joined across Behring's Strait, and Europe is joined to North America across the British Isles, Iceland, and Greenland; Australia is joined to Asia through Borneo and New Guinea, and the Australasian continental region nearly reaches the Antarctic region by way of New Zealand. At this depth also South America does not taper to the south, but spreads out, and is separated from the Antarctic region by a very narrow channel. By going down to great depths our problem is very much simplified. We find that the surface of the earth can be divided into continental and oceanic regions of approximately equal area by a

curve which approaches a regular geometrical shape. By smoothing away the irregularities we obtain the curve shown in Fig. 3, which exhibits the surface as divided up into a continuous continental region and two oceanic regions—the basin



of the Pacific Ocean and the basin of the Atlantic and Indian Oceans. We may take our problem to be this: to account on dynamical grounds for the separation of the surface into a continental region and two oceanic regions which are approximately of this shape.

The key of the problem was put into our hands four years ago by Jeans in his theory of gravitational instability. If there are any differences of density in different parts of a gravitating body, the denser parts attract with a greater force than the rarer parts, and thus more and more of the mass tends to be drawn towards the parts where the density is in excess, and away from the parts where it is in defect. In every gravitating system there is a tendency to instability. In a body of planetary dimensions this tendency, if it were not checked, would result in a concentration of the mass either towards the center or towards some other part. But concentration of the mass means compression of the material, and it can not proceed very far without being checked by the resistance which the material offers to compression. There ensues a sort of competition between two agencies: gravitation, making for instability, and the

elastic resistance to compression, making for stability. Such competing agencies are familiar in other questions concerning the stability of deformable bodies. A long thin bar set up on end tends to bend under its own weight. A steel knitting-needle a foot long can stand up; a piece of thin paper of the same length would bend over. In order that a body may be stable in an assigned configuration there must be some relation between the forces which make for instability, the size of the body, and the resistance which it offers to changes of size and shape. In the case of a gravitating planet we may inquire how small its resistance to compression must be in order that it may be unstable, and, further, in respect of what types of displacement the instability would manifest itself. If we assign the constitution of the planet, the inquiry becomes a definite mathematical problem. The greatest difficulty in the problem arises from the enormous stresses which are developed within such a body as the earth by the mutual gravitation of its parts. The earth is in a state which is described technically as a state of "initial stress." In the ordinary theory of the mechanics of deformable bodies a body is taken to be strained or deformed when there is any stress in it, and the strain is taken to be proportional to the stress. This method amounts to measuring the strain or deformation from an ideal state of zero stress. If the ideal state is unattainable without rupture or permanent set or overstrain, the body is in a state of initial stress. The commonest example is a golf-ball made of india rubber tightly wound at a high tension. Now the problem of gravitational instability can be solved for a planet of the size of the earth on the suppositions that the density is uniform and the initial stress is hydrostatic pressure. If the resistance to compression is sufficiently small the body

is unstable, both as regards concentration of mass towards the center and as regards displacements by which the density is increased in one hemisphere and diminished in the other. A planetary body of sufficiently small resistance to compression could not exist in the form of a homogeneous sphere. It could exist in a state in which the surface is very nearly spherical, and the mass is arranged in a continuous series of nearly spherical thin sheets, each of constant density; but these sheets would not be concentric. They would be crowded together towards one side and spaced out on the opposite side somewhat in the man-



ner shown in Fig. 4. The effect would be a displacement of the center of gravity away from the center of figure towards the side where the sheets are crowded together. How small must the resistance to compression be in order that this state may be assumed by the body instead of a homogeneous state? The answer is that, if the body has the same size and mass as the earth, the material must be as compressible as granite. Granite, as we know it at the earth's surface, is not a typically compressible material. A cube of granite 10 feet every way could be compressed from its volume of 1,000 cubic feet to a volume of 999 cubic feet by pressure applied to every part of its surface; but according to the recent measurements of Adams and Coker the pressure would have to be rather more than two tons per square inch. homogeneous sphere of the same size and

mass as the earth, made of a material as nearly incompressible as granite, could not exist; it would be gravitationally unstable. The body would take up some such state of aggregation as that illustrated in Fig. 4, and its center of gravity would have an eccentric position.

