

# EARTHQUAKES

By CHESTER A. REEDS



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# Earthquakes

An account of the sharp movements of the earth that often bring tragedy to the inhabitants of certain regions, together with an explanation of the instruments that record these movements

by  
Chester A. Reeds

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THE needles on the seismograph in the American Museum may suddenly, without a moment's notice, begin to trace on moving sheets of paper a threefold series of wavy lines, which represent vibrations that have passed through the earth—somewhere there has been an earthquake and the seismograph is making a graphic record of it. If the shock is sufficiently strong, other seismographs in various parts of the world will inscribe a record of the same quake at approximately the same time. The vibrations from a strong distant quake may continue to arrive for an hour or more; those from a small near-by quake will be recorded in a much shorter time.

An earthquake is produced when the materials composing the earth are broken or displaced. The materials are hard, brittle, and elastic, and they will resist change until the forces acting upon them develop stresses greater than their strength, then they will yield suddenly and produce not only a fracture, but a shock. A sudden yielding of rocks to earth strains may give rise either to a new fracture or to movements along a previously existing fault. When a sudden movement does occur along a new or old fault, the frictional resistance offered by the opposing rock walls no doubt contributes its share to the development of vibrations. Whatever happens, the sudden shock releases energy, vibrations are set up and waves are transmitted through the earth in various directions to seismographs situated at different distances from the point of origin. The greater the dislocation, the greater the vibrations set up, and the greater the distance the waves will travel.

In the United States 62 major earthquakes and many smaller ones were recorded

instrumentally for the year 1933. The average annual number of earthquakes locally sensible to human beings is about 4000. Of this number, about 70 are major quakes capable of instrumental registration over a hemisphere or the entire globe. There are some 200-odd seismological stations scattered over the surface of the earth. Many of these stations contain only a pair of seismographs, the larger stations contain three, four, or more makes of instruments, each with a different degree of sensitivity, and capable of registering, not only the horizontal, but also the vertical components of an earth shock. It has been recently estimated that the number of earthquakes, which probably occur annually, and which are susceptible of instrumental registration, approximate 8000. A limited number of modern seismographs have been in use for the past 35 years. During this period, it has been estimated that nearly 2500 major earthquakes have been recorded, and about 140,000 smaller ones, which may have been felt locally. The number which probably occurred, both large and small, and which may have been strong enough for registration by present-day instruments, may have amounted to 240,000. It may be noted thus that earthquakes are not of infrequent occurrence.

In recent years the citizens of the United States and of other countries have manifested a widespread interest in the occurrence and distribution of earthquakes and in the kinds of instruments which have been devised for recording them. With the gradual increase in the number of seismological stations in various parts of the



*Wide World Photograph*

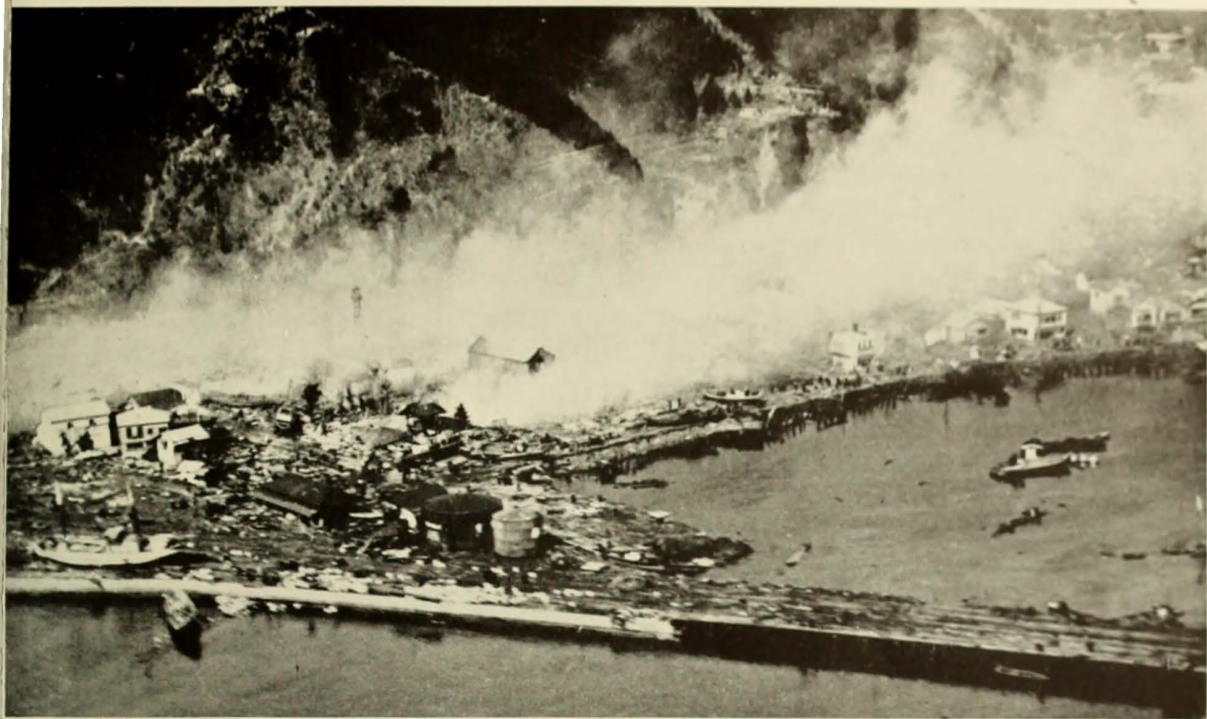
A view of the wreckage of the city of Melfi, Italy, after the earthquake of July 23, 1930. Almost the entire Mediterranean is included in the geologically "young" zone that continues across Asia Minor and the Himalayas to the East Indies and beyond

## Italy

Taormina, Sicily, looking toward the active volcano, Mt. Aetna, and with the ruins of an ancient Greek theater in the foreground. Taormina and Messina were severely shaken in 1908. The loss of life exceeded 100,000. The famous volcano of Sicily and the fact that earthquakes are not uncommonly felt in the island, demonstrate its geologic youth

