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The Seismograph and Earthquakes

BY

OTTO KLOTZ, D.Sc., F.R.A.S.

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DOMINION LAND SURVEYORS' ASSOCIATION.

CARNEGIE LIBRARY,
AFTERNOON OF MARCH 3RD, 1914.

MR. C. F. AYLSWORTH (in the chair): Gentlemen, the time has arrived to begin the proceedings this afternoon, and unfortunately I am called upon to act as your chairman. A year ago upon the resignation of Mr. Belanger, it fell upon me, your humble servant, to act as your chairman. This year I thought that a change should be made and Mr. McArthur was honored this morning, but he fell by the wayside. He became sick and is unable to proceed further with this meeting. It will therefore fall upon me to fill his place as chairman of your Association, and I feel highly honored. The lecture we are to have this afternoon is by Dr. Klotz, upon "The Seismograph and Earthquakes." I will introduce Dr. Klotz. (Applause).

(The following delivered *ex tempore*):—

DR. KLOTZ: Mr. Chairman and confreres.—If you will permit me, I will be a little reminiscent. It was on the 24th of April, 1882, that the land surveyors who were in the Government service gathered at Winnipeg, and had a meeting. Amongst other things the suggestion was made that an association should be formed. In the following year, 1883, many of the surveyors met here in Ottawa, and at this meeting it was resloved to form a Dominion Land Surveyors' Association, which met for the first time the following year, 1884, just thirty years ago. If it will not weary you, I will read to you the names of those who were present at that meeting:—

President: Otto J. Klotz.

Vice-President: A. C. Talbot.

Secretary-Treasurer: A. F. Cotton.

Executive Committee: Wm. Pearce, G. C. Rainboth, J. P. B. Casgrain.

Auditors: C. F. Miles and E. Bray.

Messrs. W. A. Ashe, F. W. Armstrong, C. B. Abrey, Edgar Bray, S. Bray, C. A. Bigger, Jas. Burke, Thos. Breene, W. Beatty, A. F. Cotton, W. Chipman, Wm. Crawford, J. P. B. Casgrain, J. J. Dufresne, J. W. D'Amours, P. T. C. Dumais, Thos. Drummond, C. Desjardins, J. Doupe, L. M. Duchesne, Z. C. Dupuis, J. Dudderidge, Jno. Francis, Thos. Fawcett, C. E. Fitton, J. F. Garden, T. S. Gore, R. W. Hermon, O. J. Klotz, J. A. Kirk, T. Kains, J. B. Lewis, C. F. Miles, G. E. McMartin, L. J. Michaud, J. J. MacArthur, A. W. McVittie, C. A. Magrath J. Maddock, G. A. Mountain, J. S. O'Dwyer, Wm. Ogilvie, L. R. Orde, Wm. Pearce, A. P. Patrick, H. B. Proudfoot, F. Purvis, T, J. Patton, H. H. Robertson, G. C. Rainboth, R. Rauscher, J. G. Sing, J. A. Snow, G. A. Simpson, I. Traynor, A. C. Talbot, C. E. Wolff, Wm. Wagner.

Honorary Members: The Surveyor General, Capt. E. Deville, W. F. King, Prof. Selwyn, Prof. Macoun, Dr. Bell, Prof. G. M. Dawson, Prof. Harrington, Andrew Russell, E. E. Taché, and Bolton Magrath.

Having read those names I am reminded of Maeterlick's Blue Bird, one of the prettiest stories in the English language. I recall that Tyltyl and his sister visit the kingdom of Memories. He meets there his grandfather and his grandmother, seated together. Tyltyl says: "I thought you were dead." "No," said his grandfather. "We are not dead when you think of us, when you speak of us, when there are kind thoughts of us, we are not dead." A good many of those surveyors have crossed the border line. Let us say, that we think of them, that there are kind thoughts of them, and therefore they are not dead, to us.

My address is given on the programme as on the seismograph and earthquakes. Now, we as seismologists, are concerned more with the effect of earthquakes than with their cause. The cause of earthquakes is not my province and I do not intend to enter into any explanation of their cause. I might refer casually, however, to one or two things. Generally the earth is considered a cooling mass. That is something we have no direct proof of, and consequently do not know the amount of heat given out by the earth and the consequent shrinkage that might be attributable thereto. It is simply a plausible explanation that has lost some of its force since the discovery of radium which gives out heat continuously. Something of which we have more definite knowledge is the stress on a body, which changes the shape or size or volume of a body,

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and the effects or strains produced by these stresses. We know that the meteorological conditions, by that I mean those due to rain, snow, sunshine, &c., have an effect in changing the stresses upon the earth.

