Dr. W. H. Collins
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THE RELATION OF THE SURVEYOR TO EARTHQUAKES

by

Ernest A. Hodgson

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Heaven sends us friends. We should, however, exercise considerable care in choosing our relations. The career of many a young man has been made or marred by his choice of an uncle, for example. My mission this afternoon is to introduce, to you as surveyors, a certain relation of yours, the science of earthquake study, or seismology. I trust I may be able to present him in such an attractive light that you will be glad to acknowledge the relationship and that both parties to the introduction may profit therefrom.

In order to discover some of the more interesting points about this relationship, we shall have to go a long way back in history; back and still farther back, long before Eve made a monkey of a man, or Evolution made men of monkeys. History of so distant a time is, of necessity, vague. Authorities differ. Our needs will be met, if we but compile a single connected series of selected hypotheses. which will serve to account for the creation and evolution of the world, according to the facts presented. The dogmatic presentation of these hypotheses is necessary for our purpose. It must not be construed as an assertion of their absolute verity. "Speculation", says Daly, "is neither science or knowledge. Speculation of the happiest kind can do no more than point the way to possible future knowledge."

Will our speculation result in a knowledge that is practical, or one that is theoretical? Millions of words and gallons of ink have been expended in an endeavour to define the boundary between these two territories, but it has proved an even greater task than that performed by those surveyors, of whom it has been said that they are engaged in placing boundary monuments in "inaccessible positions." And the boundary is less in need of delimitation, for there is complete reciprocity in this case. So then, in presenting those features of the science of seismology which should attract you, as surveyors, I shall not pause to make flesh of one and fowl of another: all the practical interests are scientific, and all the scientific appeals are practical.

A consideration of the world today reveals the fact that it is asymmetrical, or lacking in symmetry, in so far as the surface features are concerned. We can divide it (by a great circle through San Francisco, Buenos Aires and Canton) into two hemispheres, one largely covered by water, the other by land. If we examine the water hemisphere we find the land encroaching somewhat on its edges. An examination of the land hemisphere reveals great patches of water within it - notably the Atlantic, Arctic Antarctic, and Indian oceans. Considering this land hemisphere still further we are struck by the fact that if we could push the continents together we could fit the western coasts of Europe and Africa into the eastern coast of the Americas, and that Australia would fit rather well into the Indian Ocean. If we could thus consolidate the land we should be able to withdraw the edges of Asia and of the Americas from the water hemisphere. Our only ocean would then be the Pacific; our only continent a geographical League of Nations. This would be rather hard on the Atlantic Shipping Interests, but think of the grand opportunity for the railways.

A land hemisphere, one great continent; and a water hemisphere, one great ocean, may have been the condition of affairs in the early history of this globe. We shall not present the theories which attempt to account for this lack of symmetry in surface features. (Perhaps our moon was formed from the material taken from the abyss of the Pacific.) Let us imagine that such a Quaker-like arrangement of the land and water did exist at one time. Our first question is; how long ago?

To answer this we must first obtain an estimate of the age of the earth. We ask the consensus of opinion of the geologist, the astronomer and the geophysicist. These gentlemen, like most of those who deal in millions, speak with large gestures. A group of them sitting in conference for the settlement of this question are inclined to be generous. One is satisfied if they give him eight million years; another rises to remark that he must have at least ten millions. His request is granted without debate, which nerves a third to say that the work of his branch could not possibly have been completed in less than a hundred million. Finally, with all the generosity of a municipal council striking a tax rate, they decide to make it an even three hundred million - to take care of any unforseen demands.

But, simply because they do not seem to care to deal with small change, we must not infer that there is any lack of sense in their budget. Changing the similie a little, they are like a man ordering a dinner for which he is to pay in German paper marks - at someone else's expense. Why make a fuss when an extra pat of butter raises the bill another hundred thousand? The total doesn't mean very much. When the bill is presented however, the relative value of the items is as well determined as though the meal cost a dollar instead of ten million marks or so. In the same way, the estimate of 300 million years may be out, on the whole, by a year or two - or even more - but the relative lengths of the geologic eras are fairly well determined.

