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The Saint Lawrence Earthquake

March 1, 1925

BY

ERNEST A. HODGSON

OTTAWA
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PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
CONTROLLER OF STATIONERY
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PREFACE

The manuscript of this report on the Saint Lawrence Earthquake of 1925 was prepared for publication in 1930. For reasons which no longer obtain, it was decided not to print it at that time.

It now seems desirable that this document, of historical as well as scientific interest, should be placed on permanent record; hence, the decision finally to print it.

However, it must be remembered that the statements were made twenty years ago. There appears no reason to change any of the conclusions drawn at that time; but, in the light of the progress made in seismological studies in the interim, the reader might be inclined to regard the outlook as somewhat out of date unless he bears in mind the lapse of time since the report was drafted.

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TABLE OF CONTENTS

APPENDIXES

PUBLICATIONS OF THE DOMINION OBSERVATORY

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ABSTRACT

The Saint Lawrence Earthquake, the latest in a long series of severe shocks originating in the lower St. Lawrence valley, occurred at $9^h19^m20^s$ p.m. E.S.T. Saturday, February 28, 1925. It caused wide-spread damage in the region east of Quebec city, particularly north of the river, including the towns in the vicinity of Lake St. John. The damage in the city of Quebec was serious but confined almost altogether to the section known as Lower Town. Considerable damage was also found on deep alluvium locations to the west of Quebec especially in Three Rivers and Shawinigan Falls.

The epicentre was located by means of seismograph records. The earthquake was studied in the field and by means of widely-distributed questionnaires. This paper presents the data obtained in these studies and indicates the position of the epicentre as Lat. 47°.6 N.; Long. 70°.1 W. These coordinates define a point in the St. Lawrence river between the mouth of Malbaie river on the north shore and the mouth of Rivière Ouelle on the south.

As this earthquake is one of a long series of heavy shocks recorded historically as having occurred at intervals since the voyages of Cartier, a summary is given of the known records and their publication data.

INTRODUCTION

The Saint Lawrence Earthquake has been the subject of continued investigation by the Seismological Division of the Observatory. The following interim reports have been published:

1. "Preliminary Report on the Saint Lawrence Earthquake, February 28*, 1925" (in French and in English), 3 pages, mimeographed for distribution, Ottawa, March 23, 1925.

2. "The Saint Lawrence Earthquake of February 28, 1925" (Text of a paper presented before the Royal Society of Canada), 4 pages, mimeographed for distribution, Ottawa, May 20, 1925.

3. "The Saint Lawrence Earthquake, February 28, 1925" (Text of a paper presented before the Portland, Oregon, meeting of the Seismological Society of America, June 19, 1925), *Bulletin of the Seismological Society of America*, Vol. 15, No. 2, 1-16, 16 half-tone reproductions from photographs, Stanford, June, 1925.

4. "Rotation Effects of the Saint Lawrence Earthquake, February 28, 1925", *Journal of the Royal Astronomical Society of Canada;* Vol. 19, No. 6, 169–178, 1 map, 6 half-tone reproductions from photographs, Toronto, October, 1925.

*February 28, 21^h, E.S.T. or March 1, 2^h, G.M.T.

5. "The Saint Lawrence Earthquake" (A short article prepared for *The Canadian Review*), 1 page, Ottawa, May 14, 1926.

6. "The Saint Lawrence Earthquake, February 28, 1925". (A final analysis of the data collected), *Transactions of the Royal Society of Canada*, Third Series, Vol. 21, Section IV, 145-152, Ottawa, 1927.

7. "Tremblement de terre sur les rives du Saint-Laurent le 28 février 1925." (Analyse finale des données recueillies), *Bulletin de la Société de Géographie de Québec*, Vol. 22, Nos. 1 and 2, 56-64, Quebec, January-May, 1928.

As might be expected, some earlier conclusions, tentatively adopted in the interim reports, have been amended in the light of further investigation. Especially is this true with regard to the position of the epicentre. The first three of the above-mentioned reports favour the possibility of the epicentre being "near the eastern boundary of the Laurentides Park", rather than the alternative possibility now adopted. One point which lent weight to the location being so far north was a story that the ice in Lake Cartier had "exploded" at the time of the earthquake. That is to say, the ice of the entire lake had been broken up. After repeated attempts to obtain an interview with some responsible persons who had been there at the time, an opportunity presented itself, on July 21, 1926, to meet Mr. Michael Fragasso, an engineer, in charge of construction work on that lake at the time of the earthquake. The information given by him contradicted the circulated reports. This contradiction, coupled with further study of the damage at Rivière Ouelle, has led to the above location being abandoned in favour of the other alternative, i.e., in the bed of the Saint Lawrence between Rivière Ouelle and Malbaie.

In the present, final and complete publication, an attempt is made to show the extent of the observational data and to outline some typical and important parts of it. To avoid interfering with the systematic development of the subject, it is thought best to relegate to appendixes certain related subjects, which have a bearing on the investigations of the seismicity of the Saint Lawrence valley.

1. GENERAL DESCRIPTION OF THE EARTHQUAKE

(1) *Summarized details*

The Saint Lawrence earthquake occurred at $2^h\ 19^m\ 20^s$ G.M.T. March 1, 1925, ($9^h\ 19^m\ 20^s$ p.m. E.S.T. Saturday, February 28, 1925). It was felt strongly over Eastern Canada and the New England States. Replies to questionnaires reveal the fact that the tremors were felt as far south as Virginia, as far west as the Mississippi, as far east as the Atlantic and at least as far north as a lone camp some 80 miles above lake Saint John. Records were obtained at practically all the seismographic stations in the world, very complete and well-marked ones being registered as far west as Victoria, B.C., as far east as Central Europe and as far south as La Plata. The area of maximum damage was confined to a narrow belt, approximately 20 miles long, covering both sides of the Saint Lawrence, somewhat less than 100 miles below the city of Quebec. Besides this damage indicating the position of greatest disturbance, there was some, due to the soft soil beneath heavy buildings, in less disturbed regions, notably at Quebec and in the valley of the Saint Maurice river.

The epicentre may be considered as having occurred on a fault line crossing the Saint Lawrence near the mouth of Rivière Ouelle (about 90 miles below Quebec city), entering the south shore to near Saint Pacôme, and extending into the north shore, up (perhaps) one or both the rivers Malbaie and Gouffre. The earthquake probably consisted of a sharp upward thrust on the northeast side of the fault, coupled with a strong horizontal movement toward the northeast in the case of the southwest side.

The causes advanced for this earthquake are a major, underlying one, due to an accumulation of stress caused by a slow rising of the Atlantic coast, and several "trigger" causes. Among the latter may be mentioned the Sayles theory of the effect of long periods of drought on a rising section of the coast, and also the estuary tide effect, virtually warping up the outer (east) side of the fault, due to a high tide, well inside the fault line zone, and a low tide outside that zone—the conditions which obtained at the time of the earthquake.

(2) *Areas of greatest severity*

The areas of greatest severity were three in all. The first of these was in the immediate vicinity of the epicentre (Baie Saint Paul, Saint Urbain, Les Eboulements, Pointe au Pic, Malbaie, Tadoussac and villages adjacent to these on the north shore of the Saint Lawrence; and Sainte Anne de la Pocatière, Saint Pacôme, Rivière Ouelle, Saint Philippe, Saint Denis, and Saint Pascal on the south shore), where the damage was due to the strength of the tremors, aggravated in some cases, notably at Baie Saint Paul, Saint Urbain, and Rivière Ouelle, by the deep alluvial soil on which the damaged structures were built. The damage at the other two locations (Quebec and Trois Rivières–Shawinigan Falls) was due, not so much to the intensity of the shock, as to the unstable nature of the terrain.

At Quebec the area of greatest damage was confined to a narrow belt bordering the Saint Charles river, where a heavy grain elevator and loading equipment is built on deep, made ground, held in place by piling driven along the edge of the river.

At Trois Rivières, the damaged structures were built on the deep alluvium in the delta of the Saint Maurice river. The serious damage at this point was confined to structures which were particularly top heavy. At Shawinigan Falls, unstable foundation soil was mainly responsible for the damage, but poor construction, either as regards the material or the design, or both, was an added factor of importance. The damage at the various places may, conveniently, be discussed in the order in which they are named above.

Baie Saint Paul—This town is situated in the delta of the Gouffre river, which, although a comparatively narrow stream throughout its course in the "mountains" immediately to the north, is at least half a mile wide at its mouth. The mountains, so-called, are from 900 to 1,400 feet high in the vicinity of Baie Saint Paul. They are really the dissected edge of the high plateau of the Canadian Shield, at this position about 3,000 feet above sea level. The mountains several miles inland have their tops at the level of this peneplain, rising to 2,000 feet or more above the level of the Gouffre river. The terrain on which Baie Saint Paul is built is deep alluvium. A well near the railway station is said to be dug to a depth of 80 feet through sand and clay.

The fact that this town is less than 25 miles from the epicentre, coupled with the factor of alluvial terrain, resulted in very general distribution of minor damage—fallen chimneys, broken windows, overthrown dishes, etc. It is a fortunate circumstance that most of the houses are built of wood. There are but few brick houses. The chief stone structure is the Catholic Church, at which place the greatest damage was sustained.

The great tower of this church is 150 feet high. Two of the large bells were thrown out of their bearings. The swaying of the tower dislodged about a cubic yard of stone from the inner side of the top of the tower immediately below its bell canopy. The church was just being newly decorated. The dust from the fallen stone and the plaster dislodged at the juncture of the ceiling with the tower wall were thus particularly noticeable. The damage was not nearly as serious as was reported at the time. Within a week the repairs required had been completed and the church showed little effects of the earthquake.

There were several points where minor damages were more serious than elsewhere. Probably the greatest loss occurred in the drug store of Dr. E. Allard. Practically all the bottles fell from the shelves, which are arranged around three sides of the store. Within a week after the earthquake, all the shelves had been equipped with battens nailed part way up the face to prevent a recurrence of the damage. The battens were enamelled to match the shelves and were designed as a permanent equipment. This seems to be one of the few cases where reasonable precautions have been taken in expectation of a recurrence of the earthquake.

The great stove in the Hotel Seymour was upset but no fire resulted—a rather remarkable circumstance which was true throughout the entire epicentral district in which many stoves were overturned at a time when the weather was very cold and when, in many cases, the householder rushed from his home in terror.

The Hospice de Sainte Anne is built of brick. It suffered a cracked wall which did not appear to be at all serious.

Saint Urbain—The village of Saint Urbain lies in the valley of the Gouffre river 8 miles above Baie Saint Paul. It is at an elevation of about 400 feet, the valley floor being a mile and a half wide at that point. The houses are built on clay. Magnetic oxide of iron is mined on the mountain just west of the village.

The breaking of chimneys and windows was the general type of damage sustained. As all the houses are of frame construction they were otherwise unharmed. The church is built of stone. It is very old and had survived the earthquake of 1870. The present earthquake practically wrecked the building. The spire tilted toward the northeast at a dangerous angle. Examination showed that the cross timbers in the spire were badly cracked and splintered. It fell at 3 a.m., Wednesday, March 11, 1925, breaking the telephone line connecting Chicoutimi with Quebec.

Between Saint Urbain and Baie Saint Paul cracks opened in the frozen floor of the valley. Water and sand oozed through these cracks. The water-table is only 4 feet below the surface at the point where the largest of these cracks occurred. It was visited about ten days after the earthquake. The crack ran for some 60 feet parallel with a steep bank to the west of it and with a steep drop toward a pond to the east. The frozen surface merely slipped over the water-table horizon toward the lower level of the pond, (see page 434). This crack was reported over most of the lower Quebec country at the time of the earthquake.

A description of the topography and geology of the valley of the Gouffre river is given by Dr. J. B. Mawdsley in a report entitled "St. Urbain Area, Charlevoix District, Quebec." (Canada Department of Mines, Geological Survey, Memoir 152, Ottawa, 1927).

Les Eboulements—This village lies approximately 9 miles down stream from Baie Saint Paul, on the north shore of the Saint Lawrence. It was not visited. The following is an abstract of the replies to a questionnaire returned by the postmaster at Les Eboulements: The first shock lasted thirty-five seconds. Many shocks of lesser intensity were felt during the ensuing night, and for some three weeks afterwards. The earthquake was accompanied by a very loud noise. Plaster was cracked generally. Thirteen chimneys were broken. Stone houses were cracked in several cases, on the sides facing northwest. The chimneys fell toward the northwest.

Pointe au Pic—The village of Pointe au Pic and that of Malbaie (Murray Bay) adjoin. In these two villages and to the northeast of them the damage on the north shore was greatest. At Pointe au Pic most of the chimneys were broken. Fire-place masonry was cracked and twisted. Heavy objects shifted. Statues rotated or fell. A report that one house has shifted on its foundations was investigated and found untrue. The houses in this village are built on much more solid foundations than is the case at Baie Saint Paul. In many cases they are on rock. Had this not been so the damage would certainly have been much greater. The main earthquake was so severe that it was felt by the train crew on a moving engine, which was approaching Pointe au Pic at the time.

Malbaie—This village is built partly on rock and partly on alluvium, at the mouth of the Malbaie river. The difference in the damage for the two types of terrain is very marked. Two seriously damaged structures were the jail at Malbaie and an old manoir house a mile or two down stream from that village on the banks of the Saint Lawrence. The jail is massively constructed of stone. At the time of the earthquake it was occupied by the jailer and his family and one prisoner. The building was badly cracked throughout. The courtroom was a wreck of fallen plaster. The noise of the banging cell doors and the falling stone and plaster was terrifying. The jailer reported that the shocks continued all night at short intervals with hardly any respite. Here, as in many places in the epicentral area, no one attempted to sleep all night.

The manoir house is also solidly constructed of stone. It is very old, the "modern end" having been built fifty-two years ago. As a result of the earthquake, the great chimneys at each end of the house sagged out several inches at the top, breaking connection with the roof and ripping the floors. The south wall bulged out at the top. The verandah sank and sagged out from the wall. Rifles and pictures were thrown wide of the walls on which they had been hung.

The church at Malbaie is on solid rock. Thus, although it is constructed with stone front and plaster walls, the bond between these forms of construction did not break. One could hardly ask a better example of the difference between damage to structures on rock and those on alluvium than that afforded at Malbaie (and also at Quebec city. *See* page 382).

Several stoves were upset by the earthquake in the vicinity of Malbaie, some of them being on the second floor of the house. No fires resulted, which was most remarkable considering the circumstances.

In many cases the chimneys at Malbaie were "twisted off". That is, they fell in a manner which left the bricks strewn out in a sort of spiral from the foot of the chimney. Some which remained in place but distorted showed this same "twisting". The successive jars seemed to break the bond of the mortar and the bricks, catching first at one point than at another, which caused the chimney to rotate as the bricks loosened from the chimney block in the course of disintegration.

The inhabitants of Malbaie and Pointe au Pic were much disturbed by the earthquake. Many wished to leave the area during the period of the aftershocks. Some did move temporarily to Quebec city.

Tadoussac—It was not possible to pay a visit to Tadoussac at the mouth of the Saguenay river. Several telegrams were exchanged with the mayor of that village, and questionnaires were returned by three representative citizens. Chimneys were broken generally. As a rule these fell to the east. The noise of the various shocks arrived from the west before the tremors were felt.

Between Malbaie and Tadoussac is the lighthouse station of St. Simeon. Mercury was spilled from the light float and the usual damage of broken chimneys was experienced. It was not found possible to visit the place but questionnaires were returned by the parish priest of this village and also by the parish priest of Saint Hilarion a few miles east of Saint Urbain.

Sainte Anne de la Pocatière—The point on the south shore, eastward from Quebec city, at which the area of greatest damage first appears is the village of Sainte Anne de la Pocatière. True, damage was reported from other places—Montmagny, Saint Jean Port Joli, Sainte Louise, etc.—but it was little more than the breaking of a few chimneys, presumably of poor construction, the cracking of the snow-covered surface of the ground, and the rotating of a few monuments which were, in some cases at least, not well placed.

At Sainte Anne the damage was very marked. Part of the village is on a rocky ledge, part on an alluvial plain. Damage was general throughout the entire village but was greater on the alluvium. Most of the chimneys in the village were thrown down; brick walls were cracked; frame houses were twisted out of shape in a few cases; plumbing was broken; the plaster tops of pillars in the chapel of the college were destroyed; some monuments in the cemetery were thrown down while many others were rotated; crockery was broken throughout the village; the snow which was frozen hard at the time of the quake was cracked generally in this district; the frozen earth beneath the snow was cracked into huge rectangular grids; water conduits buried in the ground were broken.

Saint Pacôme—This village is built close to a rocky outcrop to the south of the valley of Rivière Ouelle. The destruction of chimneys was general. Some were twisted and others were thrown off in a solid block, the mortar having broken at one joint only. Stoves were upset or moved along the floor. A heavy safe, on rollers, was shifted for a distance of more than a foot. The frozen road surface was cracked more or less regularly at distances of 100 feet or less, in some places as close as every 15 feet. A great crack opened in the clay at a point where the floor of the valley rises to the cliff.

At the railway station, which is about a mile from the village, 48 panes of glass were broken. The stoves shifted toward the east. The stove in the men's waiting room

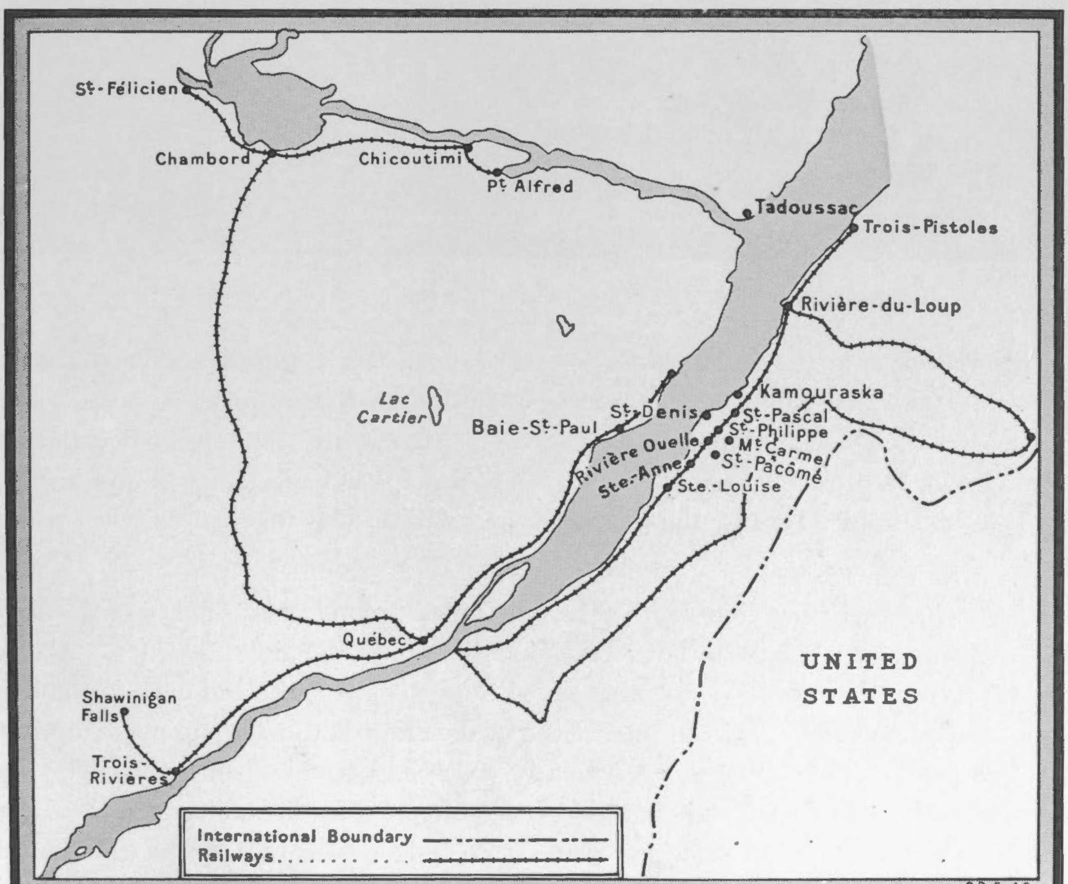

FIG. 1.—Map of epicentral region

moved east several feet by a series of jumps as was evidenced by marks on the floor. A cook stove moved east in the kitchen. A heater in the living quarters upstairs moved east. The ceiling fell in the dining room. The piano turned contra-clockwise. A cupboard fell toward the east. A latched door, fastened with a wedge before the earthquake, was found open afterwards. The boards forming the wall of the men's waiting room had had a hole cut through for a stove pipe which was no longer in use, the hole being covered with a piece of tin securely held in place with many short nails. The tin was worked and buckled until it was quite out of shape but it was still in place.