Now how would an ocean rest on a gravitating sphere of which the center of gravity does not coincide with the center of figure? Its surface would be a sphere with its center at the center of gravity (Fig. 5). The oceanic region would be on one side of the sphere and the continental region on the other side. It was pointed out many years ago by Pratt that the existence of the Pacific Ocean shows that the center of gravity of the earth does not coincide with the center of figure. There is no necessity to invoke some great catastrophe to account for the existence of the Pacific Ocean, or to think of it as a kind of pit or scar on the surface of the earth. The Pacific Ocean resembles nothing so much as a drop of water adhering to a The force that keeps the greasy shot. drop in position is surface tension. The force that keeps the Pacific Ocean on one side of the earth is gravity, directed more towards the center of gravity than the center of figure. An adequate cause for the eccentric position of the center of gravity is found in the necessary state of aggregation which the earth must have had if at one time it was as compressible as granite. The theory of gravitational instability accounts for the existence of the Pacific Ocean.

But we can go much farther than this in the direction of accounting for the continental and oceanic regions. We keep in mind the eccentric position of the center of gravity, and try to discover the effect of rotation upon a planet of which the center of gravity does not coincide with

the center of figure. The shape of a rotating planet must be nearly an oblate spheroid; but the figure of the ocean would, owing to its greater mobility, be rather more protuberant at the equator than the figure of the planet on which it rests. The primary effect of the rotation of the earth upon the distribution of continent and ocean is to draw the ocean towards the equator, so as to tend to expose the arctic and antarctic regions. We have seen that both arctic and antarctic are parts of the continental region. But there is an important secondary effect. Under the influence of the rotation the parts of greater density tend to recede further from the axis than the parts of less density. If the density is greater in one hemispheroid than in the other, so that the position of the center of gravity is eccentric, the effect must be to produce a sort of furrowed surface; and the amount of elevation and depression so produced can be described by an exact mathematical formula. It has been proved that this formula is the sort of expression which mathematicians name a spherical harmonic of the third degree.

The shape of the earth is also influenced by another circumstance. We know that at one time the moon was much nearer to the earth than it is now, and that the two bodies once rotated about their common center of gravity almost as a single rigid system. The month was nearly as short as the day, and the moon was nearly fixed in the sky. The earth must then have been drawn out towards the moon, so that its surface was more nearly an ellipsoid with three unequal axes than it is now. The primary effect of the ellipsoidal condition upon the distribution of continent and ocean would be to raise the surface above the ocean near the opposite extremities of the greatest diameter of the equator. But, again, owing to the eccentric position of the center of gravity, there would be an important secondary effect. The gravitational attraction of an ellipsoid differs from that of a sphere, and it may be represented as the attraction of a sphere together with an additional attraction. If the density was greater in one hemi-ellipsoid than in the other, the additional attraction would produce a greater effect in the parts where the density was in excess, and the result, just as in the case of rotation, would be a furrowing of the surface. It has been proved that the formula for this furrowing also is expressed by a spherical harmonic of the third degree.

We are brought to the theory of spherical harmonics and the spherical harmonic analysis. Spherical harmonics are certain quantities which vary in a regular fashion over the surface of a sphere, becoming positive in some parts and negative in others. I spoke just now of making a model of a nearly spherical surface by removing material from some parts and heaping it up on others. Spherical harmonics specify standard patterns of deformation of spheres. For instance, we might remove material over one hemisphere down to the surface of an equal but not concentric sphere (cf. Fig. 5) and heap up the material over the other hemisphere. We should produce a sphere equal to the original but in a new position. The formula for the thickness of the material removed or added is a spherical harmonic of the first degree. It specifies the simplest standard pattern of deformation. Again, we might remove material from some parts of our model and heap it up on other parts so as to convert the sphere into an ellipsoid. The formula for the thickness of that which is removed or added is a spherical harmonic of the second degree. Deformation of a sphere into an ellipsoid is the second standard pattern of deformation.

The mathematical method of determining the appropriate series of standard patterns is the theory of spherical harmonics. Its importance arises from the result that any pattern whatever can be reached by first making the deformation according to the first pattern, then going on to make the deformation according to the second pattern, and so on. If we begin with a pattern, for instance the shape of the earth, which is not a standard pattern, we can find out how great a deformation of each standard pattern must be made in order to reproduce the prescribed pattern. The method of doing this is the method of spherical harmonic analysis. Except in very simple cases the application of it involves rather tedious computations. With much kind assistance and encouragement from Professor Turner, I made a rough spherical harmonic analysis of the earth's surface. I divided the surface into 2,592 small areas, rather smaller on the average than Great Britain, gave them the value +1, or one unit of elevation, if they are above the sea, and the value -1, or one unit of depression, if they are below the 1,400-fathom line. To the intermediate areas I gave the value 0. The distribution of the numbers over the surface was analyzed for spherical harmonics of the first, second, and third degrees.

