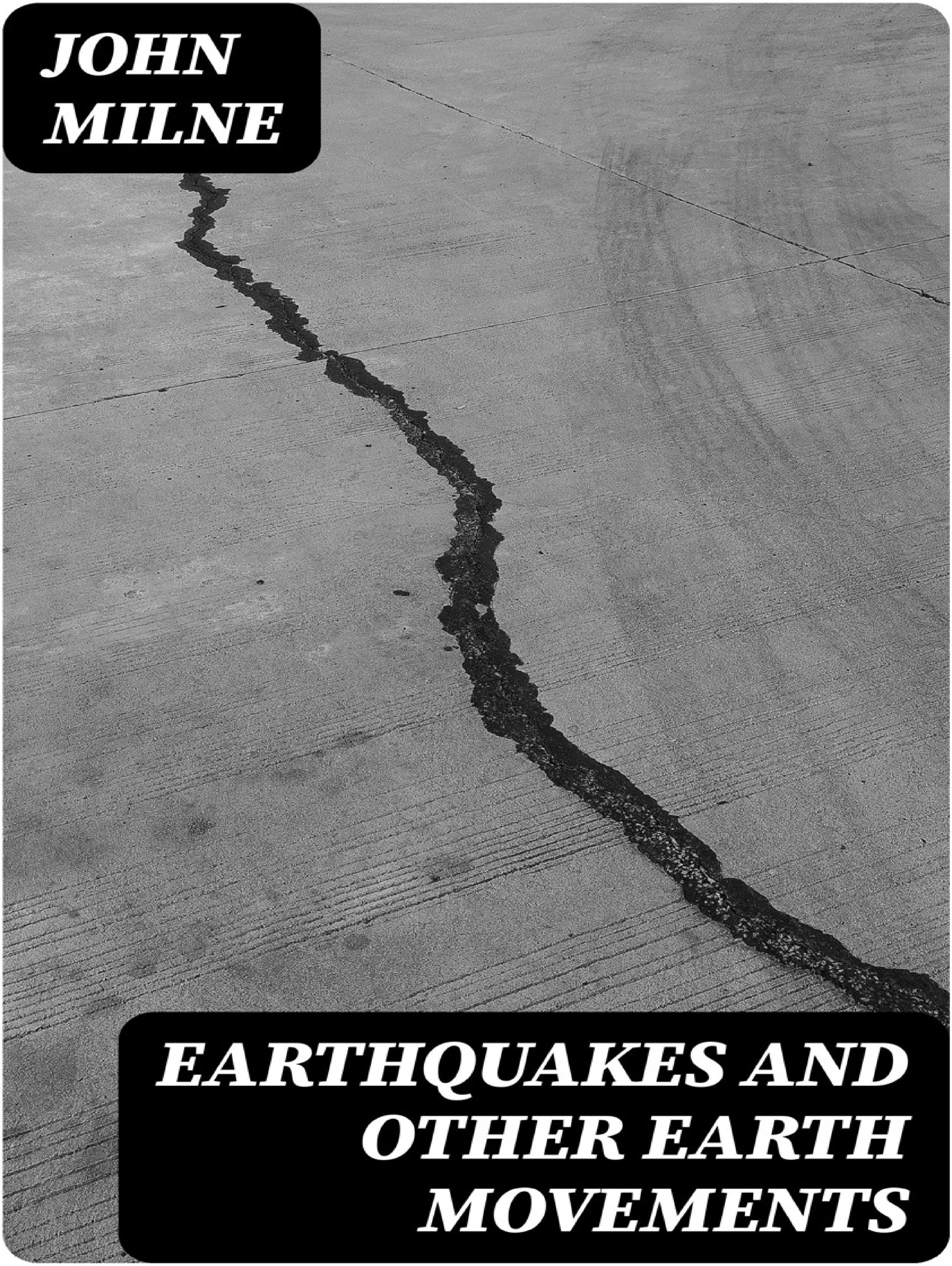

JOHN MILNE

EARTHQUAKES AND OTHER EARTH MOVEMENTS

John Milne

Earthquakes and Other Earth Movements

EAN 8596547307754

DigiCat, 2022
Contact: DigiCat@okpublishing.info

Table of Contents

PREFACE

Table of Contents

In the following pages it has been my object to give a systematic account of various Earth Movements.