At the time of the quake, the operator, who lives at the station with his family, was at the telegraph key. The earthquake struck *without a preliminary sound warning* as a single sharp bolt *from below*. The stove in the ladies waiting room broke in half. The section with fire in it rolled into the centre office and had to be rolled out in the snow. The shocks continued to be felt at intervals during the night.

FIG. 2.—Looking north over the valley of Rivière Ouelle from Saint Pacôme

This station is in the valley of Rivière Ouelle (*see* figs 1 and 2.). The soil is deep alluvium. The water table is only a couple of feet below the surface. The station is of frame construction. The stations on either side of it (Sainte Anne de la Pocatière and Rivière Ouelle, respectively) are of brick. The former was badly cracked and has some brick dislodged from its walls, the one at Rivière Ouelle was wrecked as will presently appear.

Rivière Ouelle—Every chimney for several miles around this point was destroyed. Only three stone buildings were between the station and the Saint Lawrence. All three were destroyed. Two were old stone houses with great walls 2 feet and more in thickness. The owners had to rush out at the time of the quake and could not again make use of the houses. The church was a fine stone structure which had been built in 1872. The organ pipes were projected upward and outward so that they fell in the auditorium clear of the choir loft. The stones of the wall were jarred loose (*see* fig. 3) so that the tops of the walls, especially in the transepts, were thrown down (*see* fig. 4). The great stone chimney was thrown down and crashed through the roof.

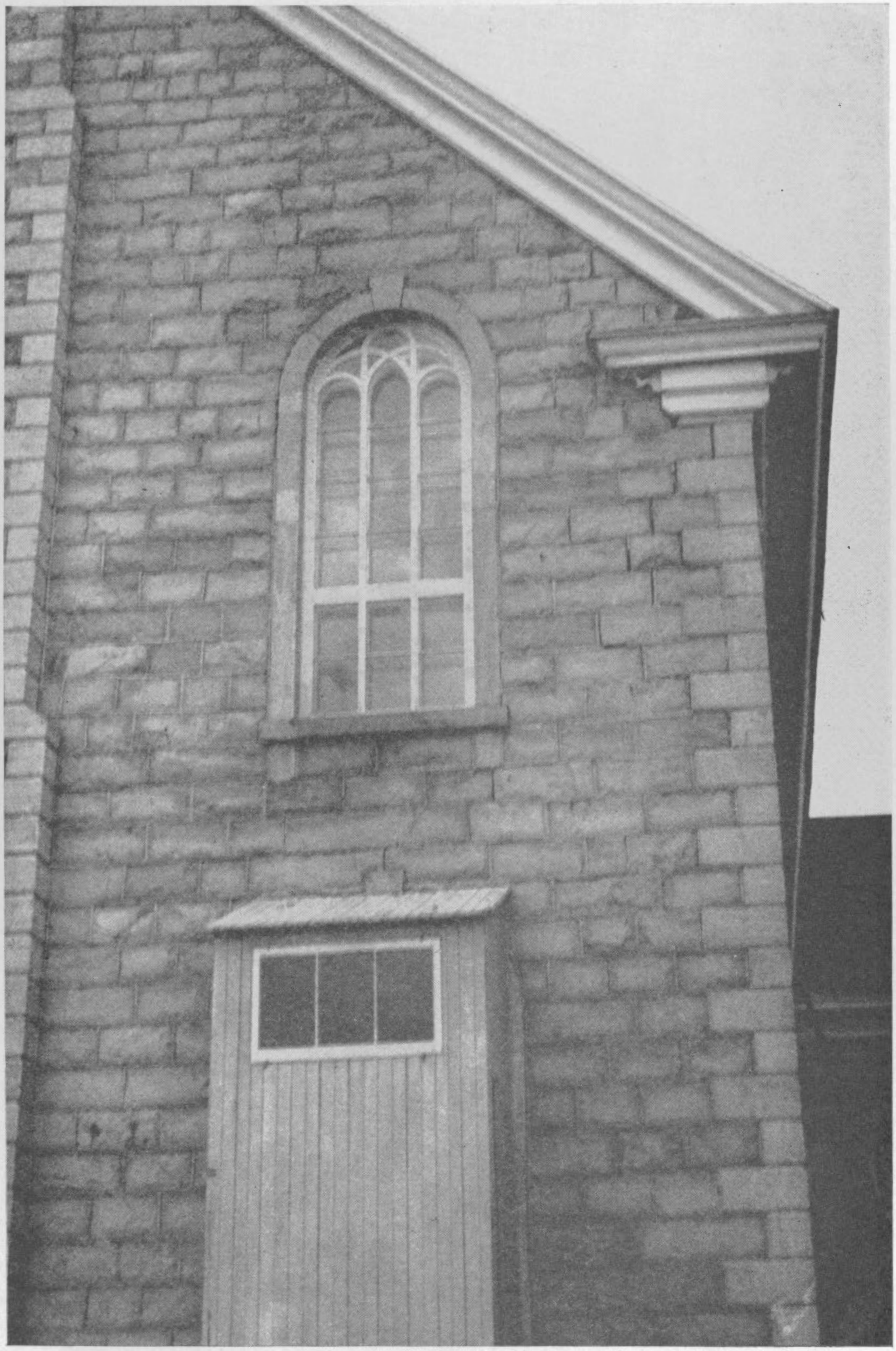

FIG. 3.—East side of front of Rivière Ouelle church

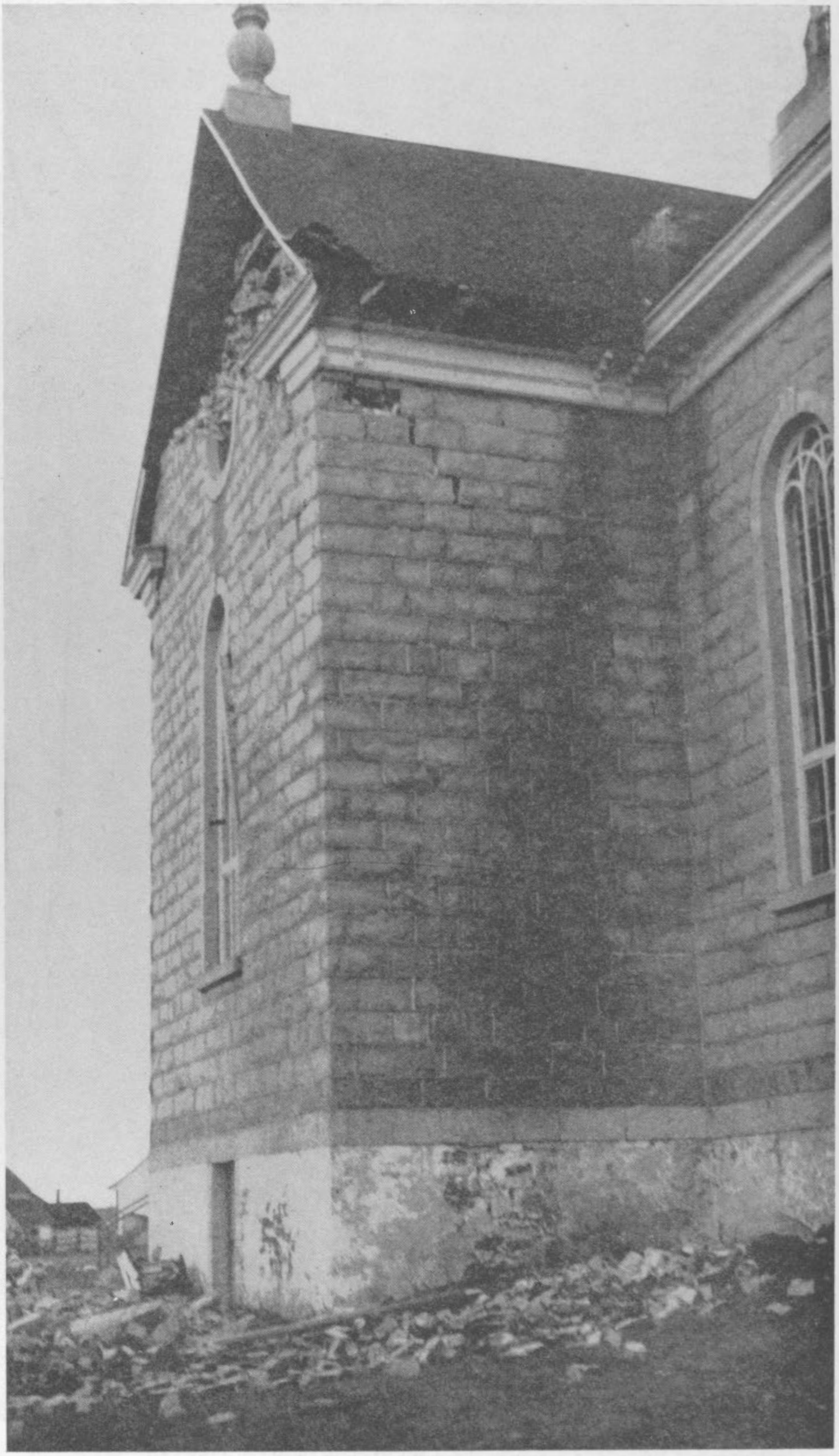

Fig. 4.—West transept wall of Rivière Ouelle church

In the churchyard, the monuments were generally thrown down or rotated (*see* figs. 5, 19, 20, 21). There were three graveyards of different age. In the oldest there were only a few flat headstones. These were probably fallen before the earthquake. Certainly none remained standing afterwards. The second oldest section has stones of various types in it but they were possibly in need of some re-setting previous to the quake. Nearly all were damaged in some way but the fall of the upper sections was in different directions depending on the way the respective monument was tilted out of plumb. The latest section had new stones, well set up and in good order. These were either rotated or thrown down. Every stone in this section which fell lay to the southeast (*see* fig. 5).

The soil at the position of the church and graveyards is very deep. Just in front of the church a bridge crosses Rivière Ouelle. The parish priest furnished the information that the foundation of this bridge rests on piles driven down through 90 feet of sand.

A great crack formed beside the roadway about a mile from the church (*see* fig. 17). The crack is parallel to the river bank which is about 33 feet distant. Six weeks after the earthquake, the crack was still visible and could be followed for about 100 feet, the edges being from 2 to 3 inches apart. At the time of the earthquake the crack could be followed for 150 feet and a stick could be thrust into it to a depth of 20 feet.

At the time of the earthquake a number of persons had gathered at the station at Rivière Ouelle to wait for the train from Lévis, which was just about to leave Sainte Anne de la Pocatière when the earthquake occurred. The shock arrived at Rivière Ouelle without warning as a single sharp jolt from below, followed by later oscillations. The first blow threw out the station wall from foundation to roof.

Saint Philippe—The houses in Saint Philippe are on rock or near rock. They are invariably frame. The station is of solid brick and suffered a crack in the east wall. Part of the west wall fell after the earthquake. The church is of cut stone. It was not damaged, nor was any appreciable damage noted in the cemetery. The road running from Saint Philippe to Saint Denis, toward the Saint Lawrence, crosses a level stretch of valley floor. It was cracked at intervals as was that at Saint Pacôme (*see* fig. 16). That the shock was severe at Saint Philippe is evidenced by the fall of a chimney on a comparatively new house. This chimney had evidently been built on a platform inside. At the time of the earthquake it was dropped down into the house. The fall of chimneys built in this way is a serious menace in a country liable to earthquakes. It is astonishing that no one was injured with destruction of chimneys so general. The story is told of one case in this section where a child had just stepped out of a bed when the earthquake occurred, piling the bricks on the pillow.

Saint Denis—This village lies between Saint Philippe and the Saint Lawrence. It has but few houses. The church has an extraordinarily high steeple. This steeple swayed so that the joint between the roof and the wall was chipped. Statues, etc., in the church fell southeast. Some of the stones turned in the small graveyard. Several stories were told of strange lights seen from this village hovering over the Saint Lawrence. The parish priest explains these by saying that the light was due to the setting moon then about six days old which was partly obscured by clouds.

Fig. 5.—Monuments all fallen eastward, Rivière Ouelle cemetery

Saint Pascal—The church in this village is a very fine one. Four statues of angels are mounted at the corners of the spire roof. These are of large size but were not displaced by the earthquake. The church walls are very thick. They were very much cracked at the time of the earthquake. A photograph taken about a year later (*see* fig. 6) shows these cracks repaired and indicates that they spread over the entire wall. It is said that a statue in this church was thrown upward and outward by the shock so that it cleared the candelabra of electric lights which was fixed above it. The ring of lights was certainly large enough to permit the statue to clear them but it is more than probable that it fell and rolled under. Every statue but one in this church was thrown down. Stones in the graveyard adjoining were rotated or thrown down, except the flat headstones which were not affected. It is said that repairs to this church cost $5,000.

The solid brick station was cracked on one side. Chimneys in the village were generally thrown down but not in all cases. Except for the church, little serious damage resulted from the earthquake. This same church suffered during the earthquake of 1870.

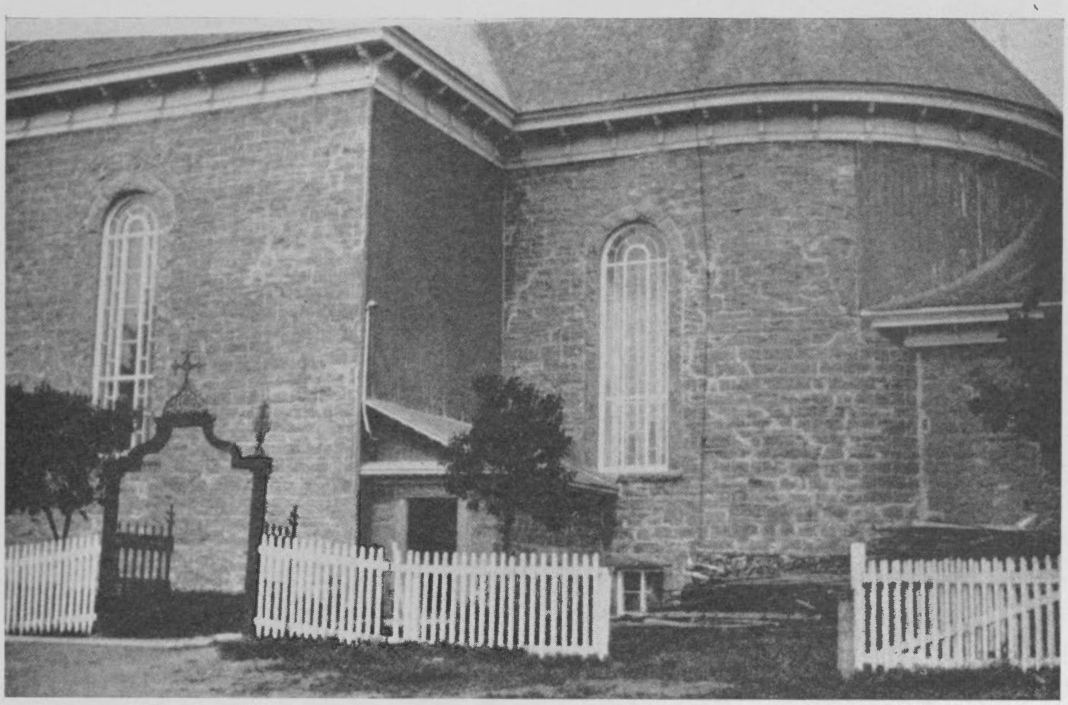

FIG. 6.—Rear of church at St. Pascal (restored)
Photo by J. W. Goldthwait

Quebec—The damage in the city of Quebec was confined to a narrow belt bordering the Saint Charles river. The structures which were chiefly damaged were the Palais Station of the C.P.R. and the grain elevators and shipping sheds which border the Saint Charles.

Palais Station is well built of steel and brick. The earthquake swayed the steel structure, breaking many panes of glass in the skylights. The swinging steel battered the top rows of bricks out of the wall in the north end of the waiting room. These piled on the floor in front of the train bulletin board, but no one was injured.

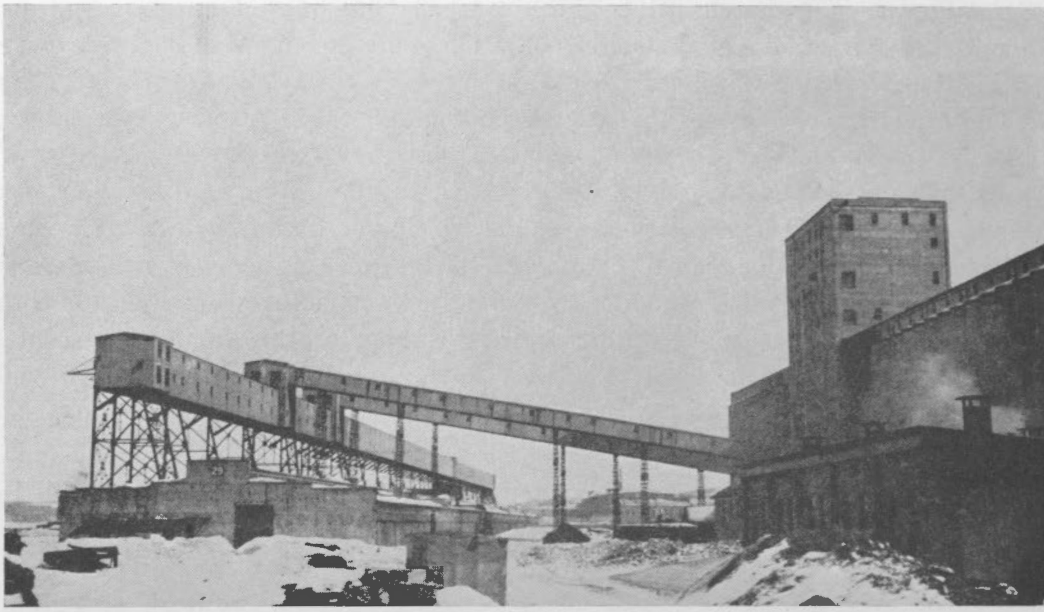

FIG. 7.—Grain elevator and freight sheds at Quebec

The grain elevator and loading sheds are built on made ground on the west bank of the Saint Charles river (*see* fig. 7). To make the ground area required, piles had been driven to a depth of 42 feet along the edge of the river. These piles extended 24 feet above the bottom of the river, being 66 feet over all. The earth required to fill behind the piles was dredged from the river floor. On the land so made a great shed was built, 1,000 feet in length and parallel to the row of piling, but far enough behind it to permit several lines of railway tracks on the water side of the sheds.