Any spherical harmonic of the first degree gives us a division of the surface into two hemispheres—one elevated, the other depressed. The spherical harmonic analysis informs us as to the position of the great circle which separates the two hemispheres, and also as to the ratio of the maximum elevation of this pattern to the maximum elevation of any other pattern. The central region of greatest elevation of this pattern is found to be in the neighborhood of the Crimea, and the region of elevation contains the Arctic Ocean and

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the northern and central parts of the Atlantic, Europe, Africa, Asia, most of North America, and a small part of South America. When the surface is mapped on a rectangle in the same way as before, the chart of the harmonic is that shown in Fig. $6.^2$ The actual disproportion between the amounts of continental area in the northern and southern hemispheres is associated with the result that the central



region of elevation, as given by the analysis, is about 45° north of the equator; and the extension of the Pacific Ocean and adjoining Southern Ocean to much higher southern than northern latitudes is associated with the corresponding position of the central region of greatest depression about 45° south of the equator. In regard to harmonics of the second degree, the spherical harmonic analysis informs us as to the ellipticity of the equator and the obliquity of the principal planes of that ellipsoid which most nearly represents the elevation of the surface above or its depression below the surface of the ocean, or the geoid. The result is an equatorial region of depression, which spreads north and south unequally in different parts and forms a sort of immense Mediterranean, containing two great basins, and separating a northern region of elevation from a southern. The northern region of eleva-

² In this figure, and in the following figures, regions of elevation are shaded, and regions of depression are left blank.

tion occupies the northern part of the Atlantic Ocean and runs down to and across the equator in the neighborhood of Borneo. The southern region of elevation occupies the southern part of the Pacific Ocean, and it runs up to and across the equator in the



neighborhood of Peru. The chart of the harmonic is shown in Fig. 7. The equatorial regions of elevation given by the analysis are near the ends of a diameter, as we should expect.

It has not been necessary to enter into a minute description of the harmonics of the first and second degrees, because they represent very simple things—a shifting of the surface to one side and a distortion of it into an ellipsoid. The harmonics of the third degree are not so familiar. There are essentially four of them, each specifying a standard pattern of deformation. The first of these, the zonal harmonic, gives us a division of the surface into two polar caps and two zones by means of the equator and the parallels of latitude about 51° north and 51° south. Alternate zones are depressed and elevated, as shown in Fig. 8.



The existence of an Antarctic continent and an Arctic Ocean is specially associated with the presence of this harmonic, and the disproportion of the continental areas in the northern and southern hemispheres is also connected with it. The second of the harmonics of the third degree, the tesseral harmonic of rank 1, gives us a division of the surface into six half-zones by means of



Fig.9.

a complete meridian circle and the parallels of latitude about 27° north and 27° south. Alternate half-zones are depressed and elevated as shown in Fig. 9. The combined effect represented by the zonal harmonic and the tesseral harmonic of rank 1 is a furrowed surface with an Arctic region of depression extending southwards in the direction of the Atlantic, a zone of elevation which runs across the Atlantic, South America and Africa, and then turns



northwards at either end, a zone of depression with the same kind of contour, and an Antarctic region of elevation which extends northwards in the direction of Australasia. These regions are shown in

Fig. 10. I have recorded the result of combining these two harmonics because they represent the particular effects that would be produced by the interaction of two causes—the rotation, and the eccentric position of the center of gravity. The third type of harmonics of the third degree, the tesseral harmonic of rank 2, gives us a division of the surface into octants by



means of the equator and two complete meridian circles. Alternate octants are elevated and depressed as shown in Fig. 11. We can name the octants where there is elevation: Asia, Australasia, North America, South America. The harmonic of this type is certainly prominent. It is specially associated with the skew position of South America to the east of North America. The fourth type of harmonics of the third degree, the sectorial harmonic, gives us a