These comprise *Earthquakes*, or the sudden violent movements of the ground; *Earth Tremors*, or minute movements which escape our attention by the smallness of their amplitude; *Earth Pulsations*, or movements which are overlooked on account of the length of their period; and lastly, *Earth Oscillations*, or movements of long period and large amplitude which attract so much attention from their geological importance.

It is difficult to separate these Earth Movements from each other, because they are phenomena which only differ in degree, and which are intimately associated in their occurrence and in their origin.

Because Earthquakes are phenomena which have attracted a universal attention since the earliest times, and about them so many observations have been made, they are treated of at considerable length.

As very much of what might be said about the other Earth Movements is common to what is said about Earthquakes, it has been possible to make the description of these phenomena comparatively short.

The scheme which has been adopted will be understood from the following table:—

I. Earthquakes.

1. Introduction.

2. Seismometry.

3. Earthquake Motion.	{	(*a*) Theoretically. (*b*) As deduced from experiments. (*c*) As deduced from actual Earthquakes.
4. Earthquake Effects.	{	(*a*) On land. (*b*) In the ocean.

5. Determination of Earthquake origins.

6. Distribution of Earthquakes.	{	(*a*) In space. (*b*) In time (geological time, historical time, annual, seasonal, diurnal, &c.)

7. Cause of Earthquakes.

8. Earthquake prediction and warning.

II. Earth Tremors.

III. Earth Pulsations.

IV. Earth Oscillations.

In some instances the grouping of phenomena according to the above scheme may be found inaccurate, as, for example, in the chapters referring to the effects and causes of Earthquakes.

This arises from the fact that the relationship between Earthquakes and other Earth phenomena are not well understood. Thus the sudden elevation of a coast line and an accompanying earthquake may be related, either as effect and cause, or *vice versâ*, or they may both be the effect of a third phenomenon.

Much of what is said respecting Earthquake motion will show how little accurate knowledge we have about these disturbances. Had I been writing in England, and, therefore, been in a position to make references to libraries and persons who are authorities on subjects connected with Seismology, the following pages might have been made more complete, and inaccuracies avoided. A large proportion of the material embodied in the following pages is founded on experiments and observations made during an eight years' residence in Japan, where I have had the opportunity of recording an earthquake every week.

The writer to whom I am chiefly indebted is Mr. Robert Mallet. Not being in a position to refer to original memoirs, I have drawn many illustrations from the works of Professor Karl Fuchs and M. S. di Rossi. These, and other writers to whom reference has been made, are given in an appendix.

For seeing these pages through the press, my thanks are due to Mr. Thomas Gray, who, when residing in Japan, did so much for the advancement of observational Seismology.

For advice and assistance in devising experiments, I tender my thanks to my colleagues, Professor T. Alexander, Mr. T. Fujioka, and to my late colleague. Professor John Perry.

For assistance in the actual observation of Earthquakes, I have to thank my friends in various parts of Japan,

especially Mr. J. Bissett and Mr. T. Talbot, of Yokohama. For assistance in obtaining information from Italian sources I have to thank Dr. F. Du Bois, from German sources Professor C. Netto, and from Japanese sources Mr. B. H. Chamberlain. For help in carrying out experiments, I am indebted to the liberality of the British Association, the Geological Society of London, the Meteorological and Telegraph departments of Japan, and to the officers of my own institution, the Imperial College of Engineering.

And, lastly, I offer my sincere thanks to those gentlemen who have taken part in the establishment and working of the Seismological Society of Japan, and to my publishers, whose liberality has enabled me to place the labours of residents in the Far East before the European public.

JOHN MILNE.

TOKIO, JAPAN; *June* 30, 1883

EARTHQUAKES.

CHAPTER I.
INTRODUCTION.

Table of Contents

Relationship of man to nature—The aspect of a country is dependent on geological phenomena—Earthquakes an important geological phenomenon—Relationship of seismology to the sciences and arts—Earth movements other than earthquakes—Seismological literature—(Writings of Perrey, Mallet, Eastern writings, the Philosophical Transactions of the Royal Society, the 'Gentleman's Magazine,' the Bible, Herodotus, Pliny, Hopkins, Von Hoff, Humboldt, Schmidt, Seebach, Lasaulx, Fuchs, Palmieri, Bertelli, Seismological Society of Japan)—Seismological terminology.