*Publishers Photo Service*





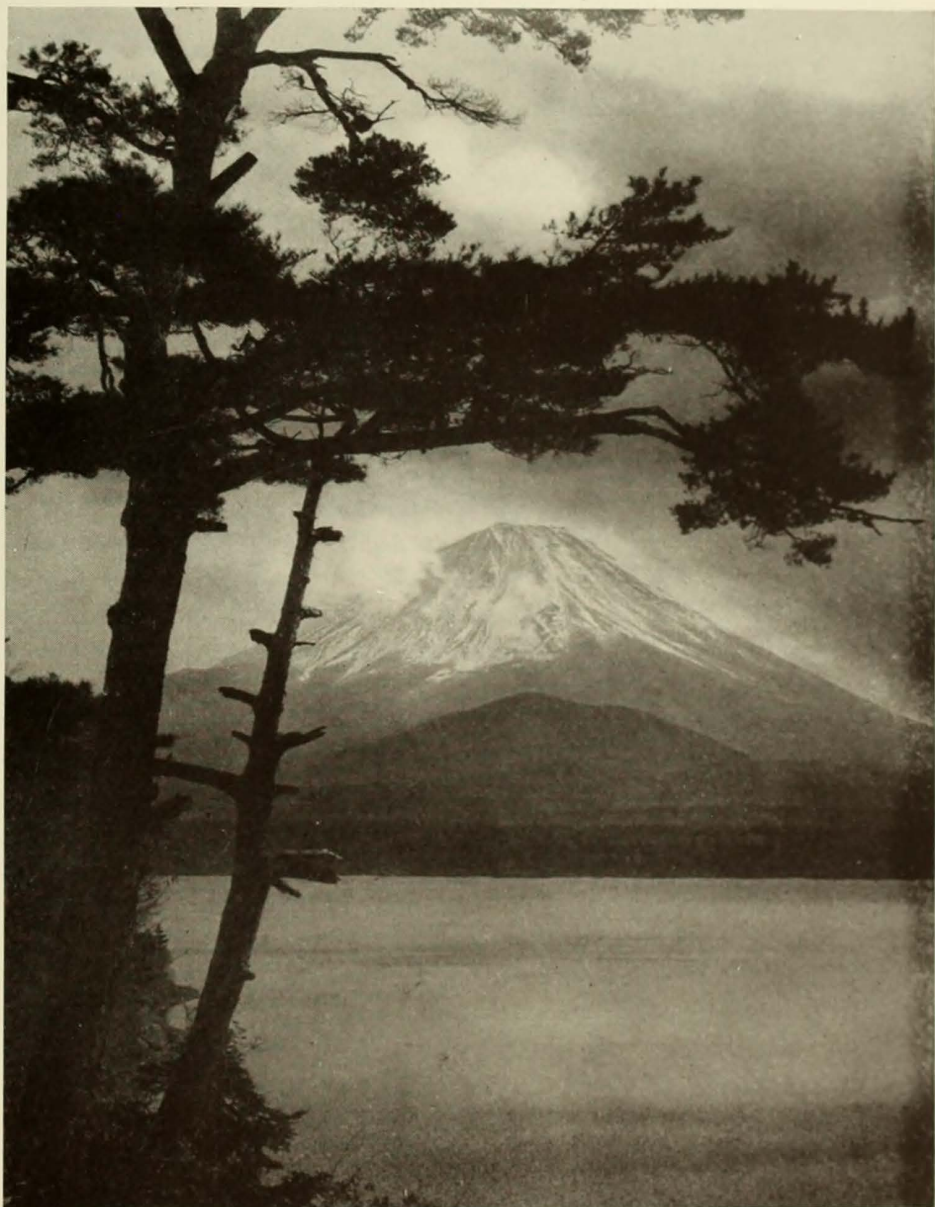
*Wide World Photograph*

An aerial view showing the ruins of Miyagi, Japan, as they were burning, following the destructive earthquake of March 3, 1933

## Japan

Looking across Shoji Lake toward Fuji-yama. This particular volcano is quiescent but others in Japan have played their part in the periodic earthquakes that are common in the Japanese archipelago

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civilized world, together with the improvements that have been made in the different types of self-recording instruments, there has been a marked increase in the number of earthquakes recorded.

#### THE COMPOSITION OF THE EARTH

The study which has been made during the past few decades of seismograph records has revealed that the earth has a crust composed of solid material, and that it has a thickness variously interpreted as being 40 to 60 miles in depth. The irregular configuration of the earth's outer surface is a matter of common knowledge. The highest point of land, represented by Mount Everest, has an elevation of 29,141 feet; the greatest depth of the sea, known as the Swire Deep, off the east coast of the Philippines, measures 35,433 feet. The maximum relief of the earth's surface is thus approximately  $12\frac{1}{4}$  miles. The average height of the land, however, is but 2,300 feet above sea level, or nearly a half mile, while the oceans have an average depth of 11,500 feet, or a little more than two miles. The difference in relief between the average height of land and the average depth of the oceans is thus 2.6 miles. Only 28 per cent of the earth's surface is above sea level, the remaining 72 per cent being below. In other words, one part is land while nearly three parts are covered by water. This relative distribution of land and water is in keeping with the location of earthquakes, for maps showing the distribution of earthquake epicenters, for periods of one or more years, show that earthquakes are far more abundant at sea than on the land. It has been recognized by geologists and other scientists that the earth's surface has an irregular relief, because of the presence of materials of different densities near the earth's surface. Under the continents the densities, which average 2.67 times an equal volume of fresh water, are less than they are for the materials under the oceans, which are of the order of 3. The average density of the entire earth is considerably greater. It is 5.6 times as much as

an equal volume of water. As a consequence, the materials of the inner parts of the earth must be denser and heavier than those of the outer crust.

We know, too, that the crust of the earth is rigid, although it is composed of materials of different consistencies, for, otherwise, the high areas would slump down and the materials composing them would move forward to fill the valleys, the ocean basins and their deeps, and produce a true spheroid, which would be covered with water to an average depth of about 7,500 feet.