division of the surface into six sectors by means of three complete meridian circles. Alternate sectors are depressed and elevated as shown in Fig. 12. The southward tapering of Africa is specially associated

with the harmonic of this type. The combined effect of all the harmonics of the third degree is shown in Fig. 13. It represents the sphere deformed into a sort of



irregular pear-shaped surface. The stalk of the pear is in the southern part of Australia and contains Australasia and the Antarctic continent. This is surrounded on all sides but one (towards South America) by a zone of depression, the waist of the pear. This, again, is surrounded on all sides but one (towards Japan) by a zone of elevation, the protuberant part of the pear: and finally we find the nose of the pear in the central Atlantic between the Madeiras and the Bermudas. I do not, however, wish to emphasize the resemblance of the surface to a pear or any other fruit, but prefer to describe it as an harmonic spheroid of the third degree. Another way of regarding it would be as a surface with ridges and furrows. From a place in the South Atlantic there run three ridges: one northwestwards across America, a second northeastwards across Africa and Asia, and the third southwards over the Antarctic continent, continuing northwards across Australia nearly to Japan. From the Sea of Okhotsk there run three furrows: one southwestwards across Japan, the Malay Peninsula, and the Indian Ocean; a second southeastwards across the Pacific; and the third northwards over the Arctic Ocean, continuing southwards by way of the Atlantic. Harmonics of the first and third

degrees have in common the character of giving depression at the antipodes of elevation; the harmonics of the second degree give depression at the antipodes of depression and elevation at the antipodes of elevation. The maxima of the harmonics of the first and third degrees are found to be rather greater than the maximum of the harmonic of the second degree. Of three quantities to be added together the two larger ones agree in giving depression at the antipodes of elevation; a result which is in accordance with the fact that most continents have oceanic antipodes.

When we superpose the effects represented by all the various harmonics of the first, second and third degrees, so as to make, as it were, a composite photograph of all the various elevations and depressions represented by them severally, each in its appropriate amount as determined by the harmonic analysis, we find the curve



shown in Fig. 14 as the theoretical curve of separation between regions of elevation and depression which are approximately equal in area. I showed before a smoothed curve (Fig. 3) which I proposed to take as representing the facts to be accounted for. The resemblance of the two curves seems to be striking. Incidentally it has been noticed how the prominent features of the distribution of continent and ocean are associated with the presence of various harmonics. As regards the contour of the great ocean basins, we seem to be justified in saying that the earth is approximately an oblate spheroid, but more nearly an ellipsoid with three unequal axes, having its surface furrowed according to the formula for a certain spherical harmonic of the third degree, and displaced relatively to the geoid towards the direction of the Crimea.

As regards the amount of elevation and depression in different parts, the agreement of the theory with the facts is not so good. The computed elevation is too small in southern Africa. Brazil and the southern part of South America, too great in the Arctic regions, to the south of Australasia, and in the Mediterranean region. There are many reasons why we could not expect the agreement to be very good. One is the roughness of the method of harmonic analysis that was used. But there is also the fact that many causes must have contributed to the shaping of our actual continents and oceans besides those which have been taken into account in the theory. It appears, however, that the broad general features of the distribution of continent and ocean can be regarded as the consequences of simple causes of a dynamical character: eccentric position of the center of gravity, arising from a past state of inadequate resistance to compression, an inherited tendency, so to speak, to an ellipsoidal figure, associated with the attraction of the moon in a bygone age, the rotation, and the interactions of these various causes.

In attempting to estimate the bearing of the theory on geological history we must be guided by two considerations. The first is that the earth is not now gravitationally unstable. From observations of the propagation of earthquake shocks to great distances, we can determine the average resistance to compression, and we find that this resistance is now sufficiently great to keep in check any tendency to gravitational in-