The sheds proper are about 30 feet in height. Between the roof of the sheds and the floor of a row of "grain galleries" above, the steel frame stands open. The galleries are themselves about 30 feet in height, making an overall of about 110 feet. The supporting steel is in the form of I-beam columns which are spaced 20 feet apart each way. The sheds are 100 feet wide. The columns along each side are braced by having a 20-foot L-bar carried over from each to its respectively opposite column in the next inner row. The foot of each column rests on its individual cement pier. The galleries are connected to the grain elevator by an overhead coupling at shed 28.

Obviously the structure is very top heavy. At the time of the earthquake the made ground yielded. The galleries lurched toward the river forcing back the foot of each column by about 3 inches (*see* fig. 8), thereby bending the L-braces (*see* fig. 9). Then, the elastic strength of the steel proving sufficient to prevent the structure overturning altogether, the whole swayed back again, this time forcing the foot of each column on the back wall out of its place on its pier. The swaying pulled the overhead coupling several inches away from the warehouse. The sheds are cased with sheet metal but have ceilings of concrete. At the time of the earthquake several sections of this concrete ceiling were thrown down. Fortunately, the sheds were empty at the time of the quake.

The grain elevator is provided with more than a hundred massive, cylindrical, concrete bins about 100 feet high and 16 feet in diameter, with a "workroom" above, which is

200 feet high, 100 feet long and 60 feet wide. The top hundred feet of this section projects beyond the tops of the bins and stands clear, with four stories of floors in it. High in this upper section is a battery of scales for weighing the grain. These are immense affairs, each capable of handling 60 tons of grain. These scales were thrown off their pivots, all falling south. The counterweights, formed of plates of iron about 2 inches thick and 18 inches square, built up into a mass 5 feet high by means of two bolts seven-eighths of an inch in diameter, were swung so violently that the bolts were sheared off and the plates flung to the floor 5 feet below. Four automatic scales, which could not be thrown off pivots, swung to and fro in the steel plate enclosures, banging on the doors until the latter were battered, as if made of lead, by the projecting points of the swaying scales.

The whole upper section of the work room swayed with the heavy machinery so that practically all of the reinforced concrete columns about the outer walls were cracked at the point where the superstructure meets the top of the main building. These were not simple cracks. Some had worked back and forth until great sections of concrete were ground out of the face, several feet long, a foot into the wall, and a foot to eighteen inches wide

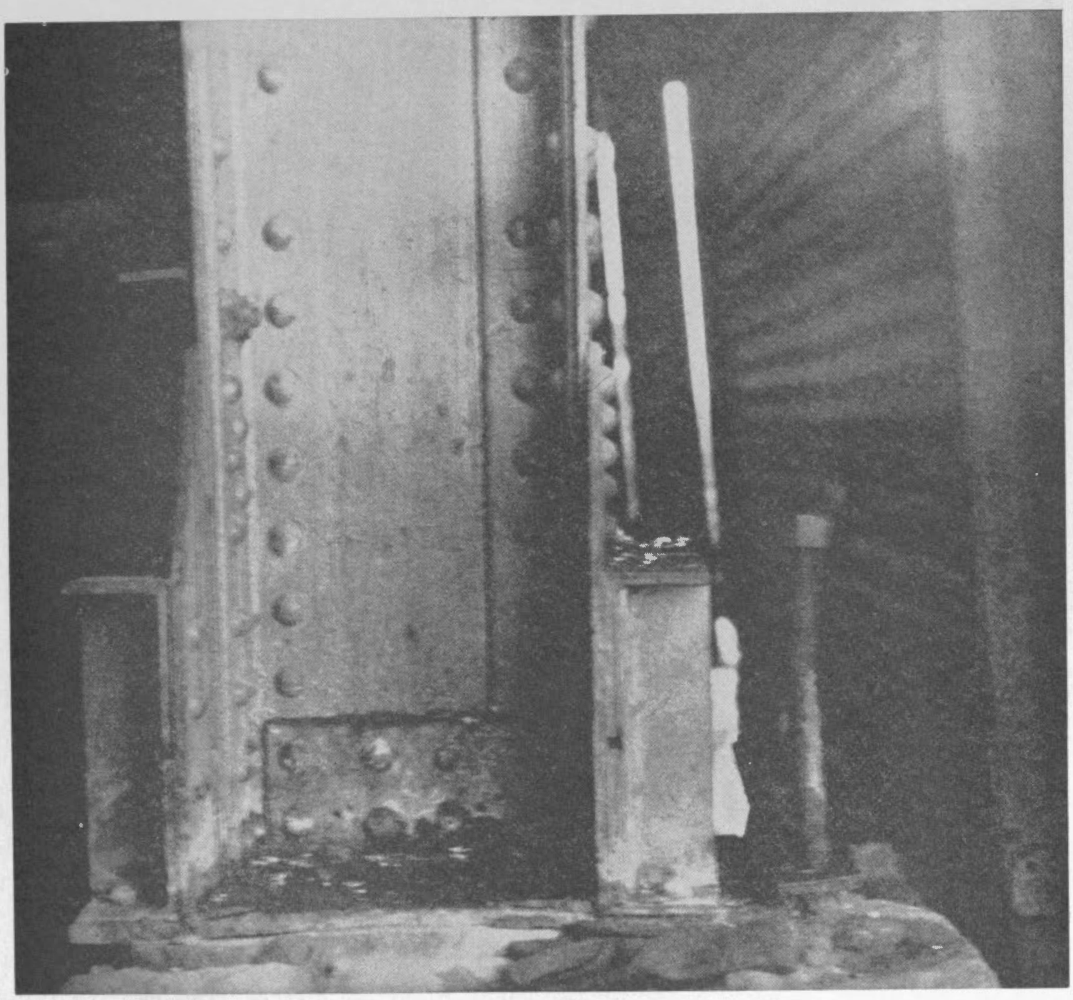

FIG. 8.—Shift of foot of steel supporting column of the freight sheds at Quebec

on the face. The reinforcing irons, rods about half an inch in diameter, were in some cases worked out through these cracks. No one was in the building at the time. The noise and the swaying would surely have been terrifying.

Less than half a mile from the elevator and shed stands the Chateau Frontenac, the great Canadian Pacific Railway hotel. It is on the rocky cliff supporting the central part of Quebec. Some persons in this building did not hear the earthquake at all. No one was greatly alarmed by it. The difference between the effects observed at these

FIG. 9.—Bent back brace at freight sheds at Quebec

two spots so close together is due entirely to terrain. The buildings at the harbour are very well constructed. Had they not been they must have been completely wrecked. They were built where the need demanded, beside the river. The soft ground was the cause of the damage rather than proximity to the epicentre.

At the time of the earthquake great icicles hung on the eaves of many buildings in Quebec (*see* fig. 10). Some of these, on the rocky foundation of centre town, were quite undisturbed by the quake. A number of ice statues and arches (*see* fig. 11) are constructed

FIG. 10.—Icicles at Neptune Inn, Quebec

FIG. 11.—Ice arch at Quebec

here and there about this city in the winter. None of these was damaged by the shock. The breaking of chimneys was not at all general, those which yielded being in poor repair, as a rule, and nearly all in the lower sections of the city.

It may be noted in passing that the sheds at the harbour were built in 1917-18. When first built they used to sink about an inch in six months due to the settling of the filled ground, but they had not been sinking appreciably at the time of the earthquake.

Trois Rivières—Damage at this point was not serious. Three cases require special mention. . The Wabasso Cotton Co. plant was damaged because a water tank was supported by steel columns which were tied into the walls of the factory. The swaying of the top-heavy structure filled with water resulted in the wall being cracked The Wayagamack Pulp and Paper Company's plant was damaged to some extent. One of the brick stacks, 250 feet high, had about 25 feet thrown off the top by the earthquake. There was some damage to one of the furnaces also. These plants are both on deep sedimentary deposits resting on clay of unknown depth. Damage was also sustained by the Saint Lawrence Paper Mills, one of their brick stacks being badly shaken by the earthquakes. It was not thrown down and was repaired afterwards without having to be entirely rebuilt.

Shawinigan Falls—The damage at Shawinigan Falls was, in each case, due to one or more of four factors: poor workmanship, shoddy material, insecure terrain, or improper design. A number of brick walls were thrown down in part and one altogether (*see* figs 12 and 13) due in each case to a combination of poor workmanship and insecure terrain. Many stone and brick walls were cracked (though they were well built) due to the buildings being placed on or near the slopes of clay banks. The brick transept wall of Saint Marc church was thrown down (*see* fig. 14). The steel frame of the factory plant of the Aluminum Company acted as a battering ram, under the influence of the earthquake movements. It battered out the top of the gable ends at each of the units.

A report on the damage at Trois Rivières and Shawinigan Falls was made by C. D. Abbott of the Inspection Department of the Associated Factory Mutual Insurance Companies. He places the total damage at both places for factories and private dwellings combined at $17,000. His conclusions may well find place at this point as they sum up concisely the situation in the valley of the Saint Maurice as elsewhere in the region subjected to the earthquake tremors:

"*Conclusions*—1. Deep alluvial deposits such as those at Trois Rivières and high unstable ridges like those at Shawinigan Falls are particularly susceptible to earthquake vibrations. Buildings founded on rock are unlikely to be damaged.

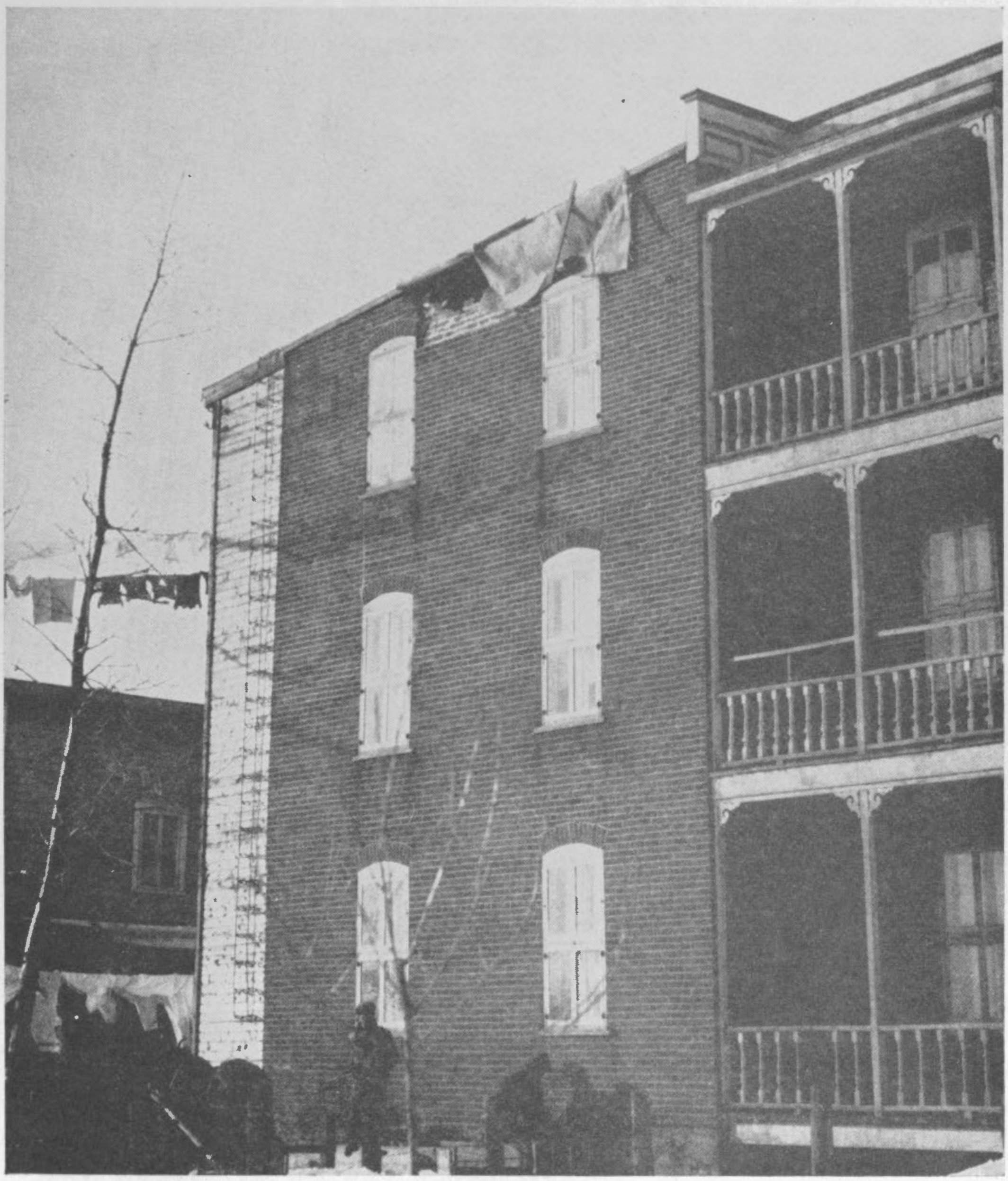

FIG. 12.—Damaged wall at Shawinigan Falls

FIG. 13.—Damaged wall at Shawinigan Falls

"2. Although the instability of foundation soil augmented the earthquake vibrations and was therefore in part responsible for the damage, certain weaknesses or peculiarities of construction were equally influential in causing damage. The maximum intensity of the earthquake at Shawinigan Falls and Trois Rivières is not considered great enough to have damaged properly-designed, well-built, and well-maintained structures.

"3. The Wabasso Cotton Company would have received no injury had it not been for the heavy water load at the top of the stair tower and the difference in the vibration periods of the main building and the tower.

"4. The stack and furnace at the Wayagamack Pulp and Paper Company and the stack at the Saint Lawrence Paper Mills would not have been damaged if the mortar had not been loosened or even eroded from the joints.

"5. The injury to the buildings at the Aluminum Company of Canada was not due to inferior brick work but rather to the large pitched roofs supported on flexible steel frames which swayed longitudinally with a greater amplitude and different period than the gabled ends.

"6. Other structures at Shawinigan Falls were damaged because of obvious weaknesses. The brick walls that fell were of inferior construction, unbraced, thin, and laid in poor mortar.

"7. Unless different parts of buildings are well tied together they are very likely to crack along the intersection at the time of even a light earthquake shock. Plaster on metal lath is more resistant to cracking than plaster on wooden lath.

"8. As shown by all earthquakes a steel frame while exceedingly resistant to damage in itself must be very thoroughly tied into brick walls, otherwise it will pound the walls down because of its greater amplitude of motion.

"9. Heavy tile roofs are very susceptible to earthquake damage and the heavy roof is a menace to the building as a whole."

In closing this section of the report, dealing with the areas of greatest severity, it is well to consider for a moment the probable extent of the damage and loss of life had the industrial plants and their attendant homes for workmen been built in the vicinity of, say, Rivière Ouelle church at the time of the earthquake. Rivière Ouelle church has been rebuilt, as nearly as possible exactly the same as before. It was torn down to the foundation and re-erected with the same stone. Except with a picture of the original church before one, the difference cannot be detected. It will almost certainly have to pass through another such earthquake during its probable life, yet no precautions have been taken to prevent a recurrence of the destruction of 1925, which, fortunately, occurred at a time when there were no worshippers in the building. Will the next earthquake be so happily placed in the day's program? Furthermore, industrial plants are to-day being built within striking distance of this epicentral region, trangressing some or all of the known rules for buildings in such areas. If an earthquake originating in this region can cause $17,000 damage to buildings at a distance of 120 miles, what will be the effect of the next great

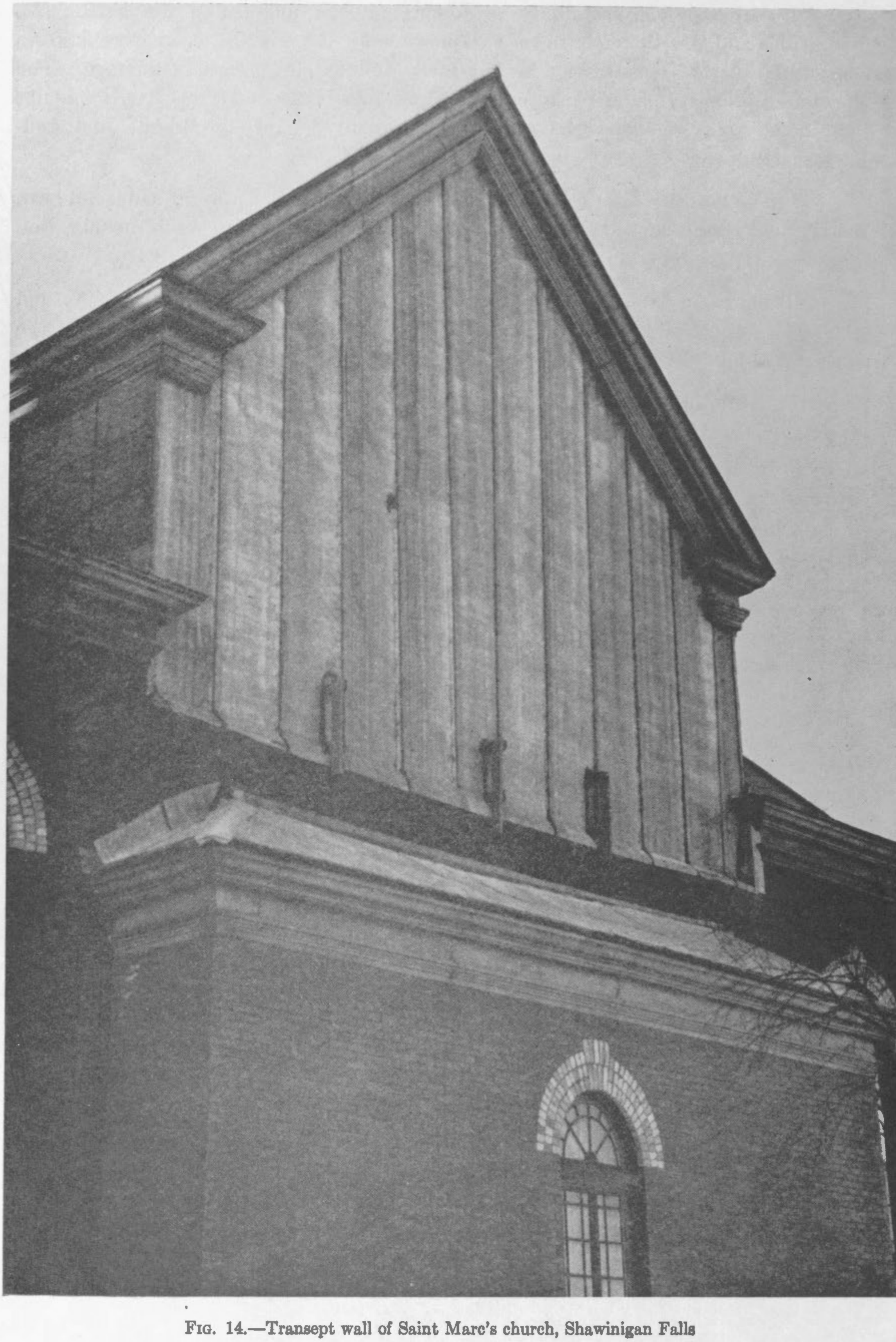

FIG. 14.—Transept wall of Saint Marc's church, Shawinigan Falls

shock on buildings, erected in the interval, within 25 to 50 miles of the centre? As will be shown later, earthquakes are known to have occurred at intervals of about sixty years for the past three centuries and more, their epicentres being, presumably, in about the same position as that of 1925.