In bygone superstitious times lightning and thunder were regarded as supernatural visitations. But as these phenomena became better understood, and men learned how to avoid their destructive power, the superstition was gradually dispelled. Thus it is with Earthquakes: the more clearly they are understood, the more confident in the universality of law will man become, and the more will his mental condition be advanced.

In his 'History of Civilisation in England,' Buckle has laid considerable stress upon the manner in which earthquakes, volcanoes, and other of the more terrible forms in which the workings of nature reveal themselves to us, have exerted an influence upon the imagination and understanding; and just as a sudden fright may affect the nerves of a child for the remainder of its life, we have in the annals of seismology records which indicate that earthquakes have not been without a serious influence upon the mental condition of whole communities.

To a geologist there are perhaps no phenomena in nature more interesting than earthquakes, the study of which is called Seismology. Coming, as shocks often will, from a region of volcanoes, the study of these disturbances may enable us to understand something about the nature and working of a volcano. As an earthquake wave travels along from strata to strata, if we study its reflections and changing velocity in transit, we may often be led to the discovery of certain rocky structures buried deep beneath our view, about which, without the help of such waves, it would be hopeless ever to attain any knowledge.

By studying the propagation of earthquake waves the physicist is enabled to confirm his speculations respecting the transmission of disturbances in elastic media. For the physicist earthquakes are gigantic experiments which tell him the elastic moduli of rocks as they exist in nature, and when properly interpreted may lead him to the proper comprehension of many ill-understood phenomena. It is not impossible that seismological investigation may teach us something about the earth’s magnetism, and the connection between earthquakes and the ‘earth currents’ which appear in our telegraph wires. These and numerous other kindred problems fall within the domain of the physicist.

It is of interest to the meteorologist to know the connections which probably exist between earthquakes and the fluctuations of the barometer, the changes of the thermometer, the quantity of rainfall, and like phenomena to which he devotes his attention.

Next we may turn to the more practical aims of seismology and ask ourselves what are the effects of earthquakes upon buildings, and how, in earthquake-shaken countries, the buildings are to be made to withstand them. Here we are face to face with problems which demand the attention of engineers and builders. To attain what we desire, observation, common sense, and subtle reasoning must be brought to bear upon this subject.

In the investigation of the principle on which earthquake instruments make their records, in the analysis of the results they give, in problems connected with astronomy, with physics, and with construction, seismology offers to the mathematician new fields for investigation.

A study of the effects which earthquakes produce on the lower animals will not fail to interest the student of natural history.

A study like seismology, which leads us to a more complete knowledge of earth-heat and its workings, is to be regarded as one of the corner-stones of geology. The science of seismology invites the co-operation of workers and thinkers in almost every department of natural science.

We have already referred to the influence exerted by earthquakes over the human mind. How to predict earthquakes, and how to escape from their dangers, are problems which, if they can be solved, are of extreme interest to the world at large.

In addition to the sudden and violent movements which we call earthquakes, the seismologist has to investigate the smaller motions which we call earth tremors. From observations which have been made of late years, it would appear that the ground on which we dwell is incessantly in a state of tremulous motion.

A further subject of investigation which is before the seismologist is the experimental verification of the existence of what may be called ‘earth-pulsations.’ These are motions which mathematical physicists affirmed the existence of, but which, in consequence of the slowness of their period, have hitherto escaped observation.

The oscillations, or slow changes in the relative positions of land and sea, might also be included; but this has already been taken up as a separate branch of geology.

These four classes of movements are no doubt interdependent, and seismology in the widest sense might conveniently be employed to include them all. In succeeding chapters we will endeavour to indicate how far the first three of these branches have been prosecuted, and to point out that which remains to be accomplished. It is difficult, however, to form a just estimate of the amount of seismological work which has been done, in consequence of the scattered and uncertain nature of many of the records. Seismology, as a science, originated late, chiefly owing to the facts that centres of civilisation are seldom in the most disturbed regions, and that earthquake-shaken countries are widely separated from each other.

As every portion of the habitable globe appears to have been shaken more or less by earthquakes, and as these phenomena are so terrible in their nature, we can readily understand why seismological literature is extensive. In the annals of almost every country which has a written history, references are made to seismic disturbances.