stability. The eccentric position of the center of gravity must be regarded as a survival from a past state in which the resistance to compression was not nearly so great as it is now. The second guiding consideration is that, according to the theory, the inequalities which are expressed by spherical harmonics of the third degree are secondary effects due to the interaction of the causes which give rise to inequalities expressed by harmonics of the first and second degrees. We should expect, therefore, that the inequalities of the third degree would be much smaller than those of the first and second degrees; but the harmonic analysis shows that the three inequalities are entirely comparable. We must conclude that the harmonics of the first and second degrees which we can now discover by the analysis are survivals from a past state, in which such inequalities were relatively more important than they are now. Both these considerations point in the same direction, and they lead us to infer that certain secular changes may have taken place in the past, and may still be going on. Sixty-nine years ago Charles Darwin wrote: "The form of the fluid surface of the nucleus of the earth is subject to some change the cause of which is entirely unknown, and the effect of which is slow, intermittent, but irresistible." Fortytwo years later Sir George Darwin showed that any ellipsoidal inequality in the figure must be gradually destroyed by an irreversible action of the same nature as internal friction or viscosity. The same may be said of a state in which the center of gravity does not coincide with the center of figure when the resistance to compression is great enough to keep in check the tendency to gravitational instability. The state would be changed gradually in such a way as to bring the center of gravity nearer to the center of figure. A symptom

of such changes might be the occurrence of great subsidences in the neighborhood of the Crimea, where we found the maximum of the first harmonic. Such subsidences are supposed by geologists to have taken place in rather recent times. Symptoms of the diminution of the inequalities expressed by harmonics of the second degree would be found in the gradual disappearance of seas forming part of the great depression which was described above as a sort of immense Mediterranean (cf. Fig. 7) in the destruction and inundation of a continent in the northern Atlantic and in a gradual increase of depth of the southern Pacific. The disappearance of seas from a vast region surrounding the present Mediterranean basin, and containing the Sahara and southern Asia as far east as the Himalayas, is one of the best ascertained facts in geological history; and the belief in the destruction of a north Atlantic continent is confidently entertained. In parts of the southern Pacific a depression represented by harmonics of the third degree is superposed upon an elevation represented by harmonics of the second degree, and we should therefore expect to find the depth of the ocean to be increasing gradually in this region. The region in question is that of the coral reefs and coral islands, such as Funafuti, and the result is in accord with Darwin's theory of the formation of coral reefs. So far as the general distribution of the mass within the earth is concerned, the reduction of the inequalities of the first and second degrees would seem to have already proceeded very far; for we are assured by geodesists that harmonics of the first degree, and those of the second degree which do not represent the effect of the rotation, are far from prominent in the figure of the geoid-much less prominent than we found them to be in the distribution of continent and ocean. We infer

that the inequalities of the first and second degrees must have been progressively diminished in comparison with those of the third degree. The general result of such changes would be a gradual diminution of the depths and extents of the oceans which correspond with the harmonics of the first and second degrees, and a compensating increase in the depths and extents of the oceans which correspond with the harmonic of the third degree. To see the character of the changes which would thus be brought about, we may examine a figure which shows the composite elevations and depressions that are represented by harmonics of the first and second degrees, and, separately, those which are represented by harmonics of the third degree. In Fig. 15



the composite elevations of the first and second degrees are shaded vertically, and the elevations of the third degree are shaded horizontally. The deep parts of the Atlantic that border the coasts everywhere from Brazil to Ashanti are regions in which a depression represented by the third harmonic is superposed upon an elevation represented by the other two harmonics, and the same is true of the deep parts of the Indian Ocean which border the shores of Africa and Asia from Madagascar to Burmah. The deep parts of the Pacific that border the western coast of America from Alaska to Chile are regions in which an elevation represented by the third harmonic is superposed upon a de-

pression represented by the other har-These observations suggest that in monics. the greater part of the Atlantic and the northern and western parts of the Indian Ocean the direction of secular change may have been that of an advance of the ocean to encroach upon the continental region, while in the Pacific Ocean on the American side the direction of secular change may have been that of a retreat of the ocean. permitting an extension of the continental region. This difference would lead us to expect different types of coast in the two regions, and such a difference has been observed. Whereas in the Atlantic region, with few exceptions, the coast cuts across the directions of the mountain chains, in the Pacific region on the American side the coast generally corresponds in direction with the neighboring mountain chains of the continent. The deep parts of the Pacific which are nearest to the Asiatic coast from Kamchatka to Siam, are regions where a moderate depression represented by the third harmonic is superposed upon a moderate elevation represented by the other harmonics. These shores of the Pacific are distinguished by the wide margin which separates the deep ocean from the coast of the continent. It might perhaps be desirable to recognize in this region a type of coast differing from the two main types associated with the Atlantic and the American side of the Pacific. The analysis does not represent South Africa or the southern parts of South America sufficiently well to warrant us in expecting these regions to exhibit one type rather than the other; but the way in which Australia is represented, as an elevation of the third degree superposed upon a depression of the first, suggests that the coasts of Australia, and especially the eastern coast where the elevation in question is greater, should be of the same type as the American shores