The length of time during which the earth has had this irregular configuration is not definitely known. It has been long and may be of the order of the oldest known rocks, which are now regarded as exceeding a billion and a half years. High mountains such as the Alps, Andes, Caucasus, Himalayas, Rocky Mountains, and Sierra Nevadas have not always been high, for they are of comparatively recent origin geologically speaking; older mountains, such as the Appalachians of the United States, the Caledonian and Hercynians of Europe, have been greatly reduced in height by the action of the agents of erosion during many millions of years. The still older Laurentides of Canada, and the upturned strata of Manhattan Island and the adjacent mainland of New York have been reduced by these same agents of erosion to rolling uplands. Their present relief does not suggest mountains, but their geologic structure does. We may conclude from this evidence that while the high spots of the land and the low places of the sea have not always been where they are now, the relative distribution of the continental land masses and the oceanic basins has, with minor variations, remained more or less constant for vast geologic ages.

#### WHAT HAPPENS WHEN THE EARTH QUAKES

In regions where large earthquakes occur, it has been noted that either vertical or horizontal changes, or both, take place in the crust of the earth. The amount of change produced at any one time may be of

the order of a few inches or a small number of feet, and have a lineal extent of either a few miles, or as in the San Francisco earthquake of 1906, of several hundred miles. In the course of irregular periods, of long or short duration, earthquakes may recur in the same place or in closely adjacent areas; the combined result of a number of such recurring earthquakes is to produce a well marked change in the configuration of the earth's surface at that place. Earthquakes, which accompany either vertical or horizontal changes in the surface of the earth, are not only happening now, but they have occurred frequently during the past history of the earth. In fact, there is no portion of the earth's surface which is absolutely free of faults, those large fractures, which appear as mute evidence that earthquakes have occurred along them at one time or another during the past history of the earth.

It is also true that during past geologic ages parts of the earth's crust have been either down-warped, uplifted or broken, and in many cases, tilted. Evidence of this may be seen in many of our highest mountains where beds of limestone, sandstone, or shale, which contain fossil remains of shells that once lived in the sea, have been found at high elevations. Volcanoes also periodically bring up molten materials from great depths and pour them out at different elevations on the earth's surface. It would be of interest in this connection if we knew more precisely from what depth this white hot lava arises.

#### WHERE EARTHQUAKES ORIGINATE

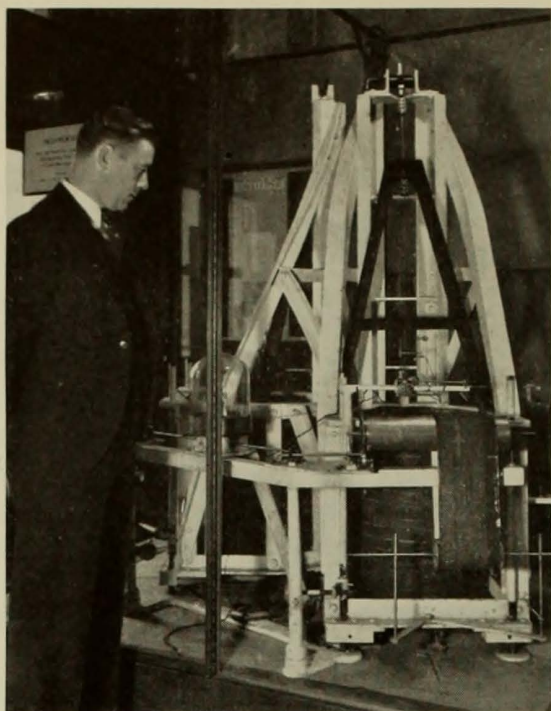
The depth at which earthquakes originate is a problem concerning which we would like to have more precise data. Many earthquakes produce evidence of shift of earth-blocks at the surface of the earth, others leave no trace of such movements. While some earthquakes undoubtedly occur near the surface, with movements extending downward, others appear to be deep-seated. A study of Japanese earthquakes by K. Wadati, 1928, shows that they may be either

shallow or deep-seated. The shallow ones have an average depth of 25 miles, while the deep-seated ones may originate at depths of more than 186 miles. A few other investigators have made studies of this problem with varying results. The studies of B. Gutenberg in 1929 of sixteen different earthquakes show that the focus or point of origin of these quakes lies, with a few exceptions, at a depth of 28 miles or less. Some investigators of this problem say that, if the velocity of propagation of seismic waves through the uppermost layers of the earth's crust were more precisely known, there would be less uncertainty in determining the depth at which earthquakes originate.