(3) *Earth cracks and slumps*

At the time of the earthquake the ground was deeply frozen over the entire epicentral region. The snow covering was deep and had an icy crust. The frozen crust and the frozen earth surface beneath it were generally cracked in the region on the south shore from Sainte Louise to Saint Philippe. The frozen crust was cracked as far east as Gaspé. The following note by the late Dr. John M. Clarke of the State Museum, Albany N.Y., appeared in *Science*, No. 1580, p. 392, April 10, 1925.

> "A few days before the earthquake of February 28, there was rain over the snow-covered fields of Gaspé. This froze into a hard crust. The morning after the tremor this crust over the snow fields was found to be cracked in long parallel lines running

FIG. 15.—Cracks in soil at Sainte Anne de la Pocatière

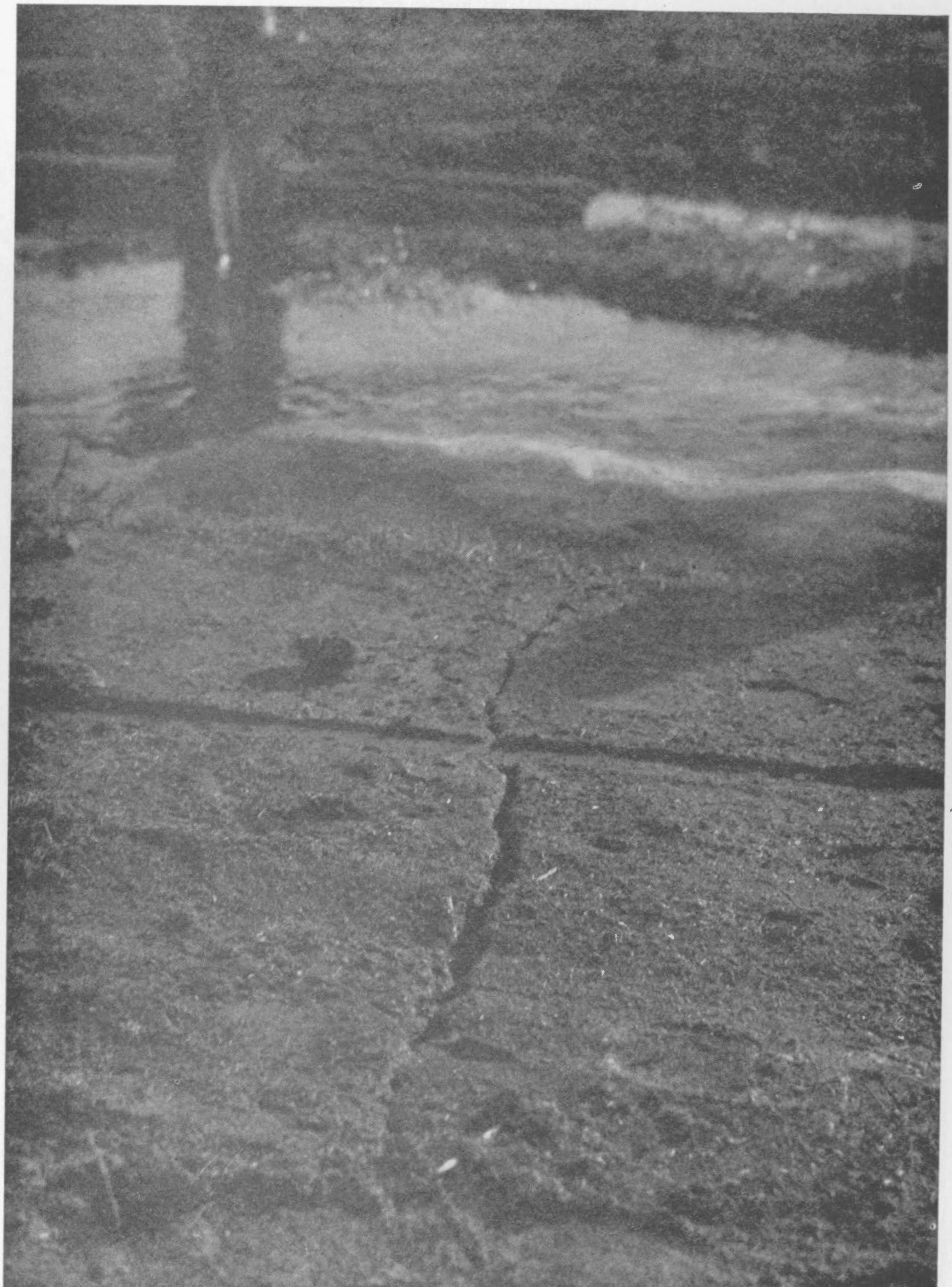

FIG. 16.—Typical crack in the road near Kamouraska

NW-SE, a little E. This observation was reported to me by Mr. F. J. Richmond of Gaspé, a close observer, who adds that when the snow settles naturally, cracks in the crusts will follow the sags of the ground surface. This automatic register of the movment of the earth wave indicates a course at right angles to the directions given, namely NE to SW. The direction of these crust cracks has been verified since, by observations made by lumbermen 40 miles inland from Gaspé."

These snow cracks were not observed on the north shore and were found on the south shore only as far west as Sainte Louise. It is possible that they escaped notice during the visits to those places which were inspected previous to the Rivière Ouelle district. At Sainte Anne de la Pocatière they were very noticeable. They were so well marked that they attracted attention as one passed in a train.

That the cracks in the snow reached to the ground itself was very well verified at Sainte Anne. To the north of the village the land slopes down rapidly to a level plain just above the level of the Saint Lawrence at high tide. This section is very good farm land. Certain cracks in the snow were so well marked that they were noted at the time. Several were inspected shortly after the earthquake. The following spring, when the farmers ploughed the fields, the furrows, one after another, broke as they were being turned, as if cut by a knife. These cuts, as defined furrow by furrow, traced out the mark of the great cracks in the snow at the time of the earthquake.

One particularly well-defined case was observed and photographed just west of the village af Sainte Anne (*see* fig. 15). A field had been in potatoes the summer of 1924 so that the surface was free from weeds. At the time of the earthquake it was, of course, deeply covered with snow. After the snow had melted, six or seven weeks after the earthquake, the marks of the cracks were well-defined in the moist earth surface. These were in the form of a grid, the cracks being approximately at right angles and about 100 feet apart each way.

The roads, from near Sainte Anne de la Pocatière to Kamouraska, were broken at intervals, the cracks extending, apparently to the bottom of the road embankment (*see* fig. 16). These cracks persisted until after the snow had melted. Many of them were photographed. It was noticed that the cracks were much better defined and were at more regular intervals on roads running north-south than on others at right angles. On one road, running from Saint Pascal to Kamouraska, an attempt was made to determine whether there might be any regularity in the breaks. The observer walked the entire length of this north-south road. It was found that the cracks were about 30 paces (approximately 100 feet) apart and that there was undoubted regularity in this flat-lying road, traversing an alluvial plain.

It was reported that springs opened in the fields near this road at the time of the earthquake. A row of fence posts was also reported to have been broken off at the ground line but the report was not followed up. A horse is said to have been mired by stepping into a concealed crack when working on the land in this vicinity the following spring.

The largest earth cracks reported were inspected. One was between Saint Urbain and Baie Saint Paul and has been referred to on page 371. A second was near the church of Rivière Ouelle parish and has been described on page 377 (*see* fig. 17). The third was at Saint Pacôme. It has been mentioned on page 373, but further details may be given. It

FIG. 17.—Slump crack in ground near Rivière Ouelle church

was visited within a couple of weeks after the earthquake. It was along the edge of a hill where the valley of Rivière Ouelle slopes up to a rocky ledge. The crack was well defined for a distance of more than 100 yards. After the snow melted it was still well defined. After the lapse of six weeks or so, a stick could be put in it freely to a depth of about 16 inches. It was, of course, very much deeper when first opened in the deeply frozen soil.

In every case the cracks in earth occurred where the water table was only a foot or two below the surface, in deep alluvial soil, where the clay deposits lay against the steep slopes of outcropping rock ledges, or where there was a sharp difference in level in the clay, as at Rivière Ouelle church, where the section of frozen ground, about 33 feet wide and some 150 feet long, slid toward the river, which has cut down a channel about 15 feet deep at this point. None of the cracks could be considered as defining the position of a shifted fault in the underlying rock.

(4) *Effects on wells and springs*

Many reports were received as to the effects on wells and springs, but in no case was it found possible to visit the places reported *after* the information had been obtained. In one or two cases the region had previously been visited without any mention being made by those interviewed of the effects on wells or springs in the neighbourhood.

A report was received of one well in Rivière du Loup which dried up at the time of the earthquake and of another which had been "hard" water before the earthquake but which was found to have "soft" water in it afterwards.

A spring was said to have opened in the field near Kamouraska at the time of the earthquake.

The water of a well at Saint Denis, not far from the Saint Lawrence, which is tide water at this point, was reputed to have been excellent before the earthquake but to have turned "fishy" at the time of the shock, and so continued.

At Saint Onésime to the south of Sainte Anne de la Pocatière, a well is reported to have dried up and another to have opened, one of these being at the presbytery.

It is quite to be expected that wells and springs in these regions should have been affected by the earthquake. None of these wells is, presumably, of very great depth, as the water table at all points is reported as being less than 15 feet from the surface. The ground was frozen to a depth of perhaps 5 to 6 feet, as it had been a very cold winter. The comparatively shallow subterranean water channels might well have been changed by the earthquake shock. As in the case of the earth cracks, the effects on the wells cannot be considered as indicating the exact location of the shifted fault or faults.

(5) *Effects on chimneys*

The effect on chimneys in the immediate epicentral district has been sketched in subsection (2) above. Practically every chimney was thrown down in the district within 5 miles in every direction of Rivière Ouelle church. This includes the parishes of Sainte Anne de la Pocatière, Saint Pacôme, Saint Philippe, and Saint Denis. The destruction of chimneys was quite general at Pointe au Pic and at Malbaie on the north shore, but was not universal. At Baie Saint Paul and at Les Eboulements many chimneys were overthrown. As to the rest of the area affected, it may be said that if chimneys fell they were in poor repair or the houses on which they were built stood on deep soil, possibly on the bank of a stream or on a slope of some sort.

The twisting of chimneys to which reference has been made on page 372 was common at Pointe au Pic and at Malbaie on the north shore, and at Sainte Anne de la Pocatière on the south shore.

At Saint Pacôme one chimney came off in a block, having broken loose at the house roof. It was said to have been thrown clear of the roof. No marks of it were to be seen on the shingles but it is probable that the roof was covered with snow at the time of the earthquake and that this protected the shingles as the chimney rolled off.

In general it serves little purpose to record the direction of fall of a chimney. The fact that the interaction of the brick and the frame construction (for most ofthe houses in the district were of frame) probably causes the first break in a well-built chimney, makes the orientation of the house a large factor in determining the direction of fall. Again, many chimneys are in poor repair. An hour's observation of chimneys along any route during a country drive will establish the fact that repairs are frequently in order. This is even more true in towns and cities, in the poorer residential sections, and also in some of the best.

(6) *Opening of doors*

Certain typical stories are told to every investigator of earthquake in the field. One of these typical stories is to the effect that locked, latched, or bolted doors are opened by the earthquake. It seems worth while to record two such cases which were reported first hand. It is impossible to escape the feeling that the doors may have been thoughtlessly opened in the confusion following the shock, but that does not necessarily follow. Frame structures can be warped out of shape to a remarkable degree by settling alone or by injudicious application of jacks in lifting them. The earthquake performs the function of shifting the building in different directions in rapid sequence. It is quite probable that both the cases here reported really happened substantially as outlined.

The first is at the station at Saint Pacôme, the story of which was given on page 374. There is no doubt that this loosely-built frame structure was greatly racked by the extraordinarily severe movements. An outer door is provided with a large latch of the type common in country houses and in barns—an iron latch hinged at one end on a screw, lifted by a hooked iron lever in the side of the latch itself and by a projecting thumb plate on the other side of the door. The latch fits down into a notched iron plate on the door jamb. To prevent the latch being lifted a wooden plug is pushed in above the latch and inside the guide which keeps the latch close to the door. This plug was set in place shortly before the earthquake. After the quake, the heavy door stood open, the plug still being in place above the latch. The notch out of which the latch had to lift in order that the door might open was about a quarter of an inch deep. An illustration showing the sturdy nature of the door and the latch and plug is given in fig. 18.

The second case is one observed at the manoir house near Malbaie. A workshop or tool house had been very well constructed of frame. Across one end were several pairs of windows opening inward on hinges. These windows were held shut in each case by a

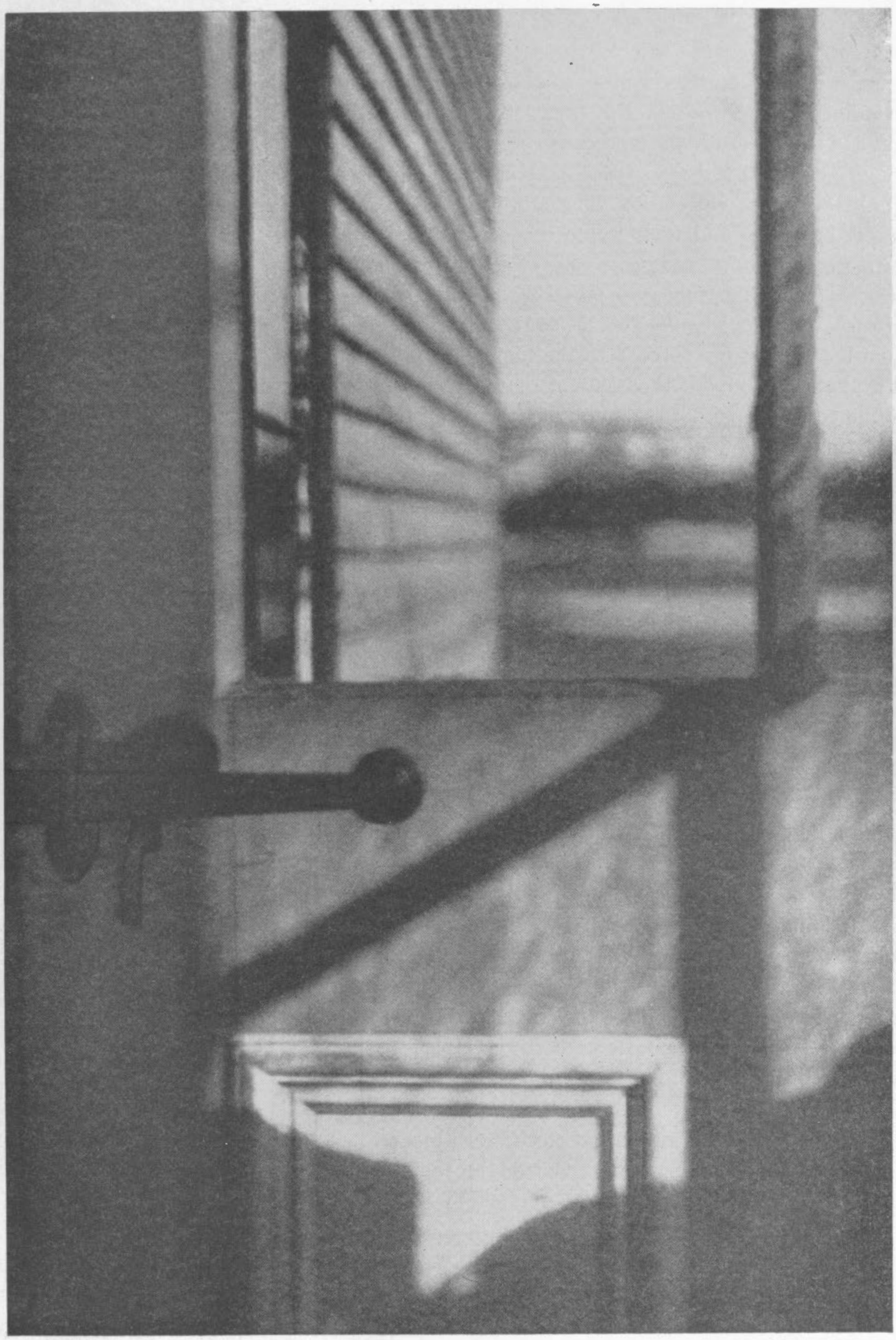

FIG. 18.—Door latch at Saint Pacôme station

wooden "button" set by a screw in the central bar of the window frame. The windows were all closed at the time of the earthquake. The following morning they were found open with the button still crosswise preventing their closing. These windows were examined. The workmanship was of the very best, the buttons were friction tight, the glass of the windows was not broken.

Undoubtedly these stories of doors and windows opening at the time of an earthquake are often authentic. The established fact serves to show the great flexibility of frame buildings and their value in an earthquake region. It may safely be said that *in the case of any earthquake which we may reasonably expect to experience, no well constructed frame building in any part of the province of Quebec, on any kind of ground which will not actually slide laterally with the house on it, is in danger of collapse.* The dangers to be guarded against are three. In the first place the chimney should be so constructed that it is altogether outside the house or that its fall inside will be within a specially constructed frame-covered space. Secondly, at the time of the earthquake the first thought should be to extinguish all fires. A third precaution is worth noting: Statues, pictures, crucifixes, ornaments, etc. should be so placed that they cannot fall on a bed. At least two cases were reported where children were cut by objects falling from above their beds.