Daily, these meteorological conditions alter and influence and play a great part in changing the stresses upon the earth. There are other meteorological influences that are contributory to setting off an earthquake, when the strain reaches the limit in the crust and interior of the earth, and that is, for instance, a very rapid change in the barometric pressure, which is ordinarily supposed to be nothing. However, we may have a rapid change of two inches in the barometer. It means that you get an increased pressure at the sea level of about 144 pounds to the square foot. Put that additional strain on the earth's surface and it may be just sufficient to fire—to set off—our earthquake. Not that it will directly cause the earthquake, but it may be the one cause that fires the earthquake when it is nearly "ripe." Another cause is that of the physical tides of the earth. We all know of the tides of the oceans of the earth, but we have also physical tides of the earth itself. The moon produces stresses upon the earth, and that, under certain circumstances, may fire our earthquake. Now to get down to my subject. I have made a few notes to prevent me talking too long, and I want to show you a number of records of earthquakes. I will just say in passing, a word about volcanoes. It is the general belief that volcanoes and earthquakes are associated. They are quite distinct phenomena. Volcanoes are confined to the skin of the earth, while earthquakes are generally much deeper. But there are effects that follow both volcanic activity and earthquakes that we are concerned with. Earthquakes, of course, affect the very life of our earth. These great volcanic eruptions, the greatest in historic times being that of Krakatoa, in Sumatra, in 1883, poured immense quantities of fine dust into the upper regions of the atmosphere. In the case of Krakatoa, this dust remained there for several years and was noticeable by the many beautiful sunsets which were prevalent soon after that eruption. These particles in the high regions, however, interfere with the radiation from the sun and prevent us from getting all the heat and solar energy we should receive. Another recent eruption was the one at Katmai, in Alaska, only two years ago. Here again, immense quantities of dust were thrown into the atmosphere and interfered with the radiation to a very great extent. One of the constants which scientists have been trying to determine is called the solar constant, that is the amount of heat that is poured out by the sun falling vertically upon a square centimetre of the earth's surface during one minute. In this last volcanic eruption at Katmai, observations were going on for the determination of this solar constant at Mount Wilson in California, and on the northwest coast of Africa, in order to see whether the constant was the same in the Mediterranean as at Mount Wilson, where the altitude was far greater. Professor Abbot, who was observing in Africa, noticed on a certain day in the latter part of June, 1912, that there was a very material reduction in the constant, and he could not explain the reason. This was on the northwest coast of Africa, where the weather is habitually fine and the sky cloudless. However, directly he learned of this eruption in Alaska, he concluded it was undoubtedly attributable to it, because the similar phenomenon was observed at Mount Wilson, and I may add, also at our observatory here, where, although we were not making observations of the solar constant, we noticed a diminution of the light and of the transparency of the air. An interesting fact in connection with this eruption is that, although California is much nearer to Katmai than is Africa, yet Professor Abbot observed this reduction of temperature sooner than it was observed in California; showing that the particles in the upper atmosphere were carried to Africa before they reached California. With these preliminary remarks about the earthquake causes, let me just refer to another matter before I go to the instruments, and that is, as to whether we will ever be able to make any forcast of earthquakes. That is a very difficult matter, but Professor Kövesligethy has made an effort, based on physical, scientific and mathematical reasoning. I will simply indicate the idea which underlies his forecasting, which is only applicable in a seismic region, which we are not here, but in Japan and Italy it should receive consideration. The idea is this, that every time there is an earthquake, there are strains produced in the material by the disturbance which affect its conductivity as far as its velocity is concerned. So that if you get a series of records of earthquakes, you will find a definite velocity in the seismic wave for each, and will then be able to predict when a cataclysm must come, when the material is approaching a strain which it will not be able to stand any longer. This theory is not to be put in a class with that of the proximity of the moon, conjunctions of planets, or some other untenable theory. It is based on a theory of mathematics.