An idea of the attention which earthquakes have received may be gathered from the fact that Professor Alexis Perrey, of Dijon, who has published some sixty memoirs on this subject, gave, in 1856, a catalogue of 1,837 works devoted to seismology.[1] In 1858 Mr. Robert Mallet published in the Reports of the British Association a list of several hundred works relating to earthquakes. Sixty-five of these works are to be found in the British Museum. So far as literature is concerned, earthquakes have received as much attention in the East as in the West. In China there are many works treating on earthquakes, and the attention which these phenomena received may be judged of from the fact that in A.D. 136 the Government appointed a commission to inquire into the subject. Even the isolated empire of Japan can boast of at least sixty-five works on earthquakes, seven of which are earthquake calendars, and twenty-three earthquake monographs.[2] Besides those treating especially of earthquakes, there are innumerable references to such disturbances in various histories, in the transactions of learned societies, and in periodicals. To attempt to give a complete catalogue of even the books which have been written would be to enter on a work of compilation which would occupy many years, and could never be satisfactorily finished.

In the ‘Philosophical Transactions of the Royal Society,’ which were issued in the eighteenth century, there are about one hundred and eighty separate communications on earthquakes; and in the ‘Gentleman’s Magazine’ for 1755 there are no less than fifty notes and articles on the same subject. The great interest shown in earthquakes about the years 1750–60 in England, was chiefly due to the terrible calamity which overtook Lisbon in 1755, and to the fact that about this time several shocks were experienced in various parts of the British Islands. In 1750, which may be described as the earthquake year of Britain, ‘a shock was felt in Surrey on March 14; on the 18th of the same month the whole of the south-west of England was disturbed. On April 2, Chester was shaken; on June 7, Norwich was disturbed; on August 23, the inhabitants of Lancashire were alarmed; and on September 30 ludicrous and alarming scenes occurred in consequence of a shock having been felt during the hours of Divine service, causing the congregations to hurry into the open air.’[3] As might be expected, these occurrences gave rise to many articles and notes directing attention to the subject of earthquakes.

Seismic literature has not, however, at all times been a measure of seismic activity: thus, in Japan, the earthquake records for the twelfth and sixteenth centuries scarcely mention any shocks. At first sight it might be imagined that this was owing to an absence of earthquakes; but it is sufficiently accounted for by the fact that at that time the country was torn with civil war, and matters more urgent than the recording of natural phenomena engaged the attention of the inhabitants. Professor Rockwood, who has given so much attention to seismic disturbances in America, tells us that during the recent contest between Chili and Peru a similar intermission is observable. We see, therefore, that an absence of records does not necessarily imply an absence of the phenomena to be recorded.

Perhaps the earliest existing records of earthquakes are those which occur in the Bible. The first of these, which we are told occurred in Palestine, was in the reign of Ahab (B.C. 918–897).[4] One of the most terrible earthquakes mentioned in the Bible is that which took place in the days of Uzziah, king of Judah (B.C. 811–759), which shook the ground and rent the Temple. The awful character of this, and the deep impression produced on men’s minds, may be learned from the fact that the time of its occurrence was subsequently used as an epoch from which to reckon dates.

The writings of Herodotus, Pliny, Livy, &c., &c., show the interest which earthquakes attracted in early ages. These writers chiefly devoted themselves to references and descriptions of disastrous shocks, and to theories respecting the cause of earthquakes.

The greater portion of the Japanese notices of earthquakes is simply a series of anecdotes of events which took place at the time of these disasters. We also find references to superstitious beliefs, curious occurrences, and the apparent connection between earthquake disturbances and other natural phenomena. In these respects the literature of the East closely resembles that of the West. The earthquake calendars of the East, however, form a class of books which can hardly be said to find their parallel in Europe;[5] while, on the other hand, the latter possesses types of books and pamphlets which do not appear to have a parallel elsewhere. These are the more or less theological works—‘Moral Reflections on Earthquakes,’ ‘Sermons’ which have been preached on earthquakes, ‘Prayers’ which have been appointed to be read.[6]

Speaking generally, it may be said that the writings of the ancients, and those of the Middle Ages, down to the commencement of the nineteenth century, tended to the propagation of superstition and to theories based on speculations with few and imperfect facts for their foundation.