(7) *Earthquake sounds*

The reports on earthquake sounds are interesting and significant. Where no sound precedes the shock and where the latter arrives as "a sharp jolt from beneath" it may safely be inferred that the epicentre is very close at hand. Where the sound is heard for some time before the jolt arrives it indicates that the epicentre is distant. It is doubtful whether the direction from which an earthquake wave is approaching can be determined from the sound. Preconceived ideas play a large part in a determination of direction. Sounds are heard often through open windows which mask the direction of approach. Reflection and refraction play a part. Rickety or frost bound structures to the south, say, may be rattling, before anything is heard from the north, though the tremors may be arriving from the north. The reports of earthquake sounds were found to be useless for the purpose of determining direction.

It is interesting to note the similes used by the reporters in their descriptions of the sound. Their past experiences are reflected therein. One will report the sound as simply "like thunder". Another states that it was "as if heavy Clydesdale horses were drawing a large rumbling waggon". One man hears it as "a roaring noise like a gasoline blow torch". A forest ranger thought it resembled "a great wind storm starting". Others considered it "like a fire in the chimney," "like a whirlwind," "like a train".

At Pointe au Pic and at Sainte Anne de la Pocatière the aftershocks were described as sounding "like the ripping of cloth," or "like a crack going across the ice in the bay". These are sounds not generally reported but were observed in these two villages on opposite sides of the Saint Lawrence by many, including the writer.

One interesting case was personally reported to the writer by a priest at Chicoutimi. He was in a room with his back to the wall toward the northwest. He thus faced a crucifix on the opposite wall toward the southeast. He heard the sounds but felt nothing until after he saw the crucifix move. This report was given before it was known that the epicentre really does lie south-southeast of Chicoutimi.

Trainmen, riding on an engine running to Malbaie at the time of the main shock, and also at 9:32 p.m. E.S.T., March 6, when one of the aftershocks was experienced, report that they heard the earthquake coming above the noise of the engine.

(8) *Effects on animals*

The effects on animals are believed to be closely associated with earthquake sounds. They seem to be able to hear something before anyone about them has noticed it. The following notes are recorded. At Maitland, N.S., rats ran up out of the cellar at the time of the earthquake. At Shelburne, N.S., hens were much excited. At Gaspé, Que., a watchdog was reported as frightened. Generally, throughout the epicentral region, the effect on the animals was lost in the effect on the people who had little opportunity to make any observations of that nature. This earthquake is rather remarkable in that the above are the only reports received of this nature.

(9) *Deaths reported as due to the earthquake*

The following deaths were reported as due to nervous shock caused by the earthquake:

Mrs. Alphonse Auger, of Quebec, fainted at the time of the earthquake and did not recover consciousness for some time. Her condition became worse and she died two days later. She was about to give birth to her first child.

Mrs. Eugène Bureau of Sainte Anne de la Pérade fell unconscious during the earthquake and died before medical help could be summoned.

Mrs. Albert Roy of Chicoutimi died of shock during the earthquake.

It was reported that one death occurred at Tadoussac but this is not established. It is possible that the victim was a resident of a nearby village.

According to a report in the Quebec Telegraph of March 3, 1925, Mrs. Oriel Smith (29) of Newark, Ohio, died as a result of nervous shock during the earthquake.

It was also reported that a man in Brooklyn was frightened by the tremors and fell off a station platform in front of a train and was killed!

The first three of these reports are well established but none indicates a death due to the mechanical effects of the earthquake. Every report reaching this office has been included above. It is most remarkable that with all the fallen chimneys and statues, not to mention the throwing down of walls near Rivière Ouelle and the falling bricks at Palais Station, Quebec, etc. no one was injured seriously as a direct result of the earthquake vibrations. It may also be mentioned again in passing that no fires resulted from overturned stoves and lamps.

(10) *Electrical phenomena*

Reports of electrical phenomena are always circulated in the case of a large earthquake. It is difficult to establish the truth of such reports. "Dead" telephone lines running into Baie Saint Paul through Saint Urbain were said to have emitted sparks and to have given operators electric shocks. At Chicoutimi several persons reported seeing lightning and hearing thunder during the earthquake. Woodsmen from the country near Port Alfred also reported thunder and lightning.

The report of a strange light to the west of Saint Denis has been referred to on page 14. The parish priest states that it was due to a partially obscured new moon which was setting at the time.

In a paper entitled "Destructive Earthquake in Sagami Bay," (Japanese Journal of Astronomy and Geophysics, Vol. 2, No. 4, 173-192, Tokyo, 1925) the author, Katsuyoshi Shiratori, comments on these electrical phenomena as applied to the earthquake he is considering—the Tokyo earthquake of September 1, 1923. He writes:

"It is said that, in the case of some earthquakes, telegraph operators often feel electric shocks, which is considered as a result of the change in the contact resistance of the electric earth-plate caused by the earthquake. Fortunately, we have for some time been observing the variation of earth-potential, by a zero method, using a potentiometer.

"Three electrodes (diameter 2 centimetres) of copper, galvanized with zinc, were arranged as shown (as at the three corners of a square one side of which is oriented parallel to the meridian, one electrode being at the southeast corner and the other two at adjacent corners; the centre electrode is labelled both E and S, the other two being, respectively, N and W). The depth of the electrode is 1 metre under ground and the distance between E and W, or E and N is ten metres; the direction of E to W is E-W and that E to N is N-S. If the magnetic flux varies in some way in the loops of the leading wires from the electrodes to the potentiometer, corresponding electromotive force must be induced; but, though we have examined this effect by making other loops parallel to those, it was too small to be observed by the potentiometer.

In fact, however, it is observed that the earth-potential shows abnormally large variation during earthquakes especially in the case of near earthquakes. Its variation during the great Sagami Bay earthquake is shown in an appended figure in which the courses of the potential difference in the three directions NS, NW, and EW are given. On October, 9, 1923, ($20^h 22^m 55^s$) a comparatively strong near earthquake at Tono, Iwate Prefecture (about 120 km. distant from Sendai), in which case the potential difference in NS and NW was affected while that in EW was not, as shown in the appended figure. There was another near earthquake with sudden shocks in the sea of Nakamura, Fukushima Prefecture (about 60 km. distant from Sendai), at $20^h 1^m 26^s$, October 31, 1923, in which case NS and EW were influenced, but NW component remained constant as shown in an appended figure." (The values of the potentials are given in following tables. The tables show the variations in potential in micro-volts for two- to four-hour intervals during the three earthquakes mentioned.) The paper continues:

"From these results it may be safely concluded that such potential variations depend on the direction of the epicentres of earthquakes. Sagami Bay is in the direction of SSW from Sendai, Tono is NNE, and the epicentre in the sea off Nakamura is ESE."

The tables show differences in potential of less than a fifth of a volt at the maximum. It is to be remembered, however, that the distances to the epicentre are as follows: for the Sagami Bay earthquake 380 kilometres; for the Tono earthquake 120 kilometres;

and for the Nakamura earthquake 60 kilometres. Baie Saint Paul is only about 25 miles from the epicentre. It is thus possible that potential differences *might* have been set up sufficient to cause the electric shocks, but the writer is very skeptical nevertheless.

A careful examination of the three cases presented by Shiratori fails to reveal any definite law as to the direction to the epicentre for a given potential effect. In the case at Baie Saint Paul, the line reported as sparking runs practically due north from that town, while the epicentre is almost exactly due east.

It is said that similar electrical phenomena were observed at Baie Saint Paul at the time of the earthquake of 1870. (It has not been possible to learn definitely that the lines were even in existence so long ago.) It may be noted, in passing, that the accounts of the earthquakes of 1663 speak of lightning and thunder and of strange lights in the sky.

It would be most interesting and valuable if further study would evolve some indication of the direction to the epicentre in potential variations. Such variations, if consistent, would permit a simple pre-arrangement for determining the position of the epicentre of a local earthquake by intersecting asimuth lines. Enquiry reveals the fact that at the time of the Grand Banks earthquake of November 18, 1929, the cables which did not break but which crossed the ocean bed to the north of the epicentre did not show a surge which was discernible in the instrument records. These normally show load conditions which vary through rather wide limits. Nothing registered which would be defined as beyond normal variations.

(11) *Reports proved erroneous*

(*a*) It was widely reported that a fine new stone church at Saint Hilarion, Que., was completely wrecked by the earthquake. This story was quite without foundation. It is possible that the damage at the church at Saint Urbain, which is not far distant, may have led to the report.

(*b*) The accounts of damage to the church at Baie Saint Paul were grossly exaggerated.

(*c*) The fire at Saint Félicien and that at Hébertville, reported as having been caused by the earthquake, were found to have been burning at least three hours before the tremors began. The situation at Saint Félicien may be put on record as a typical example of the terrifying events of that night for many localities. The houses are all of wood. The night was snappily cold. Under these circumstances the houses crack and creak in a startling fashion (as was experienced by the writer in approaching Saint Félicien on foot at night about ten days after the earthquake). About six o'clock in the evening of February 28, 1925, fire broke out in the village. This is a serious matter where structures are of wood and most of the water is frozen. There was real danger that the entire village might burn. After a strenuous three hours of fire fighting the house was a pile of glowing embers; the villagers were resting. Then the earthquake started. The houses, which had cracked at intervals before, simply volleyed in the tremors. The general impression seems to have been that the end of the world was at hand. It may safely be stated that the most sophisticated will find it difficult to gauge what their own reaction would have been to the unusual and terrifying circumstances.

(*d*) It was widely reported that, at the time of the earthquake, a long-distance conversation was under way between Chicoutimi and Malbaie and that the earthquake was felt at one place before it was felt at the other. This would have been important, if true. Thus every attempt was made to locate details regarding a long-distance connection operating at the instant of the quake, or a long-distance telegraph communication under way at that time. The manager of the telephone company at Malbaie consulted his records and proved that no such connection had been in operation. A similar service was rendered by the managers of the companies at Rivière du Loup and at Chicoutimi. No trace of a telegraph message being put through at that time could be found. Every case reported as to persons concerned was traced to its source and invariably found to be without foundation.

(*e*) The level of the Saint Lawrence did not change, up or down, at the time of the shock. Each of these results was currently reported. The tide gauge records conclusively prove these reports to be without the slightest foundation. A much more detailed story was in circulation regarding the level of lake Timiskaming. It was reported that the level of this lake "rose 4 inches at the time of the earthquake, then shortly afterwards sank 8 inches, and finally after some days regained its normal level". It was not considered worth while investigating this widely circulated report.

(*f*) The report of the shift of a house on its foundations at Pointe au Pic has been mentioned (page 371) as having been found untrue. The story of the strange fires at Saint Denis has been explained (page 377).

(*g*) It was commonly reported that a great landslide had been caused at Shawinigan Falls. The slide to which reference was made occurred during the previous autumn in the hills to the west of that city.

(*h*) The epicentre locations as made by various agencies for press purposes are interesting. As usual, the "Fundian Fault" was a convenient pigeon-hole for the hurried disposal of the epicentre position. But other "locations" were made as "near New York city—possibly in the direction of Washington," and "near the Great Lakes".

(*i*) The press reported a prediction that a second great earthquake would be experienced "in a month". The writer knows of actual cases where people within the epicentral district sat up the night of March 28, and then being afraid of a confusion of "months", since February was so short, did not breathe freely for another three days. It is a serious matter to publish such reports. The credulity of those in close contact with an earthquake is unduly sharpened and their worry is quite real.

(*j*)) As has been mentioned (page 368), the early determination of the epicentre of this earthquake by this Division was reported as "either in the bed of the Saint Lawrence near Rivière Ouelle, or north of the river about 30 miles, near the eastern boundary of the Laurentides Park." Later evidence justifies the abandoning of the second alternative, which was at first considered the more probable.

(12) *Extraordinary reports received*

The following reports may possibly have been true but it was impossible to verify or to disprove them. They are interesting possibilities and are listed only as such.

At Saint Denis, a hair net hung about a foot above a dressing table. Some hair pins lying below it were said to have been projected up to the net and to have been found caught therein after the earthquake.

The reports regarding the opening of the door at Saint Pacôme station and of the windows at the manoir near Malbaie have been outlined on page 394. These reports rightly find record here.

The story of the statue being projected upward through the ring of lights, as mentioned on page 379, is another case which might better, perhaps, have been listed in the subsection preceding.

A monument in the cemetery near Rivière Ouelle church was first thought to have been projected vertically upward off the iron pins which held it oriented on its foundation. A visit paid to this cemetery after the stone was again in place permitted a few experimental swayings of the stone by hand. It is possible that it climbed the pins sufficiently to fall off over them.

At Baie Saint Paul a bin of oats was reported as having been shaken in such a manner that "all the heavy ends pointed in one direction". Experiment with a few oats will show that this story is not as improbable as at first appears. It would be interesting to try the experiment with a large bin. Presumably only the surface oats would be oriented and only a percentage of those, but some indication of a general tendency might be expected. The direction of the heavy ends was reported to be northwest.

II. LOCATION OF EPICENTRE BY GROUND SURVEY

(1) *Trips undertaken in course of survey*

The following visits have been made into the disturbed areas:

(*a*) March 5 to March 21, 1925: To Malbaie, Pointe-au-Pic, Baie Saint Paul, Saint Urbain, Quebec, lake Saint John region, Chicoutimi, Ha! Ha! Bay, Lévis, Rivière Ouelle, Saint Pacôme, Sainte Anne de la Pocatière, Rivière du Loup, Trois Pistoles, and Shawinigan Falls.

(*b*) April 2 to April 17, 1925: To Sainte Anne de la Pocatière, Sainte Louise, Rivière du Loup, Notre Dame du Lac, Edmundston, Saint Pascal, Kamouraska, Saint Philippe de Néri, Saint Denis, Mount Carmel, Rivière Ouelle, and Saint Pacôme.

(*c*) July 21 to August 7, 1925: To Sainte Anne de la Pocatière and vicinity, including Rivière Ouelle and Saint Pacôme.

(*d*) May 27, to June 7, 1926: To Shawinigan Falls and to Saint Joachim, on north shore near Baie Saint Paul.

(*e*) June 21, to June 24, 1926: To Saint Joachim region.

(*f*) July 14 to July 24, 1926: A trip in company with Dr. J. W. Goldthwait, to Shawinigan Falls, thence along the north shore of the Saint Lawrence to Quebec and Saint Joachim, up the Sainte Anne river to Seven Falls, and around the island of Orleans, followed by a visit of several days duration to the south shore, most of the time being spent between Sainte Anne de la Pocatière and Kamouraska.

Besides the above visits to the epicentral region many trips have been made to Shawinigan Falls and to the region just west of Baie Saint Paul. These visits afforded opportunity to clear up points raised by a study of the data of this earthquake. Only the first two of the above trips were undertaken primarily for the purpose of investigating the earthquake of February 28, 1925.

(2) *Evidence of swinging suspensions*

It was first thought that an azimuth to the epicentre was defined by the plane of swing of a hanging suspension. The conflicting results obtained soon showed that some care must be exercised in selecting the evidence to be admitted. For example, some swinging objects were not observed until some minutes (in one case about fourteen hours) after the shock. The plane of swing could not be relied on for any length of time for several obvious reasons Again, some suspensions were much more free to swing in one plane than in another.

A few cases of carefully observed directions of swing may be recorded. At Trois Pistoles, the chandeliers in the hotel were observed to swing in a plane which was approximately eastwest.

At Chicoutimi a house set with its long axis from southeast to northwest had pictures on the short wall thrown off while those on the long wall were merely canted out of position, indicating a movement southeast to northwest.

Clocks in jewellers' shops were started in motion and in other cases stopped by the oscillations. The evidence was useless for defining direction. Sometimes the clock seemed to have been stopped by having the pendulum bumped against the back of the case; at other times it seemed to have been stopped by being swung out of phase with its pendulum.

An interesting case of swinging was reported by a most careful and accurate observer at Rivière du Loup. Entering the Church of Saint Patrick for mass at 11·30 Sunday morning, it was noted that the great chandeliers were swinging with an amplitude of at least 3 inches. One defined a plane which did *not* point toward the epicentre. The other was swinging in a circle. Either of these results was, of course, to be expected in the event of the swings continuing for such a long time. The chandeliers are very heavy and long.

(3) *Evidence of shifted masses*

In the vicinity of the epicentre the first motion of an earthquake may be expected to be up, or down, or nearly so. As the distance is increased one may expect to have the azimuth from observation point to epicentre defined by the line of shift of displaced objects. Care must be taken to eliminate all cases where the tendency to slippage is greater in one azimuth than another. Even with this precaution taken, it may be said that azimuths were very indefinitely indicated by the shift of objects at a distance of 15 miles or more from the epicentre.

At Saint Pacôme, objects generally shifted south or north, the first motion being south, indicating a movement toward the north. (At Saint Pacôme station, however, the stoves shifted east.)

At Sainte Louise, a heavy stove in the station moved south; statues in the church fell toward the southwest.

FIG. 19.—Rotated Monument at Rivière Ouelle Cemetery

At Pointe au Pic, bottles in the front of an east-west shelf fell north. Those at the back were struck by the wall at the back of the shelf and fell south. On the other hand, the heavy cash register, apparently free to move in one direction as readily as in another, moved west. In general, objects in one store at Pointe au Pic indicated earth movements to the south and east. A shelf in a buffet which rested on two ledges but which did not quite fill the space shifted to the north and dropped down, indicating a movement to the south.

A summary of the observations on lines of shift may be given as follows, with the reservation that exceptions were often found, most of which could be explained as due to natural slopes, etc. The movement was to the southeast at Chicoutimi, to east or west at Trois Pistoles, to the west at Tadoussac, to the northwest at Rivière Ouelle, to the north or northeast at Sainte Louise.

The observations indicate that it would be very much worth while to have some form of seismoscope set up under definite conditions at many points in an epicentral region which would, by the fall of a column or the direction of roll of a ball, etc., indicate the direction of the first sharp movement. Such seismoscopes could be placed in solid positions in the basements of churches and schools or other places where they could be carefully levelled and where they would not be liable to be disturbed. (See also page 408 for further specifications.) They might be expected to furnish valuable information as to the position of an epicentre.

(4) *Evidence of rotations*

Monuments in cemeteries, objects standing on tables, chimneys, and other heavy masses were, in many cases, rotated by the earthquake, some in a clockwise and others in a contraclockwise direction (*see* figs. 19, 20, 21). Investigation soon provided so many examples of rotation in a common direction in certain areas that it could not be overlooked in spite of the plausible explanation that irregularities of contact on the plane of shift, or tilting of that plane might be the cause of the rotations. Although it was not believed that the data obtained would be of much value in locating the epicentre, some care was taken to record all observations of rotation. It is desirable that this report should be as complete as possible, but it seems needless to repeat at this point the observations for rotation. These were sketched in some considerable detail in the paper on "Rotation Effects of the Saint Lawrence Earthquake", as indicated in No. 4, on page 367 of this report. Especially does it seem useless to repeat the account of this phase of the earthquake phenomena since it has no particular hearing on the final conclusions as to the position and nature of the epicentre. Accordingly, we may rest content with a tabulation of the summary outlined on the last page of the above report, which runs as follows:

(*a*) The rotations do not give any indication of location other than the general one that they occur only relatively close to the epicentre.

(*b*) They are greatly affected by depth of soil; the deeper the soil the greater the rotation for any given distance from the epicentre.