Now as to instruments. It is only within comparatively recent years that we have records of earthquakes. The earthquake country, per se is Japan, and there was begun the earliest attempts to register earthquakes. Japan invited scientists from various countries to come and teach them at the universities. They had professors from England, Germany and France, and among others who came were Professors Milne and Ewing. Professor Milne, the father of modern seismology, took a great interest in earthquakes and devised an instrument for recording them. Ewing had one also, so we got several different records of earthquakes. These instruments, however, in addition to recording the earthquakes, registered themselves, which was a very disturbing feature, and it was only in the beginning of the present century that German scientists took hold of seismology in order to deal first with the instruments themselves, and not with earthquakes; and let me tell you right here that the mathematics of these instruments is far more difficult than the study of telescopes. There is much more in the theory of the seismograph than in the theory of the telescope. They made a scientific investigation of the instruments and invented seismographs, and these are the instruments used at the present time, giving the most reliable data. The principal thing is to record what the earth is doing and not what the instrument is doing, so that it is necessary to have a steady mass, a mass that remains quiescent, or as nearly so as possible; and let the earth do the shaking and recording. It should be, as if there were an invisible hand which is not of the earth or on the earth, holding the instrument at one end, and when the earthquake comes along it is only the other end attached to the earth that records on the sheet; so it is essential, as I said, to have a steady mass. I have a number of well known earthquake records here, including the San Francisco one, and you have in your hands the record of the recent one in Ottawa. Now our instrument (one for the N-S component, and one for the E-W.), is comparatively simple. We have a mass of two hundred grammes suspended by fine wires from an almost vertical rod and it swings horizontally. Let me illustrate it by means of a door. If the hinges of a door are not vertical there is a certain position where the door will remain at rest. So it is with the horizontal seismograph. We tilt its support just a little and we get thereby a long period of oscillation, and a definite position of rest. This instrument records photographically. It is at the present moment, I think, the only highly sensitive instrument recording photographically on this continent. The Toronto instrument was a very good one in its day, but it is now out of date. Many of the modern instruments have mechanical registration. The reason why more have not photographic registration is that they have no photographic equipment for developing their records daily, and it is more expensive. I have now told of the steady mass of our seismograph and of the pendulum. Now the earthquake with its sudden sharp shock comes along. Of course it shakes the pendulum and the pendulum is apt to start to oscillate. What we want recorded is the movement of the earth and not the movement of the bob. We have therefore to damp down this movement of the pendulum. There are two methods of damping it. We could damp it in an air chamber, or we can damp it magnetically. Ordinarily where they have a very heavy seismograph, as in the German institutions where the mass is perhaps a thousand kilograms, that is about a ton, they use air-damping, whereas we have only a little bit of a thing weighing 200 grammes. They have also mechanical registration and hence there is a certain amount of force required to overcome the friction and write on the smoked paper. This may mean the loss of a weak shock on the record. Now, I was telling about damping. At the observatory we have a big horse shoe magnet of wolfram steel, and to the steady mass there is attached an alluminum vane which moves in the jaws of the permanent magnet. The effect of the magnet is to stop the steady mass when set in motion, and allow the earthquake alone to register by the other end. Thus the registration is of the earthquake and not of the instrument. In the ordinary clock pendulum we have the bob swinging from side to side, but in our case we have the pendulum quiescent and the earth does the swinging or oscillating. We have now the pendulum damped down. The next thing we want to do is to magnify the motion of the earth itself, which is very small, that is the earthquake. In this last earthquake here the movement of the earth was only five hundreth of an inch. So you see that we could not measure with our instrument unless we devise some means to magnify that motion. We do that very simply by having a small silver mirror over the point of rotation of the horizontal pendulum. As the earth moves and the steady mass remains quiescent, this mirror changes its position and a beam of light is reflected from it into the recording drum some 14 feet away. Our mean time clock cuts off the light for one second, every nimute, and that enables one to read the seismograph in terms of time. By means of the beam of light then we obtain the magnification. The farther away the recording apparatus is from the mirror, the greater is the magnification. Ours magnifies 120 times. This magnification, however, is theoretical, for everything the seismograph does is not magnified one hundred and twenty times. The magnification depends not only on the theoretic magnification, but it also depends upon the period of the pendulum and the amount of damping. The damping down of our pendulum is about one to five, that is, if you let the pendulum swing freely, put on your damping and the oscillation that it makes then is one fifth of the immediately preceding one. That is most suitable for reading our seismograph. You can very well understand that friction comes into play in mechanical registration. With the beginning of an earthquake having very rapid oscillations, and then only, do we obtain the theoretical magnification of 120. It may run down to thirty or less, depending on the period of your earth particle. So in reading the seismogram we have to use different magnifications. I mentioned we have our seismograph connected with our mean time clock, so that fortunately with our seismograms there is absolutely no time correction. It would only be a very small fraction of a second in any case. As far as I know, and I have visited very many stations, it is the only seismograph directly connected with an observatory mean time clock. The others have all separate clocks connected with their seismographs, necessitating a daily comparison between the seismograph clock and a standard clock, which is certainly an inconvenience. This question of time is one which affects the seismograms and is most unsatisfactory in the records from some stations. Some of the records of the earthquake on the tenth of February last, were accompanied by a note saying that they did not know whether their time was correct or not. I have one record where the time is recorded before the earthquake took place. (Laughter). That shows that the time is not very satisfactory. We are getting over this difficulty of time, however, by the wireless time signals from the Eiffel Tower, Norddeich and Arlington. These time signals are sent out daily and at present it is very easy and cheap to get a receiving apparatus, and by that means one is able to get time readily within a second.