#### SEISMOGRAPHS AND EARTH VIBRATIONS

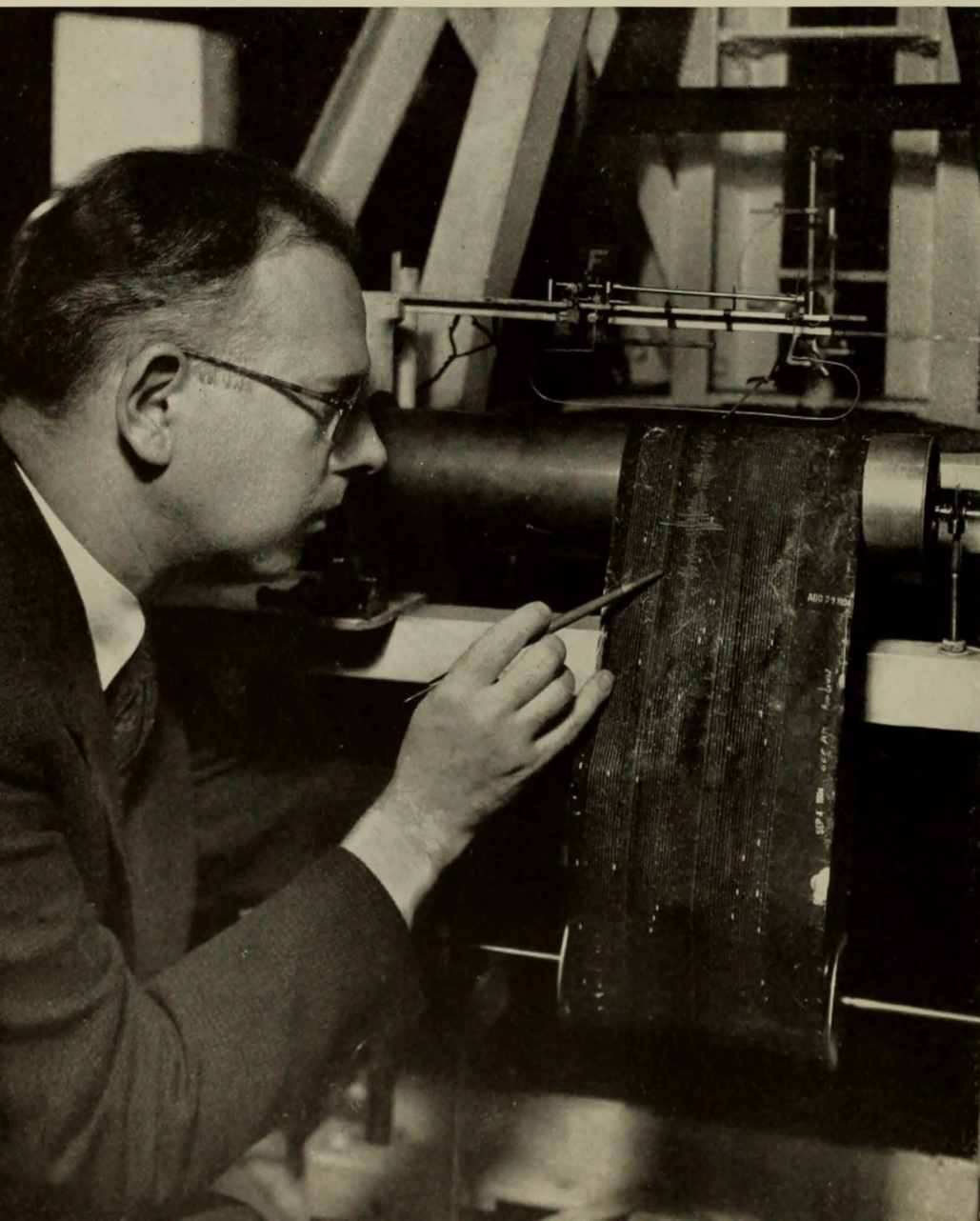
Seismographs are instruments designed to record the vibrations transmitted through the ground. During a great earthquake two things are apt to happen, namely: (1) There will be a lurch or displacement of the ground, either horizontal or vertical, or horizontal and vertical, the range of which may amount to 20 feet or more. The amount of displacement will not be recorded by the seismograph. It may be determined by resurveying the ground. (2) Vibrations will be set up in the ground.

All earthquakes develop vibrations. The period of the vibrations may vary from a fraction of a second in near earthquakes to 20 or 30 seconds in distant earthquakes. No one seismograph will record all of these varied tremors. Due to limitations in construction and recording, different types of instruments are required for the registration of near and distant earthquakes. A third type of instrument, known as a tromometer, is needed for registering the minute tremors which precede and accompany volcanic eruptions. A fourth type of seismograph is required for those regions where great earthquakes occur, for there the motion is apt to be so strong and vigorous that any machine designed for the registration of other types of earthquakes would be damaged or thrown out of action.

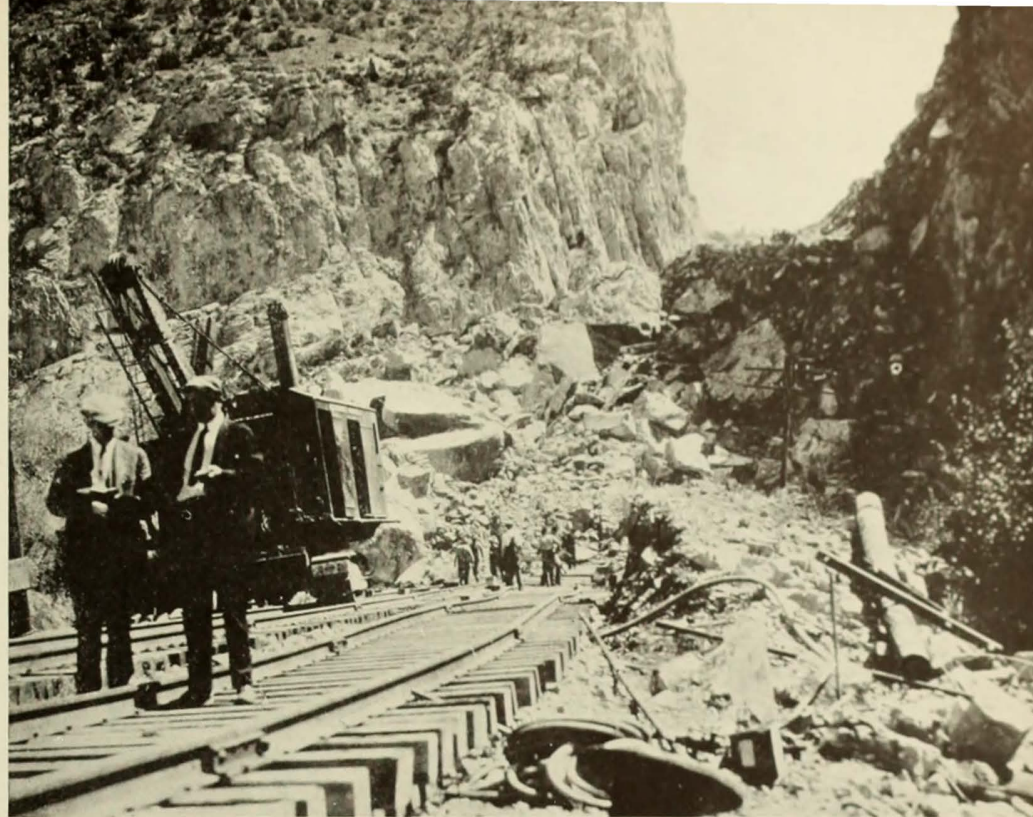
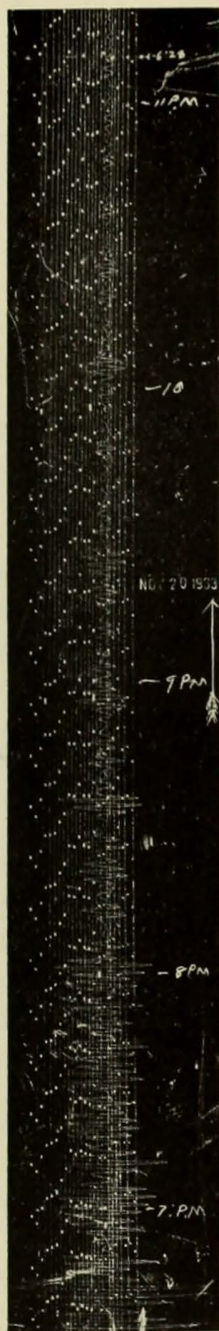


