show the relation of forces to movements of material, the origin of forces, and their causes. It would really combine the subjects of isostasy, earth tides, variation of latitude, seismology, and certain phases of volcanology. The data collected in those branches of geophysics should be considered in connection with geology in order to interpret in the light of present knowledge the various movements that have taken place in the earth. Up to this time, it is believed that these data have not been given due consideration and weight in the study of the earth, its structure, forces, etc.

Some of the subjects that have been discussed above are only incidentally related to geodesy, but the results of investigations in them are certainly of great value and interest to geodesists and it is believed that there should be committees of the Section of Geodesy of the American Geophysical Union to consider these questions and be able to inform the members of the Section at any time as to the progress made in these branches of geophysics. There are several of the subjects which have sections of their own, for instance, those of Seismology and of Volcanology.

The Geodetic Section of the American Geophysical Union will not attempt, nor does it desire, to pre-empt any field of geophysics nor will it encroach on the rights and privileges of any other organization. It will simply attempt to keep informed of what is going on in the various fields of geophysics which are of interest to geodesists and it hopes that it may from time to time give some assistance to other organizations in suggesting problems or lines of research. On the other hand, it stands ready to receive suggestions and help from any other organization dealing in any branch of geophysics.

[1] *Bulletin of the Phila. Soc. of Washington,* **11** (51–64).

[2] Supplemental Investigations of the Figure of the Earth and Isostasy from Measurements in the United States.

THE PROBLEMS OF SEISMOLOGY

BY HARRY FIELDING REID

Although earthquakes have received sporadic attention for some time in the past, their systematic study may almost be said to have begun with Mallet about the middle of the last century; and it was only towards the end of the century that instruments delicate enough to register distinct shocks were developed, making it possible to gain some knowledge of the characteristics of earthquake vibrations and the velocities with which they are propagated through the earth. But, notwithstanding the shortness of the time during which these studies have been in progress, the science has been well outlined and first approximations to the solutions of many of its problems have been obtained. The time has now arrived for more concentrated and still more systematic attacks, from which important results may be confidently expected.

We can summarize the general state of our knowledge of earthquakes as follows:

Nearly all earthquakes are due to the sudden fracture of the rock of the earth's crust, which has been strained by slow earth movements beyond its strength. Strong vibrations are set up at the fractured surface at the time of the fracture, just as vibrations are set up whenever any solid is broken. The earth consists of solid material, which is necessarily elastic, and therefore these vibrations are transmitted through it as elastic waves. There are two kinds of elastic waves: normal waves, where the movement is in the direction of propagation, and transverse waves, where the movement is at right angles to the direction of propagation. These two kinds of vibration advance with different velocities. Their velocities near the earth's surface are about 7 and 4 kms. per second, respectively; but the deeper they penetrate below the surface the faster they go. Therefore, from the characteristics of elastic waves their paths are curved and concave upwards. These important results have been obtained by a study of the time necessary for the two types of waves to pass from the place of their origin to stations at different distances where delicate instruments are installed, which record the time of their arrival. It may seem remarkable that the paths followed by the rays and the velocity in different parts of the paths could be determined merely from the time required to arrive at a number of places on the earth's surface; but, by the help of some rather abstruse mathematics, it can be done. One interesting conclusion which can be drawn from the passage of the transverse waves through the body of the earth is that the earth is a solid and not a liquid sphere; for transverse waves can be transmitted only by solid substances.

There are other waves which are transmitted along the surface of the earth; they must be started in some way when the body waves, mentioned above, arrive at the surface, but we do not know just how near the origin their starting place is.

In many instances submarine earthquakes give rise to great water waves, which have been known to travel from one side of the Pacific Ocean to the other. It has been the general belief that the first indication of these waves along a coast is marked by the withdrawal of the water; and the great elevated wave follows. Although this order is certainly frequent, it is not general, and in many cases the elevated wave is first to appear.

This is a very summary sketch of what has been learned about earthquakes in the comparatively short time that they have been systematically studied; but it will serve as a basis from which to point out the problems which are now pressing for solution.

For our present purposes we can classify seismological problems into:

A. World-wide.
B. Regional.
C. Theoretical and Auxiliary.

A. World-wide Problems

The noted seismologist, the late John Milne, has estimated that fifty or sixty earthquakes, strong enough to be recorded on seismographs in all parts of the world, occur every year. The study and comparison of the seismograms made at these scattered observatories requires international coöperation, and this will be provided for by the new International Geodetic and Geophysical Union.

The problems facing us are numerous, but perhaps the most important is the accurate determination of the time of the earthquake waves to pass from their origin to points on the earth's surface at various distances from it. We already have a fair knowledge of these times, but need more accurate determinations. This information serves two main purposes: it enables us to determine the origins of earthquakes when they occur in inaccessible regions or under the sea, and thus gives us information of the regions of seismic and therefore of geologic activity; and it enables us to trace out the paths and the velocity of the earthquake waves through the earth, thus throwing light on the physical condition of the earth's interior.