A smaller time scale will be convenient for present purposes It is now about three o'clock. Let us adopt the scale of ten million years to an hour, and place the creation of the world at about nine o'clock yesterday morning. On this reckoning the single continent was differentiated from the single ocean during the early morning hours of today. By about six o'clock the surface began to undergo a series of changes with which we are now concerned.

During the time intervening between its creation at nine yesterday morning and the time we now consider at about sunrise today, the interior of the earth was probably sorting itself out into concentric spheres of varying density, the heavier materials lying nearer the centre. The lack of symmetry in its interior was slowly being eliminated. Granitic rocks, such as form the bulk of continental structure today, are the lightest known. These formed the surface crust of the single continent. This crustal area floated in a substratum of hot lava or basalt of greater density. It floated, partly submerged, as does an iceberg or a solid ice floe.

The former rapid cooling at the earth's surface was greatly checked by the formation of this non-conducting crust. The tidal effects were comparatively severe, Moreover, due to the rotation of the earth and to the asymmetry of the interior a bulge formed at each of the poles, with mid-latitude depressions separating these polar bulges from an equatorial bulge. All this time the elements were at work. Winds, chemical action, rains and rivers, all worked their will on the face of this young continent; and this erosion had its cumulative effects.

As the mid-latitude depressions began to fill with sediments from the erosion of the surrounding parts of the ancient land hemisphere, these geosynclines as they are called began to deepen because of the accumulated mass. This exerted a tension on the higher portions of the continental area. Thus began a crumpling in mid-latitudes north of the equator. The crustal material began to pile up and raft together. A thick, and ever thickening band developed along the geosynclines. These bands sank deeper into the basalt. They became gradually warmed: very slowly for the rocks are poor conductors of heat. As they warmed their density became less and the bands were gradually elevated, floating higher in the basalt and forming mountain ranges.

We must not forget that our present continents, the two Americas, Europe, Asia, Africa, and Australia, were then all in one, occupying about half the area of the globe. The mountain ranges then formed still appear, part in America (the Appalachians) part in Europe and Asia. Daly says, "The mountain mass extended from west of Arkansas, through Alabama, New England, Newfoundland, Britain and France, Germany, Russia, and all across Asia to China. It was a colossal, probably uninterrupted chain of mountains all the way." These deductions are supported by a study of the formations of each. The fossils show the presence of similar forms at corresponding positions. In structure, composition and date of formation they are found to correspond. A similar correspondence of mountain chains, in continents now widely separated in the south mid-latitudes, which is explained in the same way as above, is found between the rock structures of South Africa and those of Argentina. Referring again to our time-scale, these mid-latitude mountain chains were undergoing their elevation at about noon today. Let us look back for a moment and see what other vicissitudes were suffered by the continental area during the course of the morning.

A study of the geological features of the world reveals the fact that the continental area suffered repeated slight elevations and depressions. The depressions are marked by the deposition of sediments in former shallow seas. The elevations are shown by erosion. One of the powerful erosion agents was ice. There have been great ice sheets at various periods in the earth's history and over various sections of the continental area. We consider now only the very ancient ones - that came and went in the early morning hours of our time scale. They scored the rocks over which they slowly made their way. Some of these glaciated surfaces are evidently of the same geological period, though occurring in what are now widely separated places. Geologists tell us that it was probably the same great ice sheet that glaciated the ancient rocks of South Africa and of South America, when these were still part of the same land area - the former "basement complex" - the original "continental shield"

Parts of it are to be seen today. One section forms the north-eastern part of Canada and Greenland - the Canadian shield, as it is called: another forms the Russian shield, and still others the Siberian, African, Brazilian, Australian, and Antarctic shields, respectively. The rocks of these shields present the evidences of their early adventures, their depressions below the level of the sea, their elevations into mountains.

If we accept the foregoing explanation of the origin of our mountains we see why sedimentary rocks are found high on their slopes. They were deposited in the crumpling geosynclines, and, after countless ages, raised to their present lofty heights, carrying with them their evidences of sea deposits in the form of fossils embedded in them. This explains the presence of sea shells on high mountains. This was a first argument against the idea of the "everlasting hills." It was objected to by a certain class of arm-chair philosophers who would limit the revelation of God to the authorized opinions of men. They are against all observation Their recent persecution of Mr. Scopes of Tennessee is characteristic of them. They are against all scopes, including microscopes and telescopes. Alas, they and we, must finally bow to the verdict of the stethescope.