## Seismograph

The photographs at the left and below show the seismograph at the American Museum of Natural History. The record which is being examined by the observer below records an earthquake of moderate intensity in the ocean bed on August 29, 1934. So accurate and sensitive are these instruments that though thousands of miles may separate them from the center of the earthquake shock, a study of the record will often determine the quake's location



Above: The seismographic record above and the one parallel to it on the opposite page are in reality two parts of one record, made on November 20, 1933, on the American Museum seismograph, recording a quake in Baffin Bay. Seismological stations have reported these shocks as being among the strongest ever recorded



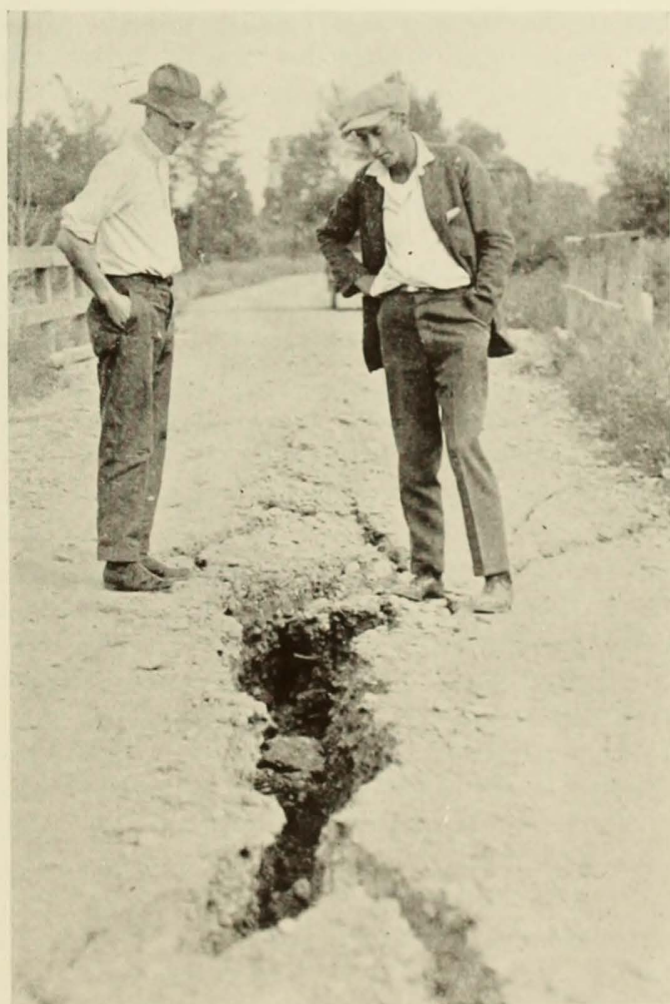
*Photograph by  
Charles C. Mook*

Above: Trouble for a railroad. This view, taken immediately after the earthquake of July, 1925, at Three Forks, Montana, shows the havoc wrought on a railroad line by the displaced masses of rock loosened by the earthquake

## Earthquake

A crack in the earth photographed after the earthquake of July, 1925, at Three Forks, Montana, not far from the spot pictured above. Such cracks in the earth are not uncommon after earthquake shocks, and sometimes can be traced for considerable distances

*Photograph by Charles C. Mook*



Each kind of seismograph consists of five essential parts, namely. (1) the "steady mass" which remains or should remain quiet during the time of an earthquake; (2) the framework which supports the "steady mass"; (3) the recording apparatus; (4) a damping device whose function is to keep the "steady mass" quiet; and (5) a pier constructed in such a manner that it stands free of buildings and is firmly connected to the ground.

#### THE MAINKA SEISMOGRAPH

In the American Museum installation there are two horizontal pendulums, known as the Mainka seismograph and built precisely alike and set at right angles to each other. One is placed in a N-S direction, the other in an E-W plane. The N-S instrument registers the E-W component, the E-W instrument the N-S component of an earthquake movement. The "steady masses" in these two seismographs have been painted black. Each consists of a series of 16 alternating iron and lead discs which have been stacked in such a way that they make a cylinder  $15\frac{1}{2}$  inches in diameter and 22 inches high. The weight of each "steady mass" is 450 kilograms or nearly 1000 pounds. Each "steady mass" is suspended from a sturdy angle-iron frame, painted white, which rests upon a concrete pier. The top of the pier, which has dimensions  $3' 8'' \times 5' 8''$  and supports both instruments, is level with the first floor of the Museum building. It is not connected with the building, however, for an air space separates them. The pier, which extends downward 24 feet, has its lower half firmly imbedded in Manhattan schist. The upper half of the pier passes through the basement of the building and there it is surrounded by a wall of hollow tile. This tile wall not only protects the pier, but it keeps the air surrounding the pier of a uniform temperature. Air conditioning of seismograph piers is an important matter, for, if not attended to, the seismograph records are apt to show unnatural earth tilts brought about by un-

equal changes in temperature in the piers.