Among the efforts which have been made in modern times to raise seismology to a higher level, is that of Professor Perrey, of Dijon, who commenced in 1840 a series of extensive catalogues embracing the earthquakes of the world. These catalogues enabled Perrey, and subsequently Mallet in his reports to the British Association, to discuss the periodicity of earthquakes, with reference to the seasons and to other phenomena, in a more general manner than it had been possible for previous workers to accomplish. The facts thus accumulated also enabled Mallet to discuss earthquakes in general, and the various phenomena which they present were sifted and classified for inspection. Another great impetus which observational seismology received was Mr. Mallet’s report upon the Neapolitan earthquake of 1857, in which new methods of seismic investigation were put forth. These have formed the working tools of many subsequent observers, and by them, as well as by his experiments on artificially produced disturbances, Mallet finally drew the study of earthquakes from the realms of speculation by showing that they, like other natural phenomena, were capable of being understood and investigated.

In addition to Perrey and Mallet, the nineteenth century has produced many writers who have taken a considerable share in the advancement of seismology. There are the catalogues of Von Hoff, the observations of Humboldt, the theoretical investigations of Hopkins, the monographs of Schmidt, Seebach, Lasaulx, and others; the books of Fuchs, Credner, Vogt, Volger; the records and observations of Palmieri, Bertelli, Rossi, and other Italian observers. To these, which are only a few out of a long list of names, may be added the publications of the Commission appointed for the observation of earthquakes by the Natural History Society of Switzerland, and the volumes which have been published by the Seismological Society of Japan.

Before concluding this chapter it will be well to define a few of the more ordinary terms which are used in describing earthquake phenomena. It may be observed that the English word *earthquake*, the German *erdbeben*, the French *tremblement de terre*, the Spanish *terremoto*, the Japanese *jishin* &c., all mean, when literally translated, *earth-shaking*, and are popularly understood to mean a sudden and more or less violent disturbance.

Seismology (σειμός an earthquake, λόγος a discourse) in its simplest sense means the study of earthquakes. To be consistent with a Greek basis for seismological terminology, some writers have thrown aside the familiar expression ‘earthquake,’ and substituted the awkward word ‘seism.’

The source from which an earthquake originates is called the ‘origin,’ ‘focal cavity,’ or ‘centrum.’

The point or area on the surface of the ground above the origin is called the ‘epicentrum.’ The line joining the centrum and epicentrum is called the ‘seismic vertical.’

The radial lines along which an earthquake may be propagated from the centrum are called ‘wave paths.’

The angle which a wave path, where it reaches the surface of the earth, makes with that surface is called the ‘angle of emergence’ of the wave. This angle is usually denoted by the letter *e*.

As the result of a simple explosion at a point in a homogeneous medium, we ought, theoretically, to obtain at points on the surface of the medium equidistant from the epicentrum, equal mechanical effects. These points will lie on circles called ‘isoseismic’ or ‘coseismic’ circles. The area included between two such circles is an ‘isoseismic area.’ In nature, however, isoseismic lines are seldom circles. Elliptical or irregular curves are the common forms.

The isoseismic area in which the greatest disturbance has taken place is called the ‘meizoseismic area.’ Seebach calls the lines enclosing this area ‘pleistoseists.’

These last-mentioned lines are wholly due to Mallet and Seebach.

Many words are used to distinguish different kinds of earthquakes from each other. All of these appear to be very indefinite and to depend upon the observer’s feelings, which, in turn, depend upon his nervous temperament and his situation.

In South America small earthquakes, consisting of a series of rapidly recurring vibratory movements not sufficiently powerful to create damage, are spoken of as *trembelores*.

The *terremotos* of South America are earthquakes of a destructive nature, in which distinct shocks are perceptible. It may be observed that shocks which at one place would be described as *terremoto* would at another and more distant place probably be described as *trembelores*.

The *succussatore* are the shocks where there is considerable vertical motion. The terrible shock of Riobamba (February 4, 1797), which is said to have thrown corpses from their graves to a height of 100 feet, was an earthquake of this order.

The *vorticosi* are shocks which have a twisting or rotatory motion.

Another method of describing earthquakes would be to refer to instrumental records. When the vibrations of the ground have only been along the line joining the observer and the epicentrum, the disturbance might be called ‘euthutropic.’ A disturbance in which the prominent movements are *transverse* to the above direction might be called ‘diagonic.’ If motions in both of these directions occur in the records, the shock might be said to be ‘diastrophic.’ If there be much vertical movement, the shock might be said to be ‘anaseismic.’ Some disturbances could only be described by using two or three of these terms.

CHAPTER II.
SEISMOMETRY.