(*c*) Generally speaking, the rotations north of the Saint Lawrence river are clockwise; those south of that river are contra-clockwise.

Fig. 20.—Rotated monument at Rivière Ouelle Cemetery

FIG. 21.—Monument shown in Fig. 20 shown here restored
Photo by J. W. Goldthwait

(*d*) The number of observations on the north shore was limited, due to the fact that rotation effects were not thought of as a special line of study until after leaving the north shore for the south on the first trip of inspection. Also the places at which observations could be made were fewer on the north shore. There are, however, practically no observed exceptions to the clockwise rule on that shore.

(*e*) There are a considerable number of exceptions to the contra-clockwise rule on the south shore, especially at Sainte Anne de la Pocatière.

(*f*) Rotations are evidently affected by the slope of the graveyard and by tree roots near individual monuments.

(*g*) No reasonable theory connecting all the observed phenomena has been deduced.

(5) *Evidence of fallen objects*

The evidence of fallen objects is somewhat better than that given by the shift of heavy bodies or by their rotations. In some cases at least it is impossible to avoid the conclusion that the bodies lie in positions where they were thrown by the first sharp impact. The stoves at the station at Saint Pacôme all moved east (page 373), one of them breaking off and rolling to the east. Moreover they left the trace of their movements in marks on the floor. The new and well-placed monuments at the latest cemetery at Rivière Ouelle church all fell to the southeast (*see* fig. 5). One may not doubt that these monuments show the direction of the first sharp jar, especially when we learn that the shock arrived without warning at that place and that the first "bump" was devastating. The difficulty about accepting in general the direction of fall as evidence of the first

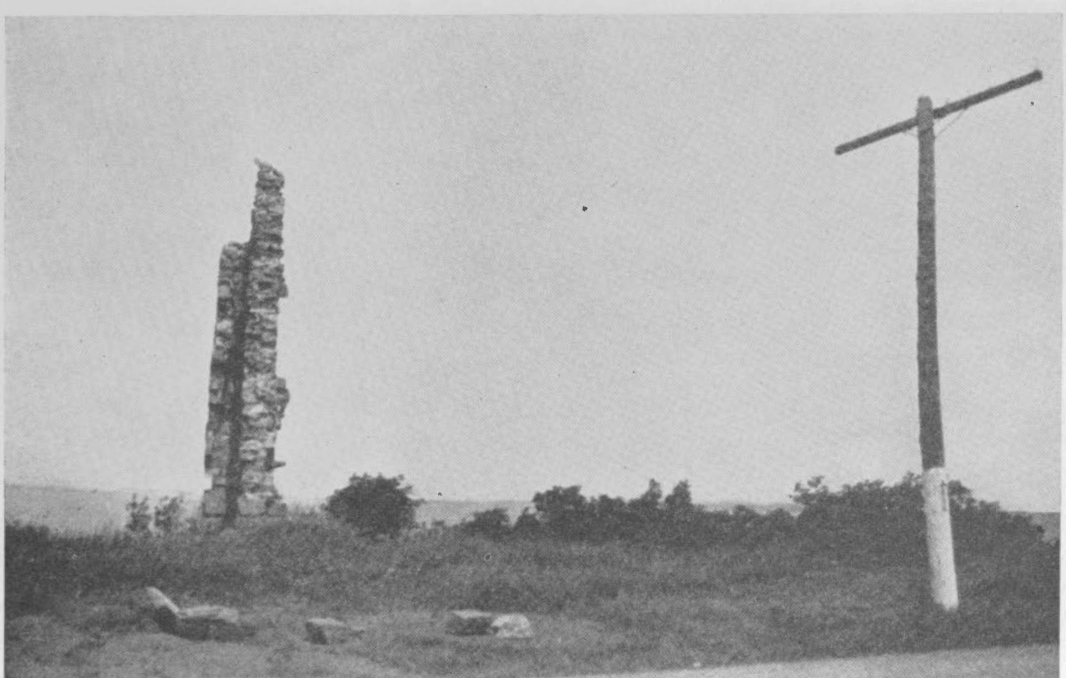

FIG. 22.—Isolated chimney near Montmagny
Photo by J. W. Goldthwait

movement is, of course, that the object may be rocked by a succession of tremors. Thus the final thrust which determines the lie of the fall may be a comparatively slight one, arriving at the moment when the object is almost out of balance and so combining with the sway that overturning results.

In arranging seismoscopes for use in epicentral regions as suggested on page 404, it would be best to provide that the object would be displaced only by the first tremor of a given minimum intensity; that it could not oscillate before that intensity was reached; that, once disturbed, it would fall in the direction opposite to that of the first disturbing thrust; and that no further shocks could affect the fallen indicator.

(6) *Negative evidence*

By negative evidence is meant those data which show that the vibrations of an earthquake could not have been very great without disturbing a condition found unaltered after the shock. One of the best types of negative evidence is that furnished by the rather numerous isolated chimneys left standing after the houses connected with them had burned. These have been noted near Beaupré on the north shore between Baie Saint Paul and Quebec, at many points on the island of Orleans, at Montmagny on the south shore (*see* fig. 22), and near Kamouraska. Many of these chimneys appear to be so insecure that it is remarkable that heavy winds have not thrown them over. That they withstood the earthquake tremors is conclusive proof that, at the points they occupy, the tremors were considerably less than at such places as Malbaie and Rivière Ouelle.

Near Chambord Junction on lake Saint John there was an old barn frame badly disintegrated and with all wall boards removed (*see* fig. 23). One upright leaned forward.

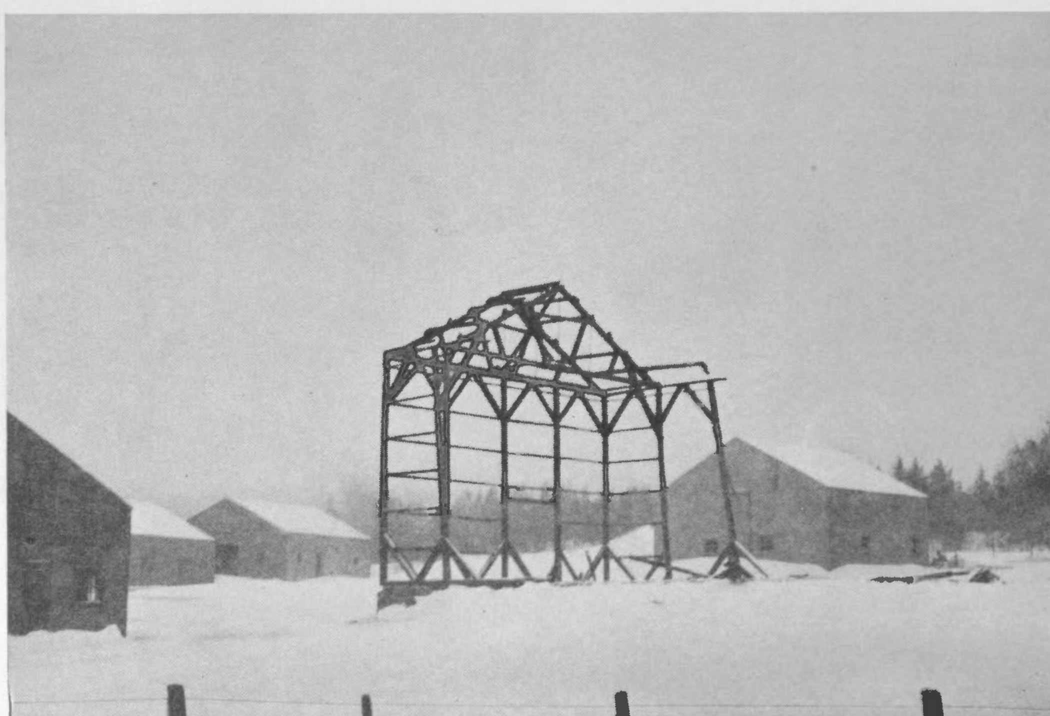

FIG. 23.—Old barn frame near Chicoutimi

It had a heavy beam tied to it on top and was free to fall except for the nails and braces at the base. The fact that it did not fall indicates that the fault must be nearer the Saint Lawrence river than to Chambord. This frees the fault running along the west side of the Saguenay up past lake Saint John from the suspicion of participation in the adjustment. The freedom from damage continues as far as Saint Félicien.

There was practically no damage in Chicoutimi. A street of houses built on sandy soil on the bank of the Saguenay was uninjured; not a chimney was damaged and no goods fell in the stores.

At the mill of the Port Alfred Pulp and Paper Co. on Ha! Ha! Bay a heavy "condenser" made of iron pipes filled with water was supported on reinforced concrete pillars. The entire equipment was thus in the form of an inverted pendulum. Some cracks were found in the tops of the pillars but examination showed them to be old cracks. They had not been further affected by the earthquake. It is not conceivable that the epicentre lay close to this place in the light of this and other negative evidence.

The above observations for Chambord Junction, Chicoutimi and Ha! Ha! Bay are grouped as negative evidence which precludes the location given by Prof. H. H. Turner in his publication "The International Seismological Summary for 1925, January, February, March" (Oxford, 1928), on page 56, as $\phi = 48° .2N$. $\lambda = 70° .8W$. This is within fifteen miles of Ha! Ha! bay and the condenser of the Port Alfred Pulp and Paper Co. and is within less than 25 miles of Chicoutimi. On page 57 of the same publication, the position of the epicentre is given as "in the mouth of the Saguenay river". The latitude and longitude given in figures by Prof. Turner place the epicentre nearer the source than the mouth of the river.

Great icicles were common in Quebec city at the time of the earthquake (*see* fig. 10). They were not displaced by it, when the houses on which they hung were on the rocky foundation in upper town. The ice statues and arches (*see* fig. 11) placed at various parts of the city were not disturbed by the earthquake, though in many cases they were top-heavy or rested on their bases at points of contact which might have been expected to shear off with any very sharp shock.

When investigating the epicentral region after the earthquake, the writer was told nearly every morning of after-shocks experienced during the night by other members of the household where he happened to be staying. He felt only one or two of these shocks himself. Most of them, even some which registered on seismographs or which were reported from other places by telegraph thus confirming the observer noting them, were quite unnoticed by him. Accordingly, after the first experience of this kind, it was his invariable custom, on retiring, to balance his fountain pen, vertically on its small end, on a smooth level surface. This made a top-heavy column which was somewhat difficult to place. Nevertheless, it was not overset by any of the reported after-shocks, experienced from March 7 to March 20, inclusive. This negative evidence, some of it obtained in locations where the soil is deep and where the vibrations might have been expected to exercise their greatest influence, indicates the feeble nature of most of the after-shocks. Those of March 6 and March 21 would undoubtedly have overset the pen.

III. LOCATION OF EPICENTRE BY QUESTIONNAIRES AND NEWS ITEMS

(1) *Sources and extent of information in Canada and in the United States*

At the time of the earthquake, questionnaires were distributed by the United States Coast and Geodetic Survey and requests for information were broadcast through the newspapers. Replies received were evaluated for intensity on the Rossi-Forel Scale (*See* Appendix A—page 427) and incorporated in an isoseismal map. Items were received from points as far south as Virginia and as far west as Minnesota. These items took the form of returned questionnaires, press clippings, and letters. The distribution of the returned items with respect to states is set forth in the following table:

SOURCES AND NATURE OF DATA COLLECTED IN THE UNITED STATES

States	Questionnaires	Clippings	Letters
Colorado	....	1	....
Connecticut	6	2	1
District of Columbia	....	5	1
Illinois	5	3	4
Indiana	13	8	....
Iowa	7	1	....
Kansas	1	....	....
Kentucky	2	....	....
Maine	7	1	1
Maryland	2	1	1
Massachusetts	20	1	2
Michigan	36	14	6
Minnesota	1	....	....
Missouri	....	....	1
New Hampshire	2	3	1
New Jersey	29	2	1
New York	16	57	16
North Carolina	1	....	....
Ohio	11	4	2
Pennsylvania	6	2	9
Rhode Island	5	1	....
Vermont	4	2	....
Virginia	4	....	....
West Virginia	2	....	....
Wisconsin	14	5	1
Totals	194	113	47

Questionnaires to the number of 222 were sent to well-distributed points in Canada to be filled in by postmasters and others. Special requests numbering 226 were addressed to the editors of newspapers in eastern Canada asking for clippings. Telegrams and special questionnaires were sent to persons from whom particular information was desired.

The data received were from places distributed as follows:

SOURCES AND NATURE OF DATA COLLECTED IN CANADA

Provinces	Questionnaires	News Clippings	Total
New Brunswick	8	7	15
Nova Scotia	11	7	18
Cape Breton	1	....	1
Prince Edward Island	2	1	3
Quebec	70	175	245
Ontario	56	140	196
Totals	148	330	478

In the case of the news clippings in the table immediately above, only the net number of those which gave values of intensity at different places is indicated. There were at least twice as many clippings which had to be checked over but which yielded only the 330 net values which could be used in preparing the isoseismal map.

(2) *Comments on the value of such data*

The work on this earthquake has convinced the writer that much of the material collected by questionnaires is of very little value as used for the preparation of isoseismal maps. The same is true of newspaper clippings. *Their real value lies in their being collected very promptly after an earthquake and forwarded at once to the investigator in the field.* To him, they are of considerable value as suggesting points of contact and lines of investigation.

In the first place, the data given are of little value for the determination of "intensity" because they are sent in by persons who are not known to those working on the earthquake. Many are sent in by quite incompetent observers. It is difficult, or impossible, to distinguish between good observers and poor ones, simply from a returned questionnaire.

In the second place, the evaluation of intensity by the Rossi-Forel scale, or any other scale that can be devised for application in a similar manner, is so poor as to be almost worse than valueless—it tends to be misleading. The application of all such scales depends on translating the sensations of the observer and the account of damage into the proper number of a "scale of intensity". The estimates of intensity based on the sensations experienced by observers are in most cases notoriously weak. Again, the damage caused by an earthquake is influenced by many factors: distance from the epicentre (perhaps also, the direction from the epicentre); nature of the terrain; the type of construction or the quality of its material and workmanship. Furthermore, it is not known whether it is the acceleration, the amplitude, the period, or some combination of these, which causes the destruction of buildings. Altogether, it seems hopeless to deduce anything very much worth while from questionnaires and press clippings *except as they are used as the basis of further investigation in the field.*

A great deal of time has been spent on the replies to questionnaires and on newspaper clippings, as will appear in the next subsection. In common with many other workers in seismology, the writer is hopeful that an efficient, economically-feasible scheme may soon evolve from present-day efforts to determine quantitatively the earthquake intensity over areas known to be liable to such disturbances.

(3) *Methods of preparation for analysis*

The questionnaires were sorted into groups, by provinces, within which they were arranged in alphabetical order by names of places. The information given by each questionnaire was typed on an analysis form, the French replies being translated into English. The forms so completed and arranged were given serial numbers for purposes of ready identification and reference. The various entries were then examined for evaluation on the basis of the Rossi-Forel scale, the number assigned being written in below the serial number of the analysis form.

A map was then prepared to include the northern section of the United States from Minnesota to the Atlantic and the provinces of Canada east of Manitoba. Over this map were laid two sheets of tracing linen, held at one common edge by drawing pins, so that registration might be conveniently and accurately maintained. The serial numbers of the analysis sheets were then plotted in the positions determined by the places respectively represented, all the serial numbers being plotted on the first sheet of tracing linen. As each serial number was plotted, the second tracing sheet was brought down over and the number indicating the evaluation on the Rossi-Forel scale was inserted on the second sheet immediately over the corresponding serial number beneath. It was thus possible at any time to determine the source of any scaled value at any point on the map.

The press-clippings, properly prepared for mounting, were sorted into alphabetical order on the basis of the place of publication. They were then mounted in a large scrap book. The items, one after another, were examined and those which gave information permitting the determination of intensity at any point (whether the place of publication or elsewhere) were given serial numbers continuous with and following those assigned to the questionnaires as transcribed on analysis forms. Some care was taken to avoid repetition of valuation numbers for any place. Where several reports applied to one place, the one requiring the highest scale number was the one selected for the purposes of the isoseismal map. The serial numbers were then plotted on the same tracing sheet with those of the analysis forms, the intensity numbers being plotted as before.

The second tracing sheet, with the scale values for both questionnaires and clippings plotted on it, was then laid over the map in proper registration and the isoseismals sketched in so that the locus of well-defined positions for any scale value at the points farthest from the epicentre were connected by a common isoseismal line. Where necessary, as at Quebec and at the Saint Maurice river, isoseismals were inserted which do not circle the epicentre. It was found that the isoseismals, as drawn for United States territory by the United States Coast and Geodetic Survey, fitted well with those indicated by our own data for Canada.

IV. LOCATION OF EPICENTRE BY MEANS OF SEISMOGRAMS

(1) *Sources of data*

The following table shows the seismograms which have been received and studied in connection with this earthquake:

Station	Instruments	Registration	Original or Copy	Components
Berkeley	Wiechert	Smoked Sheet	Original	NS
Berkeley	Wiechert	Smoked Sheet	Original	EW
Berkeley	Wiechert	Smoked Sheet	Original	Vertical
Bidston	Milne-Shaw	Photographic	Copy	NS
Cheltenham	Bosch-Omori	Smoked Sheet	Copy	NS
Cheltenham	Bosch-Omori	Smoked Sheet	Copy	EW
Chicago	Milne-Shaw	Photographic	Photostat	NS
Chicago	Milne-Shaw	Photographic	Copy	EW
Cleveland	Wiechert	Smoked Sheet	Original	NS + EW
Cleveland	Wiechert	Smoked Sheet	Original	Vertical
Fordham	Milne-Shaw	Photographic	Copy	NS
Fordham	Milne-Shaw	Photographic	Copy	EW
Georgetown	Wiechert	Smoked Sheet	Copy	NS + EW
Halifax	Mainka	Smoked Sheet	Copy	EW
Harvard	Bosch-Omori	Smoked Sheet	Copy	NS
Harvard	Bosch-Omori	Smoked Sheet	Copy	EW
Honolulu	Milne-Shaw	Photographic	Photostat	EW
Ottawa	Milne-Shaw	Photographic	Original	NS
Ottawa	Milne-Shaw	Photographic	Original	EW
Ottawa	Bosch	Photographic	Original	NS + EW
Ottawa	Wiechert	Smoked Sheet	Original	Vertical
Saskatoon	Mainka	Smoked Sheet	Original	NS
Saskatoon	Mainka	Smoked Sheet	Original	EW
Sitka	Bosch-Omori	Smoked Sheet	Copy	NS
Sitka	Bosch-Omori	Smoked Sheet	Copy	EW
Stonyhurst	Milne-Shaw	Photographic	Copy	EW
Toronto	Milne-Shaw	Photographic	Copy	NS
Toronto	Milne-Shaw	Photographic	Original	EW
Tucson	Bosch-Omori	Smoked Sheet	Copy	EW
Uccle	Galitzin	Photographic	Copy	NS
Uccle	Galitzin	Photographic	Copy	EW
Victoria	Milne-Shaw	Photographic	Copy	NS
Victoria	Milne-Shaw	Photographic	Copy	EW

The above tabulation shows component records from a total of 18 stations. Besides these records and copies of records, bulletins of readings for this earthquake were received from the following stations:

Agram, Alicante, Algiers, Almeria, Baku, Barcelona, Belgrade, Cartuja, Coimbra, Denver, Ekaterinburg, Eskdalemuir, Firenze, Hamburg, Helwan, Innsbruck, Ithaca, Königsberg, Kucino, La Paz, La Plata, Lemberg, Lick, Malaga, Manila, Melbourne, New Orleans, Osaka, Paris, Perth, Piatigorsk, Pulkovo, Rio de Janeiro, Saint Louis, San Fernando, Spring Hill, Strasbourg, Toledo, Wien, Zi-ka-wei, and Zürich.