The ancient continental shield, after ages of vicissitude was to suffer a still more drastic deformation however. The erosion of the continental area had resulted finally in the accumulation of great masses of sediments all about its edges. These would further depress the border bounding sea and land. The semi-mobile basalt sub-stratum would flow back underneath the shield, tending still more to elevate it. A horizontal stress would develop across the shield. On our scale of time we reach a point about noon today - say some thirty million years ago in fact.

The horizontal tension became greater than the strength of the forty-mile thickness of granitic rocks could sustain. The continent finally ruptured along a line which is now marked by a ridge throughout the length of the mid-Atlantic. The Americas began to anticipate the advice of Horace Greely - they went west. They let the rest of the world go by; and the rest of the world also began to slide down hill toward the east. Both sections were slipping into the Pacific ocean, but into opposite sides of it. We must not think of this "landslide" as having taken place at a rapid rate. It was rather a slow creep, the sort of motion one sees in the progress of a glacier.

The crust was depressed along the nose of these movements. Sediments gathered there at increasingly rapid rates. Finally the floor beneath the ocean broke and the crustal sediments and the ancient basement complex began to pile up like floes on the nose of a flood in a river. As they increased in thickness they sank. All was below the ocean floor at first.

The process may still be going on. This last summer a world-wide endeavour was made to determine whether the continents are still drifting. The drift may be of the order of a meter a year. If so, we should be able to detect it by the determination of longitudes by wireless, very carefully conducted today, and repeated after the lapse of a few years. Canada has had a share in the first series of observations. The representatives from the Dominion Observatory established a station in British Columbia and another at the Observatory itself. The long series of initial observations, extending over several weeks, were but recently completed.

As the separation increased between the Americas and the other continents water poured in from the Pacific forming the Atlantic. The floor of this ocean was so thin that it broke in places and we have, as a result, volcanic islands in mid-Atlantic. Presumably, too, basalt flowed up in the depression, and formed, on freezing, the floor of the new-born ocean. These regions are still subjected to earthquakes. A great quake occurred in one group, the Azores, on August 31, 1926, killing nine persons and injuring about 200. From ten to fifteen per cent of the houses in the town of Horta will have to be demolished.

But think of the great earthquakes there must have been in the van of this great emigration. And reflect on the abyssal deeps which would be formed as the pressure continued. Then consider the fact that earthquakes occur all about the Pacific margin even today and that ocean depths at places exceed five miles. Remember too, that in the Aleutian Islands, for example, the mountains are still below the sea, and may still be rising.

Careful geodetic measurements made in California, seem to indicate that part of the mountains there is being thrust up over the rest at a measureable rate. Cities are now built on part of the moving mass. From time to time the movement is held up by friction. Its release is marked by an earthquake. A concerted effort by the seismologists of California, in coöperation with the United States Coast and Geodetic Survey, the various Topographical Surveys operating in the State of California, the United States Geological Survey, and the California Institute of Technology, has been organized under the direction of a Committee of the Carnegie Institution of Washington, to determine the laws of these movements and to learn the best means of protecting life and property there. You will see that these conditions are very different from those we have in the seismic region of Quebec.

To understand the situation in Quebec we must consider another geological event, which, according to our time scale, occurred only a small fraction of an hour ago. At that time a great ice sheet covered most of Canada. We shall confine our attention to that portion of it that lay on Quebec and New England. The sheet was very thick - from 3000 to 6000 feet. This great weight on a crust but some forty miles thick and supported by a potentially mobile basalt, caused a downwarping of a considerable area. That the province of Quebec and eastern Ontario were so downwarped can be readily shown. Old sea beaches formed as the ice melted away. These are found at points now 600 feet and more above sea level. You can find sea shells in the sand, just east of the city of Montreal and also behind the city of Quebec. An old sea beach is visible near Grand Mere, over twenty miles north of Three Rivers.