Table of Contents

Nature of earthquake vibrations—Many instruments called seismometers only seismoscopes—Eastern seismoscopes, columns, projection seismometers—Vessels filled with liquid—Palmieri's mercury tubes—The ship seismoscope—The cacciatore—Pendulum instruments of Kreil, Wagner, Ewing, and Gray—Bracket seismographs—West's parallel motion instrument—Gray's conical pendulums, rolling spheres, and cylinders—Verbeck's ball and plate seismograph—The principle of Perry and Ayrton—Vertical motion instruments—Record receivers—Time-recording apparatus—The Gray and Milne seismograph.

Before we discuss the nature of earthquake motion, the determination of which has been the aim of modern seismological investigation, the reader will naturally look for an account of the various instruments which have been employed for recording such disturbances. A description of the earthquake machines which have been used even in Japan would form a bulky volume. All that we can do, therefore, is to describe briefly the more prominent features of a few of the more important of these instruments. In order that the relative merits of these may be better understood, we may state generally that modern research has shown a typical earthquake to consist of a series of small tremors succeeded by a shock, or series of shocks, separated by more or less irregular vibrations of the ground. The vibrations are often both irregular in period and in amplitude, and they have a duration of from a few seconds to several minutes. We will illustrate the records of actual earthquakes in a future chapter, but in the meantime the idea that an earthquake consists of a single shock must be dismissed from the imagination.

To construct an instrument which at the time of an earthquake shall move and leave a record of its motion, there is but little difficulty. Contrivances of this order are called *seismoscopes*. If, however, we wish to know the period, extent, and direction of each of the vibrations which constitutes an earthquake, we have considerable difficulty. Instruments which will in this way measure or write down the earth’s motions are called *seismometers* or *seismographs*.

Many of the elaborate instruments supplemented with electro-magnetic and clockwork arrangements are, when we examine them, nothing more than elaborate seismoscopes which have been erroneously termed seismographs.

The only approximations to true seismographs which have yet been invented are without doubt those which during the past few years have been used in Japan. It would be a somewhat arbitrary proceeding, however, to classify the different instruments as seismoscopes, seismometers, and seismographs, as the character of the record given by certain instruments is sometimes only seismoscopic, whilst at other times it is seismometric, depending on the nature of the disturbance. Many instruments, for instance, would record with considerable accuracy a single sudden movement, but would give no reliable information regarding a continued shaking.

Eastern Seismoscopes.—The earliest seismoscope of which we find any historical record is one which owes its origin to a Chinese called Chôko. It was invented in the year A.D. 136. A description is given in the Chinese history called 'Gokanjo,' and the translation of this description runs as follows:—