Some of the above records were incomplete for various reasons and so yielded no determination for distance to the epicentre. Of the 59 stations from which some data were received, 39 are in satisfactory agreement with the epicentre adopted, the distance circles for 20 of them passing through that position and the others within 25 miles or less. Copies of the Milne-Shaw horizontal records for Ottawa and that of the Wiechert vertical for the same station are shown in fig. 24.

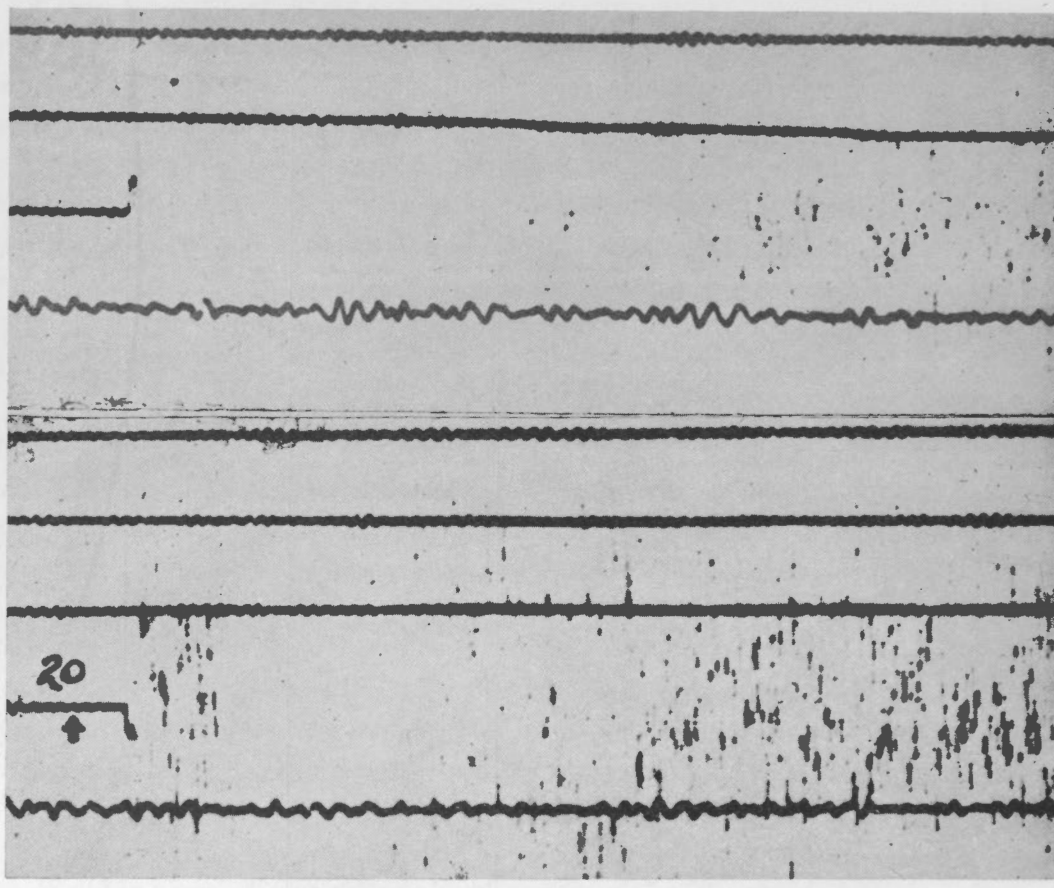

Fig. 24.—Initial sections of the Ottawa seismograms of the Saint Lawrence Earthquake of 1925

1. Milne-Shaw, north-south component.
2. Milne-Shaw, east-west component.

(Note the almost equal initial displacements on both components, indicating an epicentre in an azimuth due north-east or south-west. The first displacement on the vertical, which is too faint for reproduction, gave the information as to the required distinction, placing the epicentre as north-east from Ottawa. The east-west record was sufficiently legible to give distance, placing the epicentre as on or near the Saint Lawrence and about forty miles, more or less, below Quebec city—information given to the press the night of the earthquake.)

(2) *Presentation of summarized data*

In the following table are presented the values for epicentral distances (Δ), and time at origin in Greenwich Mean Time (0), together with the times of arrival of the direct longitudinal waves (P) and the direct transverse waves (S), for each of the 30 stations used in the determination of the epicentre. The determination of 0 and Δ from P and S is, in each case, based on the Klotz tables (Publications of the Dominion Observatory, Vol. 3, No. 2, Ottawa, 1916). The stereographic projection method indicated in that publication, which permits the projection of the distance circles, still as circles, on the plane of the equator, has been used to find the point of intersection of the distance circles. The work of reading the various records and the draughting of the stereographic projection chart by means of which the location was effected have been done by Mr. W. W. Doxsee, of this Division, whose co-operation in this and also in other parts of the work has been of material assistance.

DATA USED IN THE LOCATION OF THE EPICENTRE

Stations	P	S	O	Δ
	h m s	h m s	h m s	km
Agram	2-29-00	2-36-46	2-19-19	6180
Alicante	2-28-08	2-35-28	2-18-55	5700
Almeria	2-28-07	2-35-14	2-19-10	5450
Berkeley	2-26-42	2-32-43	2-19-06	4250
Cartuja	2-28-06	2-35-12	2-19-10	5440
Cleveland	2-21-45	2-23-35	2-19-31	1020
Coimbra	2-27-24	2-33-56	2-19-08	4820
Ekaterinburg	2-30-18	2-39-18	2-19-18	7610
Fordham	2-21-02	2-22-20	2-19-27	710
Georgetown	2-21-46	2-23-38	2-19-29	1040
Halifax	2-20-48	2-21-53	2-19-28	590
Helwan	2-31-02	2-40-43	2-19-19	8420
Königsberg	2-28-39	2-36-14	2-19-09	5990
La Paz	2-29-49	2-38-18	2-19-21	7000
La Plata	2-31·8	2-42·0	2-19·6	9020
Malaga	2-27-59	2-35-03	2-19-05	5400
Ottawa	2-20-26	2-21-19	2-19-20	480
Piatigorsk	2-30-46	2-40-06	2-19-25	8000
Pulkovo	2-28-48	2-36-30	2-19-11	6110
Rio de Janeiro	2-30-56	2-40-30	2-19-20	8280
Saint Louis	2-23-15	2-26-15	2-19-32	1750
Saskatoon	2-24-31	2-28-45	2-19-12	2610
Spring Hill	2-24-22	2-28-20	2-19-24	2410
Stonyhurst	2-27-06	2-33-26	2-19-05	4600
Strasbourg	2-28-11	2-35-20	2-19-11	5500
Toledo	2-27-47	2-34-33	2-19-14	5070
Toronto	2-21-07	2-22-30	2-19-25	760
Victoria	2-26-08	2-31-48	2-19-00	3870
Wien	2-28-45	2-36-24	2-19-11	6050

V. CONCLUSIONS WITH REGARD TO THE EPICENTRE

The position of the epicentre which agrees best with the above instrumental data, and which is also in accord with the work in the field, is determined as being

$$\phi = 47^\circ.6\text{N}.$$
$$\lambda = 70^\circ.1\text{W}.$$

These co-ordinates define a point in the Saint Lawrence river between the mouth of Malbaie river on the north and that of Rivière Ouelle on the south. It is to be understood that the epicentre is not to be considered a point, but rather a zone, the major axis of which lies NNW–SSE and which has a mid-point as indicated. It is quite possible that the line of adjustment projected somewhat into the north shore, though there are no observational data which definitely establish such a projection. It is probable that the line of adjustment entered the south shore as far as the rising land to the south of Sainte Anne de la Pocatière and Saint Pacôme, passing between these two villages. There is some evidence to support this projection.

It is believed that the territory immediately to the north and east of the fault snapped upward and, possibly, that it also had a horizontal component of motion, moving somewhat to the southwest. The territory to the south and west moved horizontally north and east. These conclusions are supported by the instrumental records and also by the investigations in the field. If the territory to the west and south of the hypothetical fault had a vertical component of motion at the time of the earthquake, it was downward.

VI. ADDITIONAL CONFIRMATORY DATA

(1) *Supporting Evidence of the After-shocks*

The after-shocks of the earthquake were carefully studied. A close observer, living near the epicentral region, tabulated 11 strong shocks during the day following the earthquake. During the waking hours of the first week he recorded a total of 37 well-marked shocks. During the night of February 28–March 1 (*Eastern Standard Time will be used in every case throughout this section dealing with reports of after-shocks*) the shocks were "almost continuous"; certainly very frequent (four besides the main shock being recorded at Ottawa).

As an indication of the frequency of the earthquakes during the night of February 28–March 1, it may be repeated that the occupants of the jail at Malbaie, as well as others in that village, assert that the tremors continued at intervals of a few minutes all night. The questionnaires returned from Saint Hilarion state that 25 tremors were recorded that night. At Saint Jean Port Joli, 8 shocks were reported.

Special mention may be made of the after-shock of 9:30 p.m., Friday, March 6. The shock, observed by the writer at Pointe au Pic, was quite marked, lasting for from five to ten seconds and causing one to wonder if the house would really stand the strain.

A much more severe shock occurred on March 21, at about 10:20 a.m. It was felt over a wide area and caused alarm as far away as Quebec city.

A special study was made of several relatively weak shocks. The first of these was one experienced on April 10 at 4:30 a.m. when the writer was at Saint Pascal. Telegrams were at once sent to Malbaie and to Chicoutimi, asking whether a shock had been felt but not giving the hour. Replies were received which checked with the report of observers at Saint Pascal (the writer did not notice the tremors himself), and showed that the earthquake was felt at Malbaie and at Chicoutimi but that it was not felt at Saint Bruno, only about 6 miles south of Saint Pascal.

The second earthquake occurred on April 25 at 11:50 p.m. It was also investigated by telegram and questionnaires, to the effect that it was felt at Chicoutimi and at Sainte Anne de la Pocatière but was not felt at any of the stations on the Canadian National transcontinental railway line, which parallels the shore of the Saint Lawrence river, about 20 miles south of the line through Saint Pascal. The stations from Monk to Rivière Bleue all reported the tremor as not felt.

Similar telegraphic investigation was carried out for a quake felt at Saint Pascal and Kamouraska at 6:30 a.m., April 11, but not felt at Saint Bruno.

The general testimony of all the telegraphic investigations was that the after-shocks originated in the general vicinity of Malbaie, Kamouraska, Saint Pascal, and Rivière Ouelle. Some of the stronger ones were felt at Sainte Anne de la Pocatière. Moderately strong shocks were noted as far north as Chicoutimi though quite unnoticed at Saint Bruno and points on the Canadian National transcontinental line. If the tremors were very weak the observations at Kamouraska, Saint Pascal, and Malbaie checked, but other places reported the tremors as not felt. The evidence of the after-shocks thus checks the deductions of section V.

The complete list of after-shocks, in order of occurrence, is tabulated as follows:

AFTER-SHOCKS NOTED UP TO JULY 31, 1925

Date		Time	Remarks
Feb.	28	11–30–42 p.m.	Felt generally, Malbaie, Tadoussac, Chicoutimi, Baie Saint Paul, Quebec, Lèvis to Trois Pistoles on South Shore. Recorded at Ottawa.
Mar.	1	1–25–21 a.m.	Felt generally over same area as above. Recorded at Ottawa.
"	1	2–25–10 a.m.	A strong shock; felt generally as above. Recorded at Ottawa.
"	1	8–21·5 a.m.	Felt generally over epicentral area; and recorded at Ottawa.
"	1	9–10 a.m.	Recorded by observer at Pointe au Pic. An asterisk indicates the other shocks reported by the same observer. (Daytime observing only)
"	1	9–20 a.m.	*
"	1	9–30 a.m.	*
"	1	10–39 a.m.	*
"	1	11–27 a.m.	*
"	1	12–24 p.m.	*
"	1	1–35 p.m.	*
"	1	2–55 p.m.	*
"	1	3–26 p.m.	*
"	1	4–15 p.m.	*
"	1	7–15 p.m.	*
"	2	6–35 a.m.	*
"	2	9–42 a.m.	*
"	2	9–43 a.m.	*
"	2	10–49 a.m.	*
"	2	3–25 p.m.	*
"	2	3–25 p.m.	*
"	2	5–26 p.m.	*
"	2	6–14 p.m.	*
"	2	6–45 p.m.	*

AFTER-SHOCKS NOTED UP TO JULY 31, 1925—*Concluded*

Date		Time		Remarks
Mar.	3	6-05	a.m.	Reported by observer at Pointe au Pic. An asterisk indicates the other shocks reported by the same observer. (Daytime observing only)
"	3	8-23	a.m.	*
"	3	11-15	a.m.	*
"	3	2-34	p.m.	*
"	3	6-33	p.m.	*
"	3	10-25	p.m.	*
"	4	2-30	p.m.	*
"	5	12-20	p.m.	*
"	5	3-32	p.m.	*
"	5	5-45	p.m.	*
"	5	6-43	p.m.	*
"	6	7-34	a.m.	*
"	6	10-30	a.m.	*
"	6	2-10	p.m.	*
"	6	9-30	p.m.	* This earthquake was also felt by the writer while at Point au Pic as has been mentioned on page 416. Reports show that it was felt at Trois Pistoles, Rivière du Loup, Saint Pacôme, Rivière Ouelle, Tadoussac, Chicoutimi, and Malbaie. It was recorded at Ottawa.
"	6	11-30	p.m.	*
"	7	7-00	p.m.	* Also felt by the writer while at Pointe au Pic.
"	8	9-02	a.m.	* Also felt by the writer while at Pointe au Pic.
"	8	10-42	a.m.	*
"	8	5-45	p.m.	* Also felt by the writer while at Pointe au Pic.
"	11	?	?	Reported from Malbaie as two shocks.
"	14	10-18	a.m.	Reported from Chicoutimi and from a point in the woods about midway between Chicoutimi and Malbaie. Registered at Ottawa.
"	17	9-45-20	a.m.	Registered at Ottawa. Presumably felt in epicentral region.
"	18	8-15-22	a.m.	Registered at Ottawa. Presumably felt in epicentral region.
"	21	10-22-24	a.m.	Reported as felt at Misère, Saint Adalbert, Saint Donat, Rivière du Loup, Malbaie, Ha! Ha! Bay. Registered at Ottawa. A very sharp earthquake which was felt as far west as Quebec city.
Apr.	10	4-30	a.m.	Felt at Saint Pascal, Malbaie, and Chicoutimi. Not felt at Saint Bruno.
"	11	6-30	a.m.	Felt at Saint Pascal, Malbaie, and Chicoutimi. Not felt at Saint Bruno.
"	25	11-50	p.m.	Felt at Paint Pascal, Kamouraska, Sainte Anne de la Pocatière, and Chicoutimi. Not felt on Canadian National railway from Monk to Rivière Bleue.
July	26	9-20	p.m.	Felt at Sainte Anne de la Pocatière but not investigated further.
"	27	4-00	a.m.	Felt at Sainte Anne de la Pocatière but not investigated further.

The writer wishes to acknowledge the assistance of a number of careful observers in connection with the investigation of the after-shocks. In particular, the following were able to render valuable coöperation in this work:

M. J. Beaulieu, Telegraph operator at Monk, Que.

M. Antoine Dubuc, Manager of the telephone company at Chicoutimi.

M. J. B. Dupuis, Manager of the telephone company at Rivière du Loup.

M. E. Guillemette, Telegraph operator at Pointe au Pic.

M. Joseph Lavoie, Telegraph operator at Saint Pascal.

M. F. Vincent, Telegraph operator at Malbaie.

To sum up, a study of the after-shocks indicates that they were always felt in the region near the assigned epicentre. If rather weak, they were felt on the south shore of the

Saint Lawrence, only within a belt 5 to 6 miles wide adjacent to the river. Such weak shocks were felt on the north shore, however, sometimes as far as Chicoutimi, a fact which lends weight to the statement that the epicentre may be an elongated one, lying along a fault extending into the north shore of the Saint Lawrence.

(2) *Supporting Evidence of Level Lines Re-run*

Immediately after the earthquake, steps were taken to find any controls which might yield quantitative measurements as to permanent displacements. The only level line run in the area was that from Lévis to Rivière du Loup. This had been completed in 1915. A request to the Director of the Geodetic Survey resulted in arrangements being made by which that organization re-ran the line of levels between these two towns. The result of that work may be said to have revealed no differences greater than the order of the errors of observation. However, the differences east of Saint Pacôme and Rivière Ouelle, were all in the same sense, the 1925 elevations being above those of 1915: all the differences west of that point were in the opposite sense, the 1925 elevations being below those for 1915, when the Lévis end of the line is considered fixed in elevation.

The observations, together with the descriptions of bench-marks, have been furnished by the Director of the Geodetic Survey.

TABLE SHOWING COMPARATIVE ELEVATIONS OF PRECISE LEVEL BENCH MARKS ALONG CANADIAN NATIONAL RAILWAY FROM RIVIÈRE DU LOUP TO LÉVIS, QUE.