Without going too greatly into details we may say that this downwarping of the ice has been followed by an upwarping on its removal. Is it still in progress? If so it may be either a slow rise (of which we shall speak presently) or it may be taking place in a series of jerks - earthquakes. On February 28, 1925, an earthquake occurred at a point about 90 miles below Quebec, which caused considerable damage at its epicentre and which was sensibly felt (without instruments) as far west as the Mississippi and as far south as Virginia. A sensitive seismograph in Belgium recorded the tremors for over five hours with a maximum amplitude on the record of over three inches. If this earthquake were due to the intermittant rising of the area depressed by the ice sheet, we would expect that precise levelling would show traces of it if the work were re-done.

The only line of precise levelling traversing the area was that run in 1915 along what was then the Intercolonial Railway from Riviere du Loup to Levis. This line was re-run in 1925, through the kind cooperation of the Geodetic Survey. It is true that the differences found were of the order of the probable errors, but they were systematic and showed an upwarping of the east end with respect to the west, a finding confirming the other field work done by the seismologists. This lends weight to the deduction that the earthquake occurred along a fault crossing the St. Lawrence near Riviere Ouelle, and that the sea-ward side of the fault snapped up, with respect to the land-ward side.

In this area then, precise levels and geodetic triangulation are extremely important controls which should be carried on with great care and as soon as possible, so that after another earthquake, suspected areas may again be worked over. This is one phase of the interest of surveyors in this region.

Before mentioning any others let us take a few moments to examine the instrumental side of seismology. We shall pass over the instruments with the brief explanation that these are of two general types, registering respectively horizontal and vertical components of the fluctuations of the pier on which they are mounted. Using two of the horizontal type and one of the vertical we obtain an automatic resolution of the complex movements of the pier in space, into three records of the component motions in three planes mutually at right angles. Let us examine the possibilities of a study of these under three conditions; first where the distance about the surface of the earth, from the station to the epicentre of the earthquake (referred to as Δ) is more than 500 and less than 10,000 km., second where Δ is over 10,000 km. and lastly where Δ is less than 500 km.

In the first case we can determine quite accurately the value of Δ and also the time at the origin when the shock occurred. This latter is designated by the symbol O. For a sharply defined earthquake the value of O is surprisingly consistent though obtained from the records of stations situated in various directions from the epicentre and at different distances therefrom. Moreover, records of the same earthquake, obtained at widely separated stations with similar instruments are notably alike in character and give the seismologist a feeling of confidence in the performance of his instruments, the comparatively homogeneous character of the earth, and the general accuracy of his tables. Where the initial phase is well marked the azimuth can also be determined from the three records obtained at one station. The records of the St. Lawrence earthquake were read within a couple of hours after the shock. Before midnight C.N.R.O. broadcast our announcement that the epicentre was "near the mouth of the Saguenay."

For distances greater than 10,000 km. the earthquake waves reaching a station are interferred with by the dense metallic core of the earth. A study of the records at stations sufficiently removed from the epicentres of large earthquakes is yielding much information as to the conditions within the earth. Ottawa is particularly well situated for such work, with respect to the many earthquakes of the Pacific islands and the East Indies.

For distances within 500 km. or thereabouts another possibility appears. If we can get a fairly regular sequence of well defined but not very heavy shocks we can arrange to study the crust of the earth at that place by means of the earthquake waves reflected at its lower surface where it meets the basaltic layer. In Quebec we have many such - we know there are at least ten a year. When the sensitive seismographs are in place we may find there are as many as a hundred. At present we do not know. From time to time relatively severe shocks occur. The one previous to that of February 28, 1925, occurred about 11 a.m., October 20, 1870. It was quite comparable with the one of two years ago. It was sensibly felt in New York City. How soon the next will happen no one can say. We have plenty of time to study the conditions, if the interval should again be 55 years or thereabouts. In the section between the St. Lawrence and Saguenay rivers and adjacent parts we have fairly regular earthquakes which would collaborate with us in such a study.

For a complete investigation we would require special vaults, arranged at the points of a triangle covering the area to be studied, say one near Quebec, one near Chicoutimi, and a third near Rivière du Loup In these we require installations of special type seismographs, three components in each vault. We drive the recording drums of all nine seismographs by means of synchronous motors, run by the same power source, and mark the time by impulses from one master clock. With such a set up we could very soon determine the position of the epicentres within a mile or so. Let us consider one such epicentre as determined and note the work which might profitably be done by the surveyor.