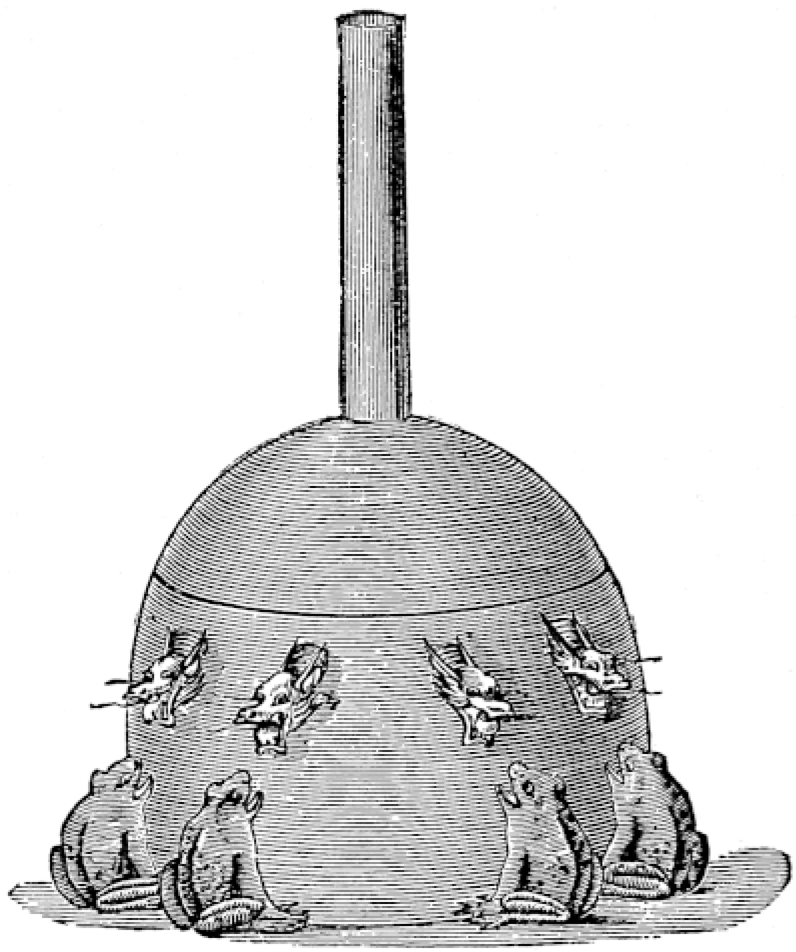

FIG. 1.

'In the first year of Yōka, A.D. 136, a Chinese called Chôko invented the seismometer shown in the accompanying drawing. This instrument consists of a spherically formed copper vessel, the diameter of which is eight feet. It is covered at its top, and in form resembles a wine-bottle. Its outer part is ornamented by the figures of different kinds of birds and animals, and old peculiar-looking letters. In the inner part of this instrument a column is so suspended that it can move in eight directions. Also, in the inside of the bottle, there is an arrangement by which some record of an earthquake is made according to the movement of the pillar. On the outside of the bottle there are eight dragon heads, each of which holds a ball in its mouth. Underneath these heads there are eight frogs so placed that they appear to watch the dragon’s face, so that they are ready to receive the ball if it should be dropped. All the arrangements which cause the pillar to knock the ball out of the dragon’s mouth are well hidden in the bottle.’

‘When an earthquake occurs, and the bottle is shaken, the dragon instantly drops the ball, and the frog which receives it vibrates vigorously; any one watching this instrument can easily observe earthquakes.’

With this arrangement, although one dragon may drop a ball, it is not necessary for the other seven dragons to drop their balls unless the movement has been in all directions; thus we can easily tell the direction of an earthquake.

‘Once upon a time a dragon dropped its ball without any earthquake being observed, and the people therefore thought the instrument of no use, but after two or three days a notice came saying that an earthquake had taken place at Rōsei. Hearing of this, those who doubted the use of this instrument began to believe in it again. After this ingenious instrument had been invented by Chōko, the Chinese Government wisely appointed a secretary to make observations on earthquakes.’

Not only is this instrument of interest on account of its antiquity, but it is also of interest on account of the close resemblance it bears to many of the instruments of modern times.

Another earthquake instrument also of Eastern origin is the magnetic seismoscope of Japan.

On the night of the destructive earthquake of 1855, which devastated a great portion of Tokio, the owner of a spectacle shop in Asakusa observed that a magnet dropped some old iron nails and keys which had been attached to it. From this occurrence the owner thought that the magnet had, in consequence of its age, lost its powers. About two hours afterwards, however, the great earthquake took place, after which the magnet was observed to have regained its powers. This occurrence led to the construction of the seismoscope, which is illustrated in a book called the ‘Ansei-Kembun-Roku,’ or a description of the earthquake of 1855, and examples of the instrument are still to be seen in Tokio. These instruments consist of a piece of magnetic iron ore, which holds up a piece of iron like a nail. This nail is connected, by means of a string, with a train of clockwork communicating with an alarm. If the nail falls a catch is released and the clockwork set in motion, and warning given by the ringing of a bell. It does not appear that this instrument has ever acted with success.

Columns.—One of the commonest forms of seismoscope, and one which has been very widely used, consists of a round column of wood, metal, or other suitable material, placed, with its axis vertical, on a level plane, and surrounded by some soft material such as loose sand to prevent it rolling should it be overturned. The fall of such a column indicates that a shaking or shock has taken place.

Attempts have been made by using a number of columns of different sizes to make these indications seismometric, but they seldom give reliable information either as to intensity or direction of shock. The indications as to intensity are vitiated by the fact that a long-continued gentle shaking may overturn a column which would stand a very considerable sudden shock, while the directions in which a number of columns fall seldom agree owing to the rotational motion imparted to them by the shaking. Besides, the direction of motion of the earthquake seldom remains in the same azimuth throughout the whole disturbance.

An extremely delicate, and at the same time simple form of seismoscope may be made by propping up strips of glass, pins, or other easily overturned bodies against suitably placed supports. In this way bodies may be arranged, which, although they can only fall in one direction, nevertheless fall with far less motion than is necessary to overturn any column which will stand without lateral support.