The records of earthquakes at distances of more than about 110° from the origin have proved very unsatisfactory. It is still uncertain whether this is due to the imperfections of our observations or, as Oldham thinks, to the existence of a central core in the earth having different physical properties from the material surrounding it, which materially changes the direction of propagation of the seismic vibrations passing through it, and may even damp some of them out entirely. This very interesting suggestion deserves to be tested.

Professor Wiechert and his collaborators have announced the existence of several shells in the earth where the velocity of propagation of the waves suddenly changes. These results are based on the form of the transmission curve; but, unfortunately, this form is not known with sufficient accuracy to justify the conclusions.

Do earthquake waves travel under the continents and the oceans at a different rate? We can say that the difference is certainly small, but we cannot say that there is no difference. These are some of the problems dependent for their solution on increased accuracy of the transmission curve.

The comprehensive work of the Count de Montessus de Ballore on the distribution of earthquake centers on the earth, has shown that 95% of all earthquakes on land occur in two broad zones, one surrounding the

Pacific Ocean and one passing through the West Indies, the Mediterranean, and the East Indies. These zones are the regions where sediments were accumulated in middle geologic times, known as the Mesozoic Age; after consolidation into rock they have been elevated and in places they now form the highest mountain ranges in the world. De Montessus de Ballore's great work need not be repeated; what is now needed is a detailed study of the distribution of earthquake origins in special regions, and this comes under our third class.

But the distribution of earthquake centers under the seas is still in an embryonic state. A good beginning in the study of this problem has been made by Rudolph, but far more data are needed and they can only be supplied by the records of many widely-spread observatories.

Much study has been given to periodic variations in earthquake activity and its possible relation to variations of latitude, to the positions of the sun and moon, to the seasons, etc. Although this line of investigation has not yielded satisfactory conclusions and, in the opinion of some competent seismologists, is not destined to be fruitful, others believe in its possibilities. If it is to be pursued successfully it is important that a good catalogue of submarine earthquakes be added to the catalogue of those occurring on land. There are a sufficient number of seismological observatories in the United States to supply the data required from this country towards the solution of these world-wide problems, though perhaps a new station somewhere in Texas and another in Montana or Idaho might be of advantage. The effort should be to improve the stations already functioning rather than to increase their number. The examination of many earthquake records has convinced me that not a few observatories are provided with poor clocks, or that insufficient care is given to them. Better time-keeping will greatly increase the accuracy of the records. Some of the best observatories should have a more complete equipment. They should have seismographs of high magnifying powers to catch the very feeble movements, and seismographs of low magnifying power, that the characteristics of the stronger movements may not be lost by too wide a range of the recording point. They should have instruments to record vertical motion, a component that has received far too little attention. I believe there are but two vertical component instruments in this country.

When we consider the important area covered by the Pacific Ocean, we find that there are stations in Japan, Formosa, the Philippines, Australia, New Zealand, Chile, Panama, Mexico, California, and Sitka; and on the islands of Oahu, H. I., Guam, and Samoa. The last station was a branch of the Physical Institute of Göttingen and should not be allowed to fall into desuetude. A station on one of the Aleutian islands would also gather valuable information.

Knott has shown that the greater part of the energy of an earthquake comes to the earth's surface within a short distance of the epicenter, and 95% within a distance of 90°. When we consider that the earthquake originates at a fault and that the mass movement there may be horizontal, inclined, or vertical, we realize that the energy sent out in different azimuths, and indeed at different vertical angles, may be dependent on the direction of the fault and of the mass movement, but no information has yet been obtained on this subject.

B. Regional Problems

The accurate surveys made by the United States Coast and Geodetic Survey of parts of California before and after the earthquake of 1906, made it very plain that slow movements of the earth's crust during some scores of years finally brought about a rupture of the rock along the San Andreas Fault, and that the two sides of the fault flung back in opposite directions under the elastic forces set up in the rock by those movements. But no information was gained regarding small ruptures taking place preliminary to the main break, nor regarding the location of the many sudden movements after the shock, causing what are known as aftershocks. A methodical study of a limited area where small shocks are frequent and strong shocks are occasional would throw much light on the sequence of events leading up to the rupture producing a strong shock, on the way in which the rupture is gradually enlarged, on the depth to which it extends, and on the order according to which quiet is gradually restored. It seems not impossible that the location of the preliminary shocks might serve to block out the fault along which a rupture was about to take place. Davison's study of the shocks preliminary to the severe Mino-Owari earthquake of Japan in 1891, seems to encourage this idea. But it is important that the actual origins of the shocks should be determined; it is insufficient merely to list the places where the shocks were felt; this last method has led to serious error in the past. By placing simple monuments in properly selected positions and fixing their relative positions and heights from time to time by careful surveys, the slow movements of the crust and the relation of these movements to earthquakes could be discovered. Information could also be gained regarding the relation of the geological structure and the physiography of a region to its seismic activity.