When we have our seismogram, the question is to read it. We have first to find what the instrument was doing. If we had a perfect one we would only read what the earth was doing. But we cannot have the seismograph held by an invisible hand out in space. You will see that if all is well and no quake, the record continues in a straight line. When the earthquake comes we have an offset. When we examine that we try to see from where the earthquake comes. Now we have learned to recognize that there are three distinct kinds of waves. There are the longitudinal waves, there are the transverse waves, and the undulatory or those on the surface of the earth. The first or longitudinal waves travel the fastest, the next with less velocity and the last with still less. With regard to velocity we know it bears a relation to the substance and its density and elasticity. We have found, as I said, the different velocities, and we know that the surface waves which are the last, are confined to the surface of the earth, and travel with a constant velocity of about 200 km. a minute, whereas the others travel through the earth and with differing velocities dependent upon the depth. The San Francisco earthquake was distant about three thousand eight hundred kilometers, and the propagating ray dipped about 300 kilometers down into the earth. The place in the earth where the earthquake occurs we call the hypocentre. We know that the earthquake does not take place at a point but rather in a plane. However, in treating it mathematically, we treat it in the first instance as emanating from a point, and you will very well understand then that waves which are propagated will be spherical waves. As we have now our hypocentre, the point directly above it on the surface of the earth, is called the epicentre. It is a term to which we refer very frequently. The velocity of the seismic wave depends on the nature of the mass through which the wave passes, that is, if we knew the moduli of elasticity and the density of the material, we can compute what the velocity through it must be; and inversely, when we know the velocity we know then the ratio of these moduli to density, thereby giving us definite information of the interior of the earth. That is something which, before modern seismology was born, was comparatively in the dark. We had always to rely for our information as to the interior of the earth upon what the geologists told us. Their inferences were naturally based on temperature readings in borings and mines to a depth of about a mile, noting that the temperature changed so many degrees in so many feet of depth, and then concluded from the conditions in this thin skin, a thickness of only $\frac{1}{4000}$ of the radius of the earth, what the conditions must be in the interior, giving us generally a molten interior. That is wholly untenable now;—the theory of a molten mass in the interior of the earth,—for, transverse waves cannot be propagated in such material. We know that these waves are propagated, and for that reason we have now a different proof of the constitution of the interior of the earth. A messenger has come to us and told us in writing the story of his path through the earth. It remains for us to interpret what he has written. We must decipher the Rosetta stone. But we must interpret it properly.

Of course it takes some experience to understand and read what the different waves are. I come along here (pointing to a seismogram), and I find the longitudinal and transverse waves fairly well defined. I get then the distance in time between the arrival of the longitudinal and the transverse waves, and by this means we are able to discover whereabout, the earthquake took place, or rather, the distance to the epicentre. Let me illustrate it by an analogy. Supposing two trains leave a certain point at the same time. One is an express train and the other a freight. You know the freight is travelling at twenty miles an hour and the express at thirty miles an hour. Now you are in some far-away place, and note the times of arrival of the two trains. Let us suppose that the freight train arrives 6 hours after the express train. From this we know that they must have travelled 360 miles in order to get 6 hours apart. That is how we get at the distance of an earthquake. We measure the distance in time between the arrival of the longitudinal and the transverse waves and from that we know the distance. Although we now know the distance to the earthquake, we do not know where it was. We now look at the first offset in the seismogram for the two components I told you about, because from this we are able to calculate the direction. There is the north and south component and the east and west one. It is not so simple as I am telling you. From the two rectangular components, expressed in microns, we obtain the diagonal of the parallelogram of forces, *i.e.*, the line or vertical plane of the propagating ray, but involving ambiguity of direction; for example, whether it is N.E. or S.W., N. W. or S.E., and so on. Our vertical seismograph, however, which I may mention has mechanical registration and necessarily a very much heavier steady mass than the horizontal seismograph, decides the ambiguity. We are dealing with the first impulse, the longitudinal wave, a wave of compression and dilatation, where the earth particle moves to and fro. In its excursions, the steady mass of the vertical pendulum will move relative to the earth up and down, and this shows itself on the seismogram; that is, on the seismogram we can tell whether the motion at the moment was one of compression or dilatation, and this will determine the ambignity, and give us the definite and unmistakable direction. I may say that in the recent earthquake here, the direction was north-east. It is frequently difficult to measure the horizontal amplitudes satisfactorily.