Projection Seismometers.—Closely related to the seismoscopes and seismometers which depend on the overturning of bodies. Mallet has described two sets of apparatus whose indications depend on the distance to which a body is projected. In one of these, which consisted of two similar parts arranged at right angles, two metal balls rest one on each side of a stop at the lower part of two inclined  like troughs. In this position each of the balls completes an electric circuit. By a shock the balls are projected or rolled up the troughs, and the height to which they rise is recorded by a corresponding interval in the break of the circuits. The vertical component of the motion is measured by the compression of a spring which carries the table on which this arrangement rests. In the second apparatus two balls are successively projected, one by the forward swing, and the other by the backward swing of the shock. Attached to them are loose wires forming terminals of the circuits. They are caught in a bed of wet sand in a metal trough forming the other end of the circuit. The throw of the balls as measured in the sand, and the difference of time between their successive projections as indicated by special contrivances connected with the closing of the circuits, enables the observer to calculate the direction of the wave of shock, its velocity, and other elements connected with the disturbance. It will be observed that the design of this apparatus assumes the earthquake to consist of a distinct isolated shock.

Oldham, at the end of his account of the Cachar earthquake of 1869, recommends the use of an instrument based on similar principles. In his instrument four balls like bullets are placed in notches cut in the corners of the upper end of a square stake driven into the ground.

Vessels filled with liquid.—Another form of simple seismoscope is made by partially filling a vessel with liquid. The height to which the liquid is washed up the side of the vessel is taken as an indication of the intensity of the shock, and the line joining the points on which maximum motion is indicated, is taken as the direction of the shock. If earthquakes all lasted for the same length of time, and consisted of vibrations of the same period, such instruments might be of service. These instruments have, however, been in use from an early date. In 1742 we find that bowls of water were used to measure the earthquakes which in that year alarmed the inhabitants of Leghorn. About the same time the Rev. S. Chandler, writing about the shock at Lisbon, tells us that earthquakes may be measured by means of a spherical bowl about three or four feet in diameter, the inside of which, after being dusted over with Barber's puff, is filled very gently with water. Mallet, Babbage, and De la Bêche have recommended the same sort of contrivance, but, notwithstanding, it has justly been criticised as 'ridiculous and utterly impracticable.'[7]

An important portion of Palmieri's well-known instrument consists of horizontal tubes turned up at the ends and partially filled with mercury. To magnify the motion of the mercury, small floats of iron rest on its surface. These are attached by means of threads to a pulley provided with indices which move in front of a scale of degrees. We thus read off the intensity of an earthquake as so many degrees, which means so many millimetres of washing up and down of mercury in a tube. The direction of movement is determined by the azimuth of the tube which gives the maximum indication, several tubes being placed in different azimuths.

This form of instrument appears to have been suggested by Mallet, who gives an account of the same in 1846. Inasmuch as the rise and fall of the mercury in such tubes depend on its depth and on the period of the earthquake together with its duration, we see that although the results obtained from a given instrument may give us means of making approximate comparisons as to the relative intensity of various earthquakes, it is very far from yielding any absolute measurement.

Another method which has been employed to magnify and register the motions of liquid in a vessel has been to float upon its surface a raft or ship from which a tall mast projected. By a slight motion of the raft, the top of the mast vibrated through a considerable range. This motion of the mast as to direction and extent was then recorded by suitable contrivances attached to the top of the mast.

A very simple form of liquid seismoscope consists of a circular trough of wood with notches cut round its side. This is filled with mercury to the level of the notches. At the time of an earthquake the maximum quantity of mercury runs over the notches in the direction of greatest motion. This instrument, which has long been used in Italy, is known as a Cacciatore, being named after its inventor. It is a prominent feature in the collection of apparatus forming the well-known seismograph of Palmieri.

Pendulum instruments.—Mallet speaks of pendulum seismoscopes and seismographs as 'the oldest probably of seismometers long set up in Italy and southern Europe.' In 1841 we find these being used to record the earthquake disturbances at Comrie in Scotland.

These instruments may be divided into two classes: first, those which at the time of the shock are intended to swing, and thus record the direction of movement; and second, those which are supposed to remain at rest and thus provide 'steady points.'

To obtain an absolutely 'steady point' at the time of an earthquake, has been one of the chief aims of all recent