The geodetic survey could run branch lines of levels into the area and spread their triangulation net over it; the topographical survey could then prepare maps of the area showing the relief. The geological survey could examine the limited region thoroughly. We would thus have precise controls. We could study the seismic movements by means of the seismographs and when next this particular spot was disturbed the surveyor would alone be able to tell us whether it had risen or fallen or the direction of horizontal shift.

At present no such complete installation has been made, nor is it in immediate prospect. But through the cooperation of the commercial interests in the province two instruments are being installed in specially constructed vaults. The vault sites have been covered by the triangulation nets of the Geodetic Survey. Topographical maps are being prepared. The vaults are completed and the instruments are about to be tested. When they are installed we shall be able to determine definitely the number and relative intensity of the local tremors, and rather indefinitely the centres affected. We shall, however, be able to measure the seismicity of the vault sites. If they prove to be the centres or near the centres of slight seismic activity, the cooperation of the surveyor will again be required to determine what the movement has been since the control observations were made. The investigations will serve to show the possibilities of a complete installation. The conditions in Quebec are not those of California by any means, but if the seismic centres there are determined, it will be the essence of good judgment to avoid them as sites for commercial enterprises which form so large a part of the present or potential wealth of the province.

In Quebec then we are studying the problem of a presumably rising area. It has risen in the past for deep sedimentary deposits are there which have been laid down when the sea covered it. Many of these deposits are unstable when wet. In the past serious landslides have occurred in them On April 6, 1908, a landslide on the Lièvre River at Notre Dame de la Salette, moved a bank over 1300 feet long and 60 feet high with an average width of 400 feet from its original position clear across the river. It slid bodily, without warning, into the river, resulting in the death of 33 people, and the destruction of fifteen houses, twenty-five outbuildings and six acres of good farm land. Such landslides have been reported since that time, at other points. Serious ones have happened within the past two or three years, but without loss of life. A study of these landslides comes within the purview of seismology. They may be set off quite readily, in damp weather, by a most moderate earthquake, and they may result in very serious damage. Where evidences of these are noted by the surveyor in his work, he would be assisting the cause of seismology by reporting them.

One more point before we leave the east. A commission has been recently appointed by the United States, National Research Council, to study the shore line of the United States, bordering the Atlantic. Is this shore rising or falling or stationary? Those surveyors who are sent far north in Canada, or by ship to Labrador or Greenland and other northern places would assist greatly by keeping notes of any evidences of elevation or depression of shore lines, taking photographs where possible. Preferably those who are going into these areas might read one or two books dealing with shore line movements. Also, if any mention is made of earthquake tremors in these northern latitudes we should like to know about them. An effort is being made to get seismographs into the far north, or near the edge of the retreating ice cap. Denmark has announced her intention of establishing a station at Jan Mayen island, lying between Greenland, Iceland, and Norway. Mr. J. J. Shaw of England has sent one of his seismographs to be set up in Greenland by a Danish scientist. The seismologists of the United States are agitating for the establishment of a seismographic station on one of the Aleutian islands. As yet no operating station has been established and reported on its findings. Any information the surveyors happen to run across in their work would be valued by those working on this disputed but important problem. It is not likely to affect us in our generation to any marked extent, but if the coast is rising we would do well to establish harbours where dredging would not be a too important factor in the future. Whether such consideration should apply to the vexed question of the location of a Hudson Bay harbour one cannot say. We don't know whether this region is rising or not. It may not be, but, on the other hand, if our hypotheses are correct, it may be rising rather rapidly.

In conclusion, let us look at the conditions on our Pacific coast. We recall the hypothesis that the continent is drifting toward the Pacific, an area of stress and strain marking its western coast line Deep ocean floors, many earthquakes, and volcanoes mark most of the Pacific shores. There are so many volcanoes that we speak of the Pacific Ring of Fire. What are volcanoes? Have we any in Canada?

Briefly, a volcano is a fault or abyssal crack through the crust of the earth, which permits the lava of the basaltic layer to rise within it, and under certain circumstances to overflow at the surface or to explode. It has been noted that the continent floats in the basalt, partially submerged, like an iceberg. We would not then expect the lava to come out unless some definite forces act. Pressures of the drifting continents may furnish such a force but the most probable one is called "gas fluxing".