of the Pacific; and it is the fact that the mountain chains of Queensland and New South Wales run parallel to the neighboring coasts. There seems therefore to be much evidence to support the view that the direction of secular change has been that of diminishing the prominence of the inequalities of the first and second degrees in comparison with those of the third degree. The process by which such changes would be brought about would be of the nature of relief of strain, expressing itself in occasional fractures of no very great magnitude; and such fractures would be manifested at the surface as earthquakes. Seismic and volcanic activities constitute the mechanism of the process of change. These activities are spasmodic and irregular, but the effect of them is cumulative. For this reason they fend in the course of ages to transform the shape of the earth from one definite type to another. The diminishing speed of the earth's rotation is another cause of change which appears to produce an alternating rather than a cumulative effect. On the one hand it tends to diminish that tendency, which we noted above, to draw the waters of the ocean towards equatorial regions; on the other hand it must result in an actual reduction of the equatorial protuberance of This reduction can the earth's figure. only be effected by seismic activity expressed by subsidences in equatorial re-The effect which would in this way gions. be produced in the distribution of continent and ocean would appear to be that there would be long periods in which the ocean would tend to advance towards the Arctic and Antarctic regions, interrupted by shorter periods in which it would tend to retreat towards the neighborhood of the equator.

The theory which I have tried to explain is a tentative one, and further investigation may prove it to be untenable; but it is to its credit that, besides tracing to dynamical causes the existing distribution of continent and ocean, it offers an explanation of the difference between the Atlantic and Pacific types of coast, it gives indications of a possible account of those alternations of sea and land which first led to the study of geology, and it suggests an origin for Charles Darwin's unknown force, the operation of which is slow and intermittent, but irresistible.

A. E. H. LOVE

PLANT PATHOLOGY 1

Your secretary has asked me to review as far as possible in ten or fifteen minutes our actual knowledge of plant diseases, the best methods of combating them, the progress that has been made, together with a suggestion or two as to some improvements that may be expected in the future. I have accepted the invitation, knowing fully that I could not in so short a time begin to cover so much ground with a sufficient degree of thoroughness to give an adequate idea even of the most important bearings of pathology on horticulture, but I concluded that the committee must have had in mind that I would use their request as an illustration of the greatest failing, not only in pathological investigation, but in the application of methods recommended for the control of diseases, namely, too much haste and lack of thoroughness. These are failings incident to work in a new country under great pressure, where the field is large and the workers few. There has been a good measure of economic justification for the mistakes of the past, and they are teaching us valuable lessons for our guidance in the future. What we need now is to study carefully these suc-

¹ Paper read at the meeting of the National Council of Horticulture, Jamestown, Va., September 23, 1907. cesses and failures and determine as accurately as may be possible their causes as a basis for improved practise.

The old conditions are rapidly changing. The new times require more careful and intensive methods.

One-crop farming, too short and unwise crop rotations, improper methods of fertilizing and culture, with destruction of humus and the life and fertility of the soil, careless methods of propagation and seed selection, the use of varieties not adapted to soil and climate, and other limiting conditions are responsible for loss from diseases in a larger degree than is realized. An orange, or plum, or peach, or apple, or any other tree or shrub, whose cambium responds to a few warm days in winter or early spring, is not a safe variety to plant in localities where such warm periods occur. Plants of northern range, accustomed to respond to lower initial heat stimulus, are thus subject to winter injury in more southern latitudes. On the other hand, plants of southern range planted north start later, are less subject to late frosts, but may be injured by early frosts. These cold injuries are often hardly noticeable, but they are sufficient to weaken the plant and open the way for trunk cankers and numerous other parasitic diseases which the trees could otherwise resist.

A soil slightly too acid or alkaline for a particular variety, though not enough to prevent growth, may nevertheless weaken the root system, or, in fact, the whole plant, making it subject to serious disease. So also the moisture or temperature fluctuations of the soil and its aeration may be unfavorable to a particular variety, making it less resistant to disease, if not actually causing a pathological condition in itself. Too little attention has been given to these factors by the farmers and horticulturists as well as by the pathologists.