The mode of suspension of the "steady masses" varies in different types of instruments. The "steady mass" may be supported in such a manner that it represents either a common pendulum, an inverted pendulum, or a horizontal pendulum. In these various types of suspension, the equilibrium of the "steady mass" is respectively stable, unstable, and neutral. Of these three types of pendulum the horizontal one offers the least amount of difficulty in providing a "steady mass," which is essential in an accurate seismograph. The horizontal pendulum, therefore, is the one generally used in the construction of seismographs. A door or gate swung on two hinges is a common example of this type of pendulum.

In order that the horizontal pendulum may have a small amount of stability and may return to its initial position after displacement, the axis of support is tilted slightly toward the center of gravity of the "steady mass." Swinging doors and gates also readily come to rest when they are not hung perfectly true.

#### THE ARRANGEMENT OF THE "STEADY MASS"

In a simply constructed horizontal pendulum the "steady mass" is usually firmly attached to one end of a boom; the other end of the boom, which is free, ends in a steel point which is pivoted in an agate cup near the base of the mast or supporting frame. The weight of the "steady mass" is supported in mid air by a wire stay, which is attached at one end to the weight and at the other to the top of the mast. This mode of attachment not only keeps the "steady mass" free of its supporting frame, but it permits adjustment of the angle which the boom makes to a horizontal plane passing through its pivoted end. This angle affects the period of the instrument, in other words, the number of vibrations which the "steady mass" will make in a second, when touched lightly with the finger. For near earthquakes a period of four to six seconds is suitable; for distant earthquakes one of thirty seconds or even greater is desirable.

In the American Museum installation of the Mainka seismograph the "steady mass" is kept free of the supporting frame by a Y-shaped yoke, the two distal ends of which are attached to the sides of the mass, while the free proximal end is fastened to the frame in such a way that a knife-blade spring is kept under tension. The lower end of the supporting stay consists of a bridle fastened to the two ends of a pipe which passes through the center of gravity of the "steady mass"; the upper end of this support terminates in a wire which is attached to the top of the supporting frame. The suspension is so delicately adjusted that, if the "steady mass" is slightly touched with the finger, it will swing back and forth in a horizontal plane and the vibrations will be registered by the recording needle on smoked paper. From such a registration the natural period of the instrument can be obtained. In this connection it may be stated that a seismograph is most sensitive to those waves which correspond to its own natural period of vibration. The period of the machine is noted at the beginning of every record. New sheets of paper are placed on the instruments, usually at the end of every forty-eight hours.

#### THE "DAMPER"

The movement of the "steady mass" when touched is just the contrary of what happens when an earthquake occurs; then the earth, the concrete pier, and the white supporting frame vibrate as a unit while the "steady mass" remains quiet, at least for a time, when it may begin, if not damped, to pick up the earth's vibrations transmitted through the supporting boom and stay.

The damper which is placed upon the side of each supporting frame consists of a rectangular metal box, a pair of round air holes near the top with adjustable covers, a sheet of metal within the box which acts as a diaphragm, and a set of rods which connect the diaphragm with the center of the "steady mass." This is an air damper; oil and magnetic dampers are also used on some types of seismographs. The damper

offers resistance to any sudden movement which may take place, especially the tendency of the pendulum to swing in its own natural period when an earthquake occurs.

#### HOW THE RECORDING APPARATUS OPERATES

The recording apparatus in each instrument consists of a connected series of multiplying levers. One end is attached to the center of gravity of the "steady mass"; the other end is a freely moving well-balanced recording needle which lightly touches a moving sheet of smoked paper. These levers magnify the earth tremors 100 times. In order that the earth movements which pass through the pier and supporting frame may be registered with reference to the "steady mass" which remains quiet, the recording levers are also attached to the center of the "steady mass," the diaphragm of the damper, and to the supporting frame. In addition to the multiplying levers, the recording apparatus in the Mainka seismograph consists of a pair of revolving drums on which sheets of smoked paper 15×90 centimeters in size, and joined at the ends, rotate past the point of the recording needles. The movement of the drums and smoked paper, which is at the rate of 15 mm. per minute, is controlled by a weight and governor. Minute and hour dots are marked on the sheets of smoked paper by a pointer, which is controlled by a master wall clock having electrical contacts.

Normal registration of a Mainka seismograph appears to consist of a series of parallel lines traced by the needle on smoked paper. Actually the needle traces a continuous line of closely appressed spirals, as when a garden hose is coiled up, for the paper moves over slightly as it climbs the higher side of the gently inclined drums.

During an earthquake the needle swings back and forth across the paper and thus inscribes the vibrations of the earth which usually arrive in three phases known as the First Preliminary tremors, *P*; the Second Preliminary tremors, *S*; and the Main Waves, *L*. In distant earthquakes one or



*Publishers Photo Service*

The photograph at the left, taken at Compton, California, shows how the wall of a building crumbled away as the result of a quake. Below is a view of San Francisco which in 1906 was fearfully damaged by an earthquake followed by fire

## California



# New Zealand

*Publishers Photo Service*

The photograph at the right was taken at Napier, New Zealand, Feb 3, 1931, while an earthquake was still in action in the vicinity. The view below is at Auckland, which was shaken by the great quake of 1931. New Zealand is periodically subject to earthquake shocks



two reflections of these waves at the earth's surface may occur, at one-third and two-thirds the distance, and be recorded as superimposed phases. The first case may be designated as PR1, SR1, and the latter as PR2 and SR2. The seismograph record of such tremors indicates not only the paths by which the various kinds of waves reached the instrument, but also the properties of the materials through which the waves passed. The earth thus not only writes its own epitaph, but this inscription is full of meaning and is worthy of our careful inspection. For distant earthquakes, the beginnings as well as the continuation of the different phases of the record are indicated on the seismogram by sudden or gradual increases of amplitude, by sudden change of period, or both, and by the order of succession in which they occur. For instance, it has been determined that the P-waves, the first to arrive, are longitudinal or compressional waves with vibrations in the direction of progress. They are fast and of small amplitude, usually less than a millimeter. Their velocity near the surface is 7 to 8 kilometers per second and their period varies from 5 to 7 seconds. They usually follow a direct path from the point of origin to the recording seismograph, but a curved one, since in passing through, they dip toward the center of the earth where the rocks are denser and their rate of propagation is faster.