When the crust formed it prevented the escape of gases from the basalt. Much was dissolved in it. When the basalt rises in one of these abyssal faults the pressure at its surface is lessened. Gas is thus released from the basalt. It is very hot, and results in a heating of the top of the column. This expands the column of lava until finally it overflows. Then, the gas being exhausted for the time being, it is unable to rise above the surface and freezes over. If it were not for fresh supplies of heat from below, the basalt would freeze over in the vent forming a plug to a depth of several hundred feet in a single day. The frozen surface formed when the gas had ceased to be given off, prevents the escape of that gas which finally makes its way to the vent from below. The pressure increases because of the gas and the local heat melts the plug. When the critical point is reached the weakened plug is blown out, carrying an onrush of lava with it - the volcano is again in eruption. The cycle repeats itself many times.

This continues until the supply of gas in the magma chamber gives out, the basalt giving up all its dissolved gases. The hot air having been expended, the volcano becomes silent, cold, and dark - like the auditorium after a political meeting.

Although, the plug freezes to a great depth in the vent of an extinct volcano, the basalt forming it is porous. If the crater stands full of water for a long time the moisture may penetrate down to the hot lava below. When this occurs steam forms and when the pressure is great enough an explosion occurs. In 1888, the extinct volcano of Japan called Bandai-San, was looked upon as a simple mountain. A priest climbed this 3,000 foot elevation one day and had his meditations rudely interrupted by a tremendous explosion, caused by the steam formed from the percolated water. A section of the mountain 2000 feet high and some four square miles in area blew up before his eyes. He lived through his experiences because the explosion was due to steam alone. Had it been an explosion of magmatic gases he would have been asphyxiated even had he been fortunate enough to escape the projectiles. Explosions of the same kind occurred in 1924 in Hawaii.

Now, have we volcanoes in Canada? Yes, many of them. But they are nearly all extinct. Montreal mountain is an extinct volcano. Even our friend the priest of Japan, would accept the verdict that it isn't loaded. In is not quite the same thing in British Columbia. The following facts were obtained from the surveyors who worked on the International Boundary between Alaska and British Columbia.

At a point about a hundred and fifty miles due north of Prince Rupert, near the head waters of a tributary of the Unuk river which flows into Behm canal, is an old crater. Many centuries ago it was in eruption for the lava flowed down two sides, forming canyons on one branch of the Unuk and filling the channel of a second triutary. This lava lay there long enough that large trees grew on it. Then at a much later date - probably of the order of a hundred years ago or less - another eruption took place. This time the lava flowed only into the tributary whose channel had been filled by the previous flow. The smaller vegetation growing on the old flow was burned at once. The larger trees were killed remaining long enough to leave pot holes in the lava where they stood while they were being burned off below the surface. Then they fell over on the lava bed. And there they are today. The situation is an ideal one for the decay of timber - the climate is moist and warm. The deduction is inevitable that the last flow was not very long ago - in geologic time at any rate.

This is an interesting and important fact. What was the elapsed time between the first and second eruptions? May we expect another? The crater is filled with ice and snow, the climate is very moist. Will the volcano ever blow up as did Bandai-San? What effect will the tremors have (if this ever takes place) on the coast cities.

Had it not been for the observations and reports of the officers of the Boundary Commissions it is doubtful whether we should ever have had anything like as good an account as we now possess, for years to come. People do not go up there very often. In 1909 a survey party went up to set a monument on the boundary. Fearing to be trapped by an impending storm they left, closing the season without setting the monument. They returned next in 1920. So confident were they that their tools would not be disturbed on the boundary line, after a lapse of eleven years, that they simply took some cement and went up to the station. There was the monument as they left it. Their tools were undisturbed.(There isn't a garage mechanic within two hundred miles). This is an added example of the opportunities surveyors have to contribute important data to seismology if they are sufficiently interested in its problems for the facts to impress them.

So then, I have given you an extended introduction to your new relation; for seismology is a new relation to surveyors in Canada. I have traced his lineage into the dim and distant past and expatiated at length upon his future. In other countries he may be looked at askance, but in Canada he is not likely to get you into any serious trouble and he is likely to prove an interesting and profitable relation to claim and to cultivate by means of both systematic and incidental opportunities as these may present themselves.

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