For finding the geographical position of an earthquake, recorded at two or more stations, I have computed tables for the principal earthquake stations of the world, by means of which the position of the epicentre can be readily found by a simple graphical construction. These tables have been published and are available. By means of these tables one can usually tell in about fifteen minutes whereabouts the earthquake was, of which there are several satisfactory records.

The degree of rigidity of the earth is made known to us through calculations which we can make based on data of earthquakes. In the old days of course the earth was looked upon as solid and unyielding. It was Kelvin that first began to question the rigidity of the earth, and that was in connection with the tides of the ocean. He began to reason that these tides on the ocean were probably not as large as they would be if the earth were absolutely rigid, and he made an investigation, and found that the earth was not absolutely rigid, and that the tides of the ocean were not as large as they should be if the earth were rigid. If the earth were perfectly elastic it would yield to the attraction of the moon equally with the ocean and there would be no tides; so that the tides we measure at the present time are simply differential tides; differential tides of the water and of the earth. I may tell you that at the present moment we are having dug two vaults at the observatory for the installation of two new seismographs and instruments to aid in measuring the "give" of the earth by the attraction of the moon.

It remained for Professor Hecker, who has been engaged in measuring these tides of the earth, to discover a remarkable anomaly. The question arises, whether the earth is as squeezable, if I may so term it, in one direction as another. Hecker found that the earth was evidently more elastic, more squeezeable, in the north and south direction than in the east and west direction. He submitted his theories and discoveries a few years ago to Professor Love, who threw out the suggestion that the apparent anomaly may be due to the effect of the oceanic tides. At the last meeting of the International Seismological Association, at Manchester, in 1911, this matter was brought up and it was then decided to make observations in several parts of the world with regard to these physical tides of the earth and the anomaly involved. The places selected are, one in the centre of South Africa, one in Siberia, one at Paris, and one in North America. For the last the above vaults are being built, and the Dominion Observatory will participate in this international investigation.

The effect of earthquakes is obvious to you all. If any of you made any enquiries regarding the recent earthquake here, you will find that the effects were different in different parts of the city. It all depends upon what the nature of the ground is, on which the houses stand. The disturbances of an earthquake depend primarily upon the acceleration or change of velocity. You can move an object a long way, even move a house without doing much damage, but when there is a rapid change of velocity, dire results may follow, although the actual motion itself is small. I recall one report of the recent earthquake given by a man, who said that it shook up his hens so much that they all immediately laid eggs and he had never had so many eggs on hand before. This was acceleration.

We had a disturbance in Canada some years ago, though the most famous one that we ever had was on Shrove Tuesday in 1663. Earthquakes in Eastern Canada are apt to take place along the St. Lawrence River, where our great geological fault in Canada is. Although we are not in a seismic region, yet should a severe earthquake take place, it will occur along the St. Lawrence and

Lake Champlain fault line, extending to Anticosti, and into the Gulf. One of the reasons for the prevalence of earthquakes in Japan is that that island is on the edge of a great trough in the Pacific, and an earthquake always seeks the weak spots. In the earthquake here in 1663, was born yellow journalism. One account says, "they saw very lofty hills striking together with brows opposed like headstrong rams, then suddenly and instantaneously swallowed up in the yawning earth. Father Charles Simon relates that a man so shuddered at the sudden earthquake, that although at other times he was brave, his hair was bristling up with horror and standing up straight shook off his fur cap."

In 1746 there was an earthquake in Peru, and an account of it says, "It is most certain that the two named causes of these calamities are heat and moisture. However, supposing such to be the case, it does not at all hinder but that the Almighty power may employ these natural occurrences as the instrument of punishment to a wicked people. There was not before the late calamity a more licentious spot upon the earth. The charm of the climate of this country, and the tranquility of life which the inhabitants enjoy, together with the extreme beauty of the women, did not a little contribute to an amorous disposition which was the prevailing passion of the inhabitants."

Now, Mr. Chairman, I am sure I have talked long enough about earthquakes, and I fear some of you would be glad if an earthquake were to stop me.

However, I can assure you that nothing would please me more than a good earthquake—of course, not here—one decent earthquake a week,—I hasten to add, in uninhabited regions,—is what we require to solve the riddle, not of the universe, but of the interior of the earth. Our earth is, after all, the most important body in the universe, and we want to study it, and the unravelling of its mysteries is one of the highest ambitions to which man can apply his energies and intellect.