#### WAVES AND VIBRATIONS

The S-waves are transverse or distortional with vibrations at right angles to the direction of progress. They are slower than the P-waves, and have a velocity near the surface of about 4.5 kilometers per second. Their period is 11 to 13 seconds. They follow approximately the same path as the P-waves.

The main or long waves, L, which pass around the surface are complex longitudinal waves. Their velocity is 3 to 4 kilometers per second, depending on conditions. According to N. H. Heck, chief seismologist of the U. S. Coast and Geodetic Survey,

their velocity under the Pacific ocean is about 20 per cent greater than under the continents. Their periods vary greatly and may be as large as 40 or 60 seconds.

The P and S waves of sharp, well defined single shocks can be definitely differentiated on a seismograph record for those earthquakes which originate at places more than 700 miles and less than 7000 miles distant from the recording instrument. Furthermore, with an accurate timing apparatus the times of arrival of these waves can usually be definitely determined on the record, the difference noted, and the distance from the receiving station to the point of origin (epicenter) calculated, or read off from an empirical table or its graph, with an error not greater than 25 to 50 miles. By using the determined distance as a radius, and the location of the station as a center, a circle may be inscribed on a globe, or scaled map, which will pass through the epicenter. Its location on the circle may be determined by applying the same method to distances obtained from two other widely separated stations, using one or the other of those stations as the center of the second and third circles. The point of intersection of the three circles, or the center of the triangle formed by them, will be the location of the epicenter. The use of the duration of the first preliminary tremor for determining the position of the epicenter of a distant earthquake is known as the Zeissig method. It is the one used by most observers. Other methods are sometimes used but they require special apparatus.

Whatever method is used it may be noted that since 1899 there has been an ever-increasing accuracy in locating earthquakes, especially those 700 to 7000 miles distant from recording stations. The location of the main seismic areas is now well known—one belt extends around the margins of the Pacific Ocean, another forms a great circle about the earth through the Mediterranean-Caribbean regions. Other areas of frequency are less well defined, for isolated occurrences are common in many parts of the world, except

*H. Armstrong Roberts, photo*

Extending in a vast horseshoe from Cape Horn up the coast of the Americas across to Asia and down to the East Indies is a great band which includes mountains and islands of geologically recent formation. Most of the West Indies also are included in this region throughout which earthquakes are occasionally experienced. The view on the right was taken on the island of Puerto Rico, and the photograph below shows the Chilean Andes rising abruptly from the sea

*Publishers Photo Service*



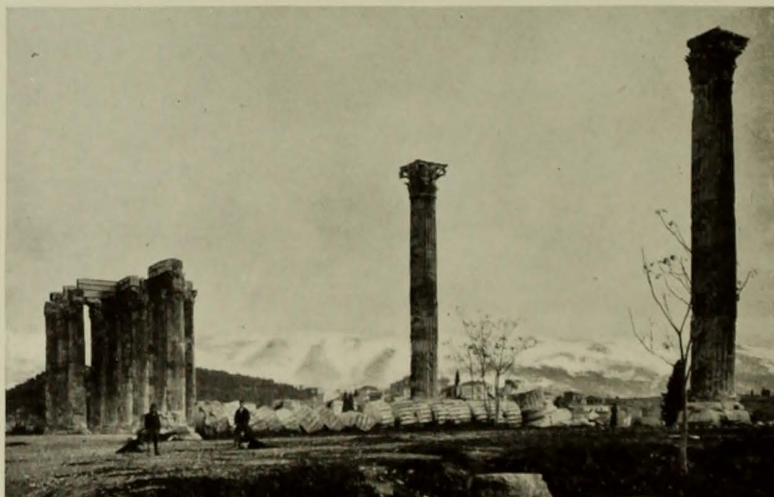


## Athens

A view of the city from the top of the Stadium. Both Greece and Palestine occasionally feel the effects of earthquakes, for old though these regions are in the history of civilization, they are comparatively young as the geologist measures the age of the earth.

Right: A view of the Temple of Jupiter with some of its fallen columns. Many of the Greek ruins have been brought to their present condition by earthquakes

*Publishers Photo Service*



in the polar regions, where few earthquakes have been registered during the past thirty-five years.

For near-earthquakes, that is, those that occur within  $10^\circ$ , or 700 miles, of the epicenter, there is no separation, on most seismograph records, of the primary waves, P, and of the secondary waves, S, and it has been suggested that for this distance each wave possesses both types of characters. In other words, the characteristic features of these waves, condensational on the one hand and distortional on the other, are not differentiated on seismograph records made by instruments designed and set for those quakes originating 700 to 7000 miles away and known as distant quakes. Specially constructed instruments are required to separate P and S waves of near-earthquakes.

Those far distant earthquakes, which originate 7000 to 10,000 miles or farther from a recording station, do not register the P waves, as the first recorded impulses, since these waves are refracted at a depth of 2900 kilometers (1802 miles) into the inner core of the earth and produce by their refractions what is known as the "blind zone." Such refracted waves, when recorded, are designated as P' waves. The velocity of these waves just outside the central core is 13 kilometers (8 miles) per second; inside it is 8.5 km. (5.3 miles) per second.

So far as we know the S-waves originating 7000 to 10,000 miles distant do not emerge from the inner core and we may assume, since they are not transmitted through substances in a liquid or gaseous state, that the inner core, with radius 3470 km. (2157 miles) or .55 of the radius of the earth, is in a liquid or gaseous condition and composed of a molten mixture of the heavy metals iron and nickel.