The velocity of transmission of earthquake vibrations in the immediate vicinity of the origin and near the earth's surface, can only be satisfactorily studied by placing a number of seismographs at comparatively short distances apart, and not far from the origin of the shock. A good determination of this velocity would add precision to many seismological problems.

There are many other problems that come in this class. Microseisms, small vibrations continuing for hours, frequently interfere with the satisfactory recording of earthquakes. The origin of these vibrations is not understood. They may be connected with meteorological conditions. The actual movements of the ground, velocity and direction of propagation of the microseisms should all be studied and compared with the direction of the wind and the direction of the barometric gradient. The concentration of a number of similar seismographs in a limited area would furnish the proper conditions for the solution of this problem.

The influence of the foundation, rock or alluvium, upon the intensity of the vibrations; the relative intensity of the movement in a mine and above ground, due to local or to distant earthquakes, etc., are examples of regional problems before us.

The study of the actual effects of strong earthquakes usually follows somewhat different methods. It requires the examination of the region where the shock has left visible marks by a competent seismologist. The experiences of persons present must be collected; the damage to buildings and other structures noted; and the relation of the earthquake to the geology of the region determined. The slow surface waves in alluvium, sometimes called "gravity" waves, are still a great enigma, and require special attention. A few portable seismographs should be available and should be placed in suitable positions to record and locate the aftershocks. If in addition to these field studies, instrumental records before, during, and after the strong shock should have been made the two kinds of information collected would not only supplement but would add greatly to the value of each other.

C. Theoretical and Auxiliary Problems

The results obtained by world-wide and by regional studies must be woven together into a unified whole and the fundamental laws of the sciences deduced. This kind of work is only done occasionally, and then by individuals who have developed an unusual insight into their science. There are many problems, however, which do not come either under the world-wide or the regional problems, which are important either in helping the solution of these problems, or in elucidating the meaning of the data collected. For instance, the theoretical and experimental study of seismographs is of great importance. It looks to a better interpretation of the seismograms, and to improvements of the instruments, or the development of new forms of instruments. This is work to be done in the study or in the laboratory, but should be in close touch with observations in the field. In particular, we need an instrument that will give a correct record in the shaken area of a strong earthquake.

Then there are many problems, such as the actual genesis of the vibrations, the transmission of body and surface waves, the changes in the character of the waves on reflection, the reasons for differences in the instrumental records of different earthquakes, the peculiarities of earthquake sea-waves, etc.

Although the various seismological problems have been, for convenience, classified into three groups, it must not be inferred that they are sharply defined and distinct; each group will contribute to the problems of the others. Instruments that are primarily intended for world-wide problems will yield information bearing on local problems in their neighborhood; and instruments meant for local problems will also record the world-shaking earthquakes.

Relations to Other Sections of Geophysical Science

For convenience we divide science into branches, influenced largely by differences in the methods used. But nature knows no such dividing lines; and we find that many problems can be solved only by the cooperation of several branches. This is especially true of the geophysical sciences. The special section of seismology looks to all the other sections for help; to geodesy to determine the slow earth movements, horizontal or vertical, that lead up to earthquakes, and the sudden movements that take place at the time of the shock; to meteorology to tell us the atmospheric conditions when microseisms are prevalent; to physical oceanography for information about the deeps of the oceans, along whose borders submarine shocks are common.

The independence of earthquakes and volcanoes has been strongly emphasized during the last thirty years, because nearly all the strong earthquakes were unaccompanied by volcanic phenomena of any kind; and, on the other hand, the great volcanic outbursts, such as Krakatoa in 1883 and Mt. Pelée in 1902, caused only insignificant earth tremors. These facts cannot be contraverted; and still we must not forget that the volcanic belts lie in or near the great earthquake zones; and there may be some common cause of both classes of phenomena.

The influence of earthquakes on suspended magnets may be assigned, with much confidence, merely to the mechanical vibrations. But may not the altered state of strain, in the neighborhood of the generating fault, change the magnetic condition of the rock there if the rock contains magnetic minerals, so that the general magnetic field might be modified? Or may not the passage of violent earthquake waves through magnetic rock alter its magnetization, especially if that magnetization was assumed at some time when the earth's field was different from what it now is?

Seismology does not ask without giving. It can contribute its conclusions to the other branches of science and help them in the solution of their problems.

THE STATUS AND PROBLEMS OF METEOROLOGY

BY C. F. MARVIN

Meteorology is one of those sciences which developed on the side of practical application for the welfare of mankind to a far greater extent