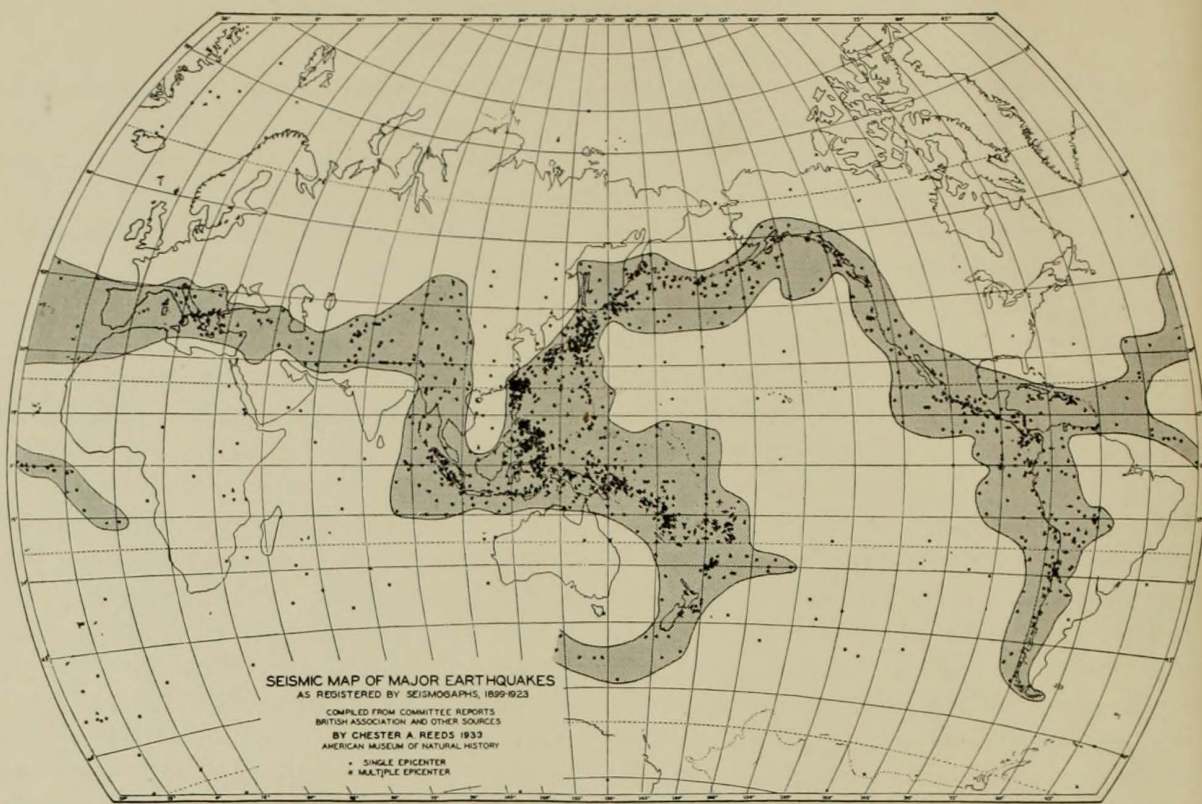
The study of distant earthquake records has indicated that the surface of the inner core is a well marked surface of discontinuity, and that it refracts or reflects the waves which meet it. Some four other less pronounced discontinuities separate the zones of the earth which appear above it.

The one appearing at a depth of about 60 kilometers (37 miles) is well marked in many seismograph records. It is the lower margin of the crust of the earth.

These planes of discontinuity change the path and energy of earthquake waves.

#### PROBLEMS TO BE SOLVED

The foregoing discussion gives a brief resumé of the general status of our knowledge concerning the earth's interior, the propagation of earthquake waves, and the significance of seismograph records. While various seismological investigations have been carried on during the past thirty-five years, which have thrown a flood of light upon hitherto unsolved problems and hidden features of the earth, we would like to know more about the earth's interior, the elastic properties of the earth, the conditions which produce earthquakes, and the composition and structure of the layers composing the crust. Geological observations on surface indications during the past 150 years lead us to believe that the crust is composed of numerous layers of rock which are variable in number, extent, origin, structure, and composition. The recent development of seismic prospecting for oil and other minerals and the effect of the propagation of earthquake waves on buildings and other structures emphasize the importance of these researches. Daily observation and studies are being conducted by various organizations. In the United States they are being carried on by the National Government through the Coast and Geodetic Survey with the cooperation of the Weather Bureau, the Geological Survey, the Bureau of Standards, and the National Research Council. Other organizations are also coöperating, such as the Carnegie Institution of Washington, the Jesuit Seismological Association, and the various universities, colleges, and museums in different parts of the country. The ultimate aim of this study is a better understanding of the elastic conditions of the earth.



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## A SEISMIC MAP OF THE WORLD

BY CHESTER A. REEDS

This map shows the epicenters of 1783 major earthquakes. These large earthquakes were recorded at various seismological stations during the twenty-five-year period 1899–1923. The data for the map were compiled from the reports of the Seismological Committee of the British Association, the Canadian Observatory, the Seismological Society of America and other organizations.

The solid black dots show the location of single major disturbances. The circles with one or more radiating rays indicate places where large earthquakes have been repeated at different times during the twenty-five-year period. Each ray represents a recurrence. Some circles have as many as sixteen rays. Major earthquakes are usually produced by pronounced movements along fault planes. They generate waves of sufficient intensity to pass through the earth and be recorded at seismological stations situated at points more than half way around the earth from the place of origin. Those numerous minor quakes which are recorded by nearby stations and which may have exceeded 100,000 in number during the twenty-five-year period, are not shown on the map. If they had been plotted they would show a more widespread distribution. Most of them, however, would be confined to the shaded zone which represents those belts of the earth where the highest and youngest mountains and deepest troughs of the oceans occur.

The map shows that most earthquakes originate in rocks beneath the oceans and that they are confined for the most part to two great belts, one running from west to east through the Mediterranean and Caribbean Seas and the other adhering to the margins of the Pacific Ocean. The ancient shields of the continental masses, which include the great ice wastes of the polar regions, are underlaid by old rocks which are, for the most part, free of earthquakes.

Prior to the development of modern seismology by John Milne and his associates in the late Nineties, our knowledge of the occurrence of earthquakes was confined to the destruction wrought by them on land. From instrumental records, we now know that most earthquakes originate beneath the oceans and in those parts of the land where geomorphic changes are taking place in the crust of the earth.