B.M. No.	Location	Elev. 1915	Elev. 1925	Diff.
821-B	C.N.R. bridge at Rivière du Loup	303·30	303·30	·00
580-B	Concrete monument 2 miles west of Rivière du Loup	329·67	329·67	·00
MCLXIV	Stone culvert 2¼ miles west of Rivière du Loup	321·89	321·84	− ·05
579-B-2	Tile culvert 1 mile east of Old Lake Road	350·61	350·58	− ·03
MCLXVI	Large stone culvert 350 feet west of Old Lake Road	336·50	336·48	− ·02
MCLII	Tile culvert 2 miles east of Saint Alexandre	414·48	414·48	·00
MCLI	Saint Alexandre station house	369·47	369·46	− ·01
579-B	Stone box culvert 1½ miles east of Saint André	345·26	345·19	− ·07
MCXLIX	Stone culvert ½ mile west of Saint André	338·18	338·11	− ·07
MCXLVIII	Tile culvert ¾ mile west of Saint Hélène	311·48	311·48	·00
577-B	Bridge ½ mile east of Dessaint	308·74	308·78	+ ·04
MCXLV	Bridge ½ mile east of Saint Pascal	219·39	219·41	+ ·02
MCXLVI	Saint Pascal Roman Catholic Church	183·84	183·83	− .01
MCXLIV	Tile culvert ½ mile west of Saint Pascal	184·77	184·73	− ·04
576-B	Bridge 1½ miles west of Saint Pascal	173·48	173·42	− ·06
MCXLIII	Bridge 3 miles east of Saint Philippe de Néri	191·74	191·69	− ·05
575-B	Tile culvert 1½ miles east of Saint Philippe de Néri	178·19	178·17	− ·02
27-G	Tile culvert at Saint Philippe de Néri	145·02	145·02	·00
MCXLII	Tile culvert ½ mile west of Saint Philippe de Néri	135·94	135·90	− ·04
MCXXXIX	Tile culvert 2½ miles east of Rivière Ouelle	97·90	97·89	− ·01
MCXXXVIII	Tile culvert 1 mile east of Rivière Ouelle	62·55	62·54	− ·01
MCXXXVII	Rivière Ouelle station house	48·38	48·30	− ·08
MXCV	Bridge ½ mile west of Rivière Ouelle	35·16	35·08	− ·08
MXCVI	Rock mass at Saint Pacôme	53·77	53·73	− ·04
MXCVIII	Large culvert 1¾ miles east of Sainte Anne de la Pocatière	70·39	70·25	− ·14
MIC	Bridge ½ mile west of Sainte Anne de la Pocatière	96·16	95·97	− ·19
573-B	Tile culvert 2¾ miles west of Sainte Anne de la Pocatière	93·96	93·78	− ·18
572-B	Boulder 3 miles east of Sainte Louise	101·46	101·25	− ·21
MCIV	Bridge 1½ miles west of Sainte Louise	129·75	129·61	− ·14

TABLE SHOWING COMPARATIVE ELEVATIONS OF PRECISE LEVEL BENCH MARKS ALONG CANADIAN NATIONAL RAILWAY FROM RIVIÈRE DU LOUP TO LÉVIS, QUE.—*Concluded*

B.M. No.	Location	Elev. 1915	Elev. 1925	Diff.
MCV	Stone culvert 1 mile east of Elgin Road	146·83	146·69	— ·14
571-B	Tile culvert ¾ mile west of Elgin Road	165·73	165·59	— ·14
MCVI	Tile culvert ¾ mile west of Saint Jean Port Joli	162·11	161·93	— ·18
570-B	Bridge 1¼ miles west of Saint Jean Port Joli	153·27	153·09	— ·18
MCVIII	Rock exposure 1¾ miles east of Trois Saumons	136·07	135·87	— ·20
MCIX	Boulder at Trois Saumons	99·45	99·24	— ·21
MCXXIII	Culvert ¾ mile west of Trois Saumons	70·25	79·03	— ·22
MCXXII	Tile culvert 1⅓ miles east of L'Islet	71·75	71·51	— ·24
569-B	Bridge 1 mile east of L'Islet	77·13	76·86	— ·27
568-B	L'Îslet station house	104·84	104·65	— ·19
MCXX	Tile culvert ¾ mile west of L'Islet	104·35	104·12	— ·23
567-B	Large boulder ½ mile east of Cap Saint Ignace	122·62	122·29	— ·33
MCXVIII	Stone culvert 1⅓ miles west of Cap Saint Ignace	105·92	105·59	— ·33
MCXVII	Boulder 3¼ miles east of Montmagny	72·70	72·38	— ·32
MCXVI	Boulder 2¼ miles east of Montmagny	54·23	53·86	— ·37
MCXV	Boulder 1¾ miles east of Montmagny	53·78	53·43	— ·35
566-B	Bridge ½ mile east of Montmagny	53·70	53·13	— ·37
MCXIII	Stone culvert 1¾ miles west of Montmagny	90·97	90·64	— ·33
564-B	Concrete monument 1¼ miles west of Saint Pierre	135·89	135·65	— ·24
MCXI	Stone culvert 1¼ miles east of Saint François	127·71	127·46	— ·25
MCX	Stone culvert ½ mile west of Saint François	128·82	128·55	— ·27
MCXXIV	Tile culvert 1½ miles east of Saint Vallier	151·12	150·89	— ·23
MCXXV	Open culvert at Saint Vallier	146·52	146·28	— ·24
MCXXVI	Stone culvert 1 mile east of La Durantaye	164·31	164·09	— ·22
563-B	Tile culvert at La Durantaye	169·44	169·22	— ·22
MCXXVIII	Small culvert 1 mile west of La Durantaye	178·00	177·79	— ·21
MCXXIX	Bridge 3¾ miles east of Saint Charles Junction	167·48	167·25	— ·23
MCXXX	Small culvert 2½ miles east of Saint Charles Junction	205·19	205·00	— ·19
MCXXXI	Stone culvert ½ mile east of Saint Charles Junction	283·20	283·04	— ·16
MCXXXII	Stone culvert 1½ miles west of Saint Charles Junction	322·70	322·51	— ·19
MCXXXIII	Stone culvert 4 miles west of Saint Charles Junction	306·64	306·47	— ·17
MCXXXV	Stone culvert at Harlaka	239·62	239·46	— ·16
219-B	Subway 1 mile west of Harlaka	177·10	176·94	— ·16
CLXVI	Same subway as above	167·69	167·52	— ·17
MCXXXVI	Subway (main road) at Lauzon	72·83	72·68	— ·15
220-B	Subway, road to Lauzon dry dock	66·84	66·69	— ·15
LXXIII	Same subway as above	58·14	57·99	— ·15
LXXIV	Lauzon dry dock	15·97	15·84	— ·13
221-B	Lévis Post Office	19·34	19·21	— ·13

NOTE.—Attention is drawn to the fact that the above holds the elevation at Rivière du Loup constant, while the graph holds the elevation at Lévis to be unchanged.

The results of the two sets of levelling, arranged with the Lévis end held constant, are shown graphically in fig. 25. It will be noted that the change in sense of the observed differences appears at a point between the station at Sainte Anne de la Pocatière and the station at Saint Pacôme. (It is to be remembered that the levels were run along the railway.)

Although the observed differences are small they are significant in that they arrange themselves as all in the same sense on one side of a given point and in the opposite sense

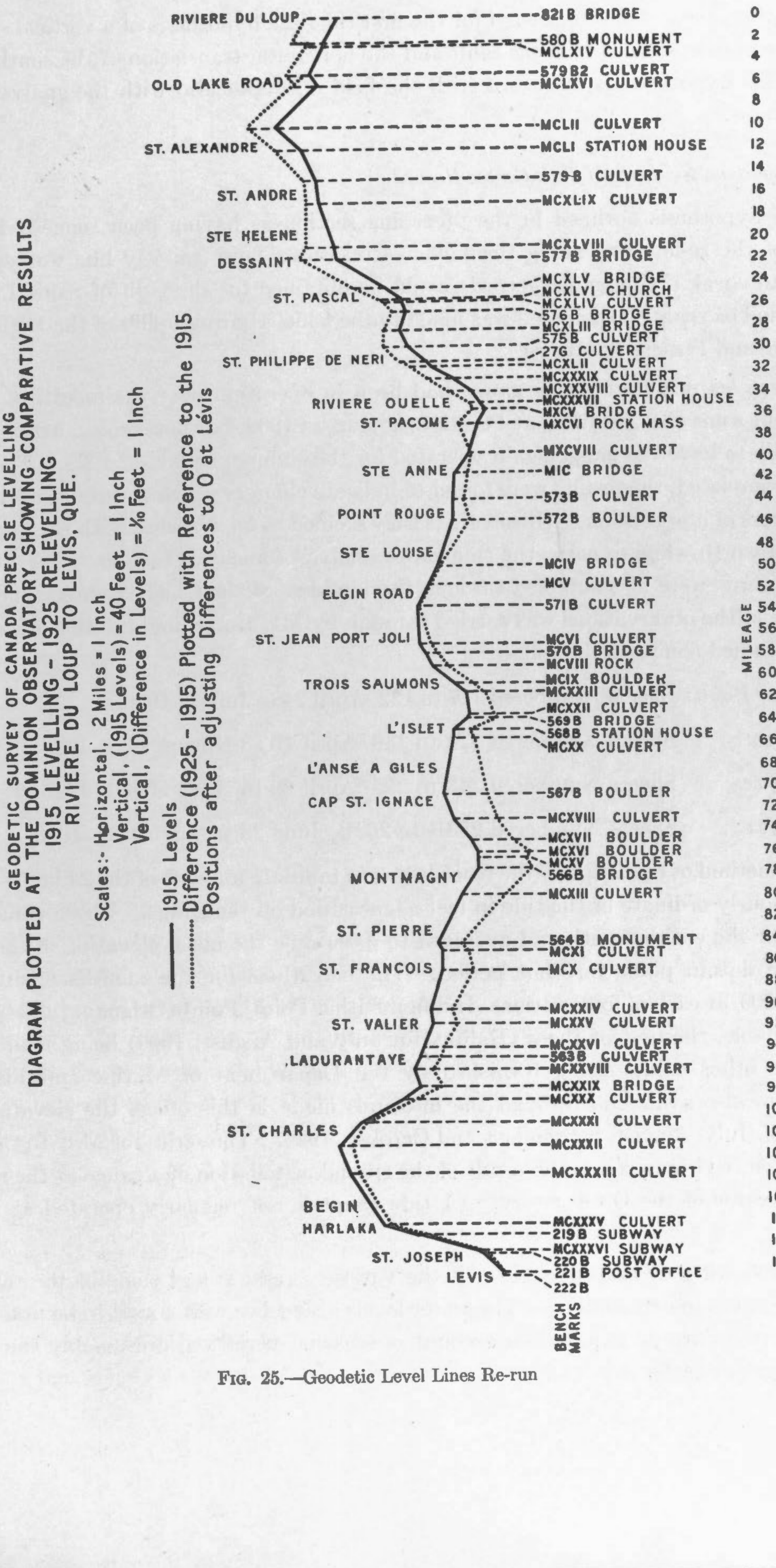

Fig. 25.—Geodetic Level Lines Re-run

on the other side. They suggested for the first time the hypothesis of a vertical snapping up of the northeastern side of the fault and the horizontal translation of the southwestern side. This hypothesis is in accord with the field data and also with the analysis of the seismograms.

(3) *Supporting Evidence of Tide Gauge Record*

The hypothesis outlined in the preceding section as having been suggested by the results of the re-levelling along the Lévis—Rivière du Loup railway line was evidently subject to check if tide gauge records could be obtained for the Gulf of Saint Lawrence for a period of years. An appeal was made to the Chief Hydrographer of the Department of Marine and Fisheries, Ottawa.

It was learned that a tide gauge had been in operation near the mouth of Rivière Ouelle, but somewhat below it, at Pointe Orignaux, in 1900, but not since. Arrangements were made to have the gauge again operated for the summer season of 1926. The observations completed, the results were found to indicate changes which were only of the order of the errors of observation. However, as they seemed to be in accord with the hypothesis it seemed worth while to carry the tide gauge analysis somewhat further. The following sets of records were also supplied through the kindness of the Chief Hydrographer. The reduction of the observations was carried through by Mr. J. Archibald in this office. The records studied comprise the following:

Father Point:	Sheets Numbered 117 to 122, April 24 to June 5, 1926.
Quebec:	Sheets Numbered 121 to 149, April 19 to November 1, 1926.
Halifax:	Sheets Numbered 243 to 295, April 29 to November 1, 1926.
Halifax:	Sheets Numbered 253B to 262B, June 28 to August 30, 1900.

The method of reduction of the records was to tabulate for each of the 24 hours of each day the hourly ordinate of the tide in feet as measured on the gauge. These values were totalled for the entire month and averaged to determine the mean elevation of the water above the datum plane for that period. The elevations for the months of July and August, 1900, at each of four stations (Halifax, Father Point, Pointe Orignaux, and Quebec) were available, the first of these (Halifax for July and August, 1900) being read in this office, the other values being furnished by the Department of Marine and Fisheries. There were also available, through the measures made in this office, the elevations for May, June, July, August, September, and October, 1926. The series for May to October, 1926, at Pointe Orignaux was the result of the special installation of a gauge at the request of the Director of the Observatory. (A tide gauge is not regularly operated at Pointe Orignaux.)

The following tabulation sets forth the various averages and some of the relations which they bear to one another. The water levels at Quebec were found to be practically useless for the purpose required on account of seasonal variation, presumably caused by meteorological effects.

WATER LEVELS FROM TIDE GAUGES

Dates	Halifax (H)	Father Point (F)	Orignaux Point (O)	Quebec (Q)	F-H	O-H	O-F
1900 July	3·19	7·35	9·80	8·97	4·16	6·61	2·45
Aug.	3·54	7·04	9·57	8·55	3·50	6·03	2·53
1926 May	3·57	7·47	9·13	9·37	3·90	5·56	1·66
June	3·44	7·65	9·20	8·55	4·21	5·76	1·55
July	3·46	7·45	9·04	8·20	3·99	5·58	1·59
Aug.	3·60	7·43	9·08	8·06	3·83	5·48	1·65
Sept.	3·55	7·29	9·03	7·96	3·74	5·48	1·74
Oct.	3·77	7·68	9·37	8·18	3·91	5·60	1·69
Variation May-Oct.	·33	·39	·34	1·41	·47	·28	·19
Average 1900	3·36	7·19	9·68	....	3·83	6·32	2·49
Average 1926	3·56	7·49	9·14	....	3·93	5·58	1·65
Difference	− ·20	− ·30	·54	....	− ·10	·74	·84
Average 1900	3·36	7·19	9·68	....	3·83	6·32	2·49
Average July-Aug. 1926	3·53	7·44	9·06	....	3·91	5·53	1·62
Difference	− ·17	− ·25	·62	....	− ·08	·79	·87

The results for Halifax, Father Point and Pointe Orignaux are quite consistent, and are valuable for the purpose of testing the above-mentioned hypothesis. The analysis in the last three columns of the table indicates that there has been no change of any importance in the relative levels of Father Point and Halifax between 1900 and 1926, while the evidence is very strong for an upheaval of about three-quarters of a foot at Pointe Orignaux during the same interval.

These results, then, entirely confirm the hypothesis as to the approximate location of the fault line of the earthquake, and the general displacement at that time.

Considerable interest was taken in this particular part of the analysis by the Director of the Observatory. The plan of bringing the monthly averages furnished by the reduction of the tide gauge records into the form of the above table which clearly shows their relationships and demonstrates the agreement of the water-level data with the hypothesis as to the position and nature of the epicentre was the result of his analysis of the reduced data.

(4) *Supporting Evidence of Tidal Loading*

At the time of the earthquake the high estuary tide had passed the mouth of Rivière Ouelle, loading the bed of the Saint Lawrence within the hypothetical fault line, as far as Quebec. It was three and a half hours past high tide at Father Point at the time of the shock, and was within an hour of high tide at Lévis at the same moment. Apparently the warping strain had nearly reached the breaking point, the swing of tidal load from the northeast side to the southwest side of the fault serving to set off the earthquake.

VII. PROBABLE CAUSE OF THE EARTHQUAKE

A statement as to the cause of any tectonic earthquake must, of course, be largely speculative. Nevertheless, the following explanation agrees with the field data and with the supporting evidence set forth in the sections immediately preceding.

Based on the evidence of the level lines re-run it may be assumed that the Atlantic coast is slowly rising, or at any rate that it has a tendency to rise, due, possibly, to re-adjustment following the relief of glacial ice loading, which may still be under way. As will be shown in Appendix B. there have been recurrences of relatively severe earthquakes in the Saint Lawrence valley in cycles of about 60 years. It is possible that the strain is adjusted thus at intervals.

To explain all the data, we may suppose a fault crossing the Saint Lawrence river passing into the north shore near Malbaie and entering the south shore between the mouth of Rivière Ouelle and Pointe Orignaux. The fault would be supposed to pass to the east of the church at Rivière Ouelle and to the west of the station at Saint Pacôme. The strike of the fault is N., 50° W. It may be considered as dipping toward the ENE.

The "trigger" causes which set off the earthquake may be two in number. A long period of dry weather in the east had possibly resulted in a lightening of the normal load on the Atlantic seaboard. Such a condition would tend to hasten the relief afforded by the earthquake. The estuary tide effect, discussed in the preceding section, was probably the final local change in surface load which set off the earthquake.

VIII. SUMMARIZED CONCLUSIONS

1. The earthquake occurred March 1, $2^h\ 19^m\ 20^s$, Greenwich Mean Time (February 28, $9^h\ 19^m\ 20^s$ p.m., Eastern Standard Time.)

2. The epicentre was $\varphi = 47°.6$ N. $\lambda = 70°.1$ W. but is to be considered as an elongated zone about a fault crossing the Saint Lawrence river from a point near Malbaie on the north shore to a point between the mouth of Rivière Ouelle and Pointe Orignaux on the south shore. The fault seems to lie west of Pointe Orignaux, east of the church at Rivière Ouelle and west of the station at Saint Pacôme. It probably extends up into the north shore above Malbaie but not for any considerable distance. The disturbed zone does not reach farther south than the rising land to the south of Saint Pacôme village.

3. The greatest damage occurred in three areas—in the immediate vicinity of the epicentre—at Quebec city close to the Saint Charles river—along the valley of the Saint Maurice. The damage at the last two of these was due largely to insecure foundation soil or to poor or improperly designed construction.

4. No deaths occurred which could be attributed directly to the earthquake. Four, or perhaps five, persons died as the result of shock, which was attributed to the earthquake.

5. No fires were caused by the earthquake in spite of the fact that it occurred in midwinter in a country where the houses were mostly frame and heated by stoves, many of which were overturned by the shock.

6. Frame houses seem admirably designed to withstand earthquakes such as may reasonably be expected to occur in this region, especially when the sheeting is applied diagonally, the studding being run through unbroken from sill to plate.

7. Chimneys should be housed in chutes or frames so that their collapse will not injure anyone in the house.

8. Pictures, crucifixes, etc. should be placed so that they will not fall on a bed, particularly where there are small children.

9. In case of an earthquake, the first thought of a householder in the epicentral region, living in a frame house, should be to take care that overturned stoves or lamps do not set fire to anything. It may be confidently expected that the shocks will not demolish the house if it is at all reasonably well-built.

10. Stone houses should not be built on deep alluvium in the Saint Lawrence lowlands. This type of structure is particularly liable to damage and is dangerous to those within.

11. Steel frame construction is admirably suited to structures designed for this region, provided it is so designed that its vibration will not batter down filler walls or adjacent construction of brick. When reinforced by concrete it would seem to be particularly earthquake resistant, but the effects at the grain elevators at Quebec city prove that even such earthquakes as we may experience in Eastern Canada can seriously damage or even destroy such buildings when they are located on deep fill. Unfortunately, such locations have been chosen in a number of cases for buildings of this type, housing heavy machinery, within striking distance of the epicentre of this last earthquake, an epicentre which, we may safety assume, will again be active sooner or later.

12. Top heavy structures, brick stacks, water tanks, etc., should be built, where possible, on secure rocky bases, but in any case they should be placed so that their swaying or collapse may not endanger life or property.

13. The investigations carried out with regard to this earthquake indicate that questionnaires as returned by volunteer observers or those to whom a general appeal has been made at the time of a heavy earthquake are almost valueless as the basis of an isoseismal map. Many examples were found where the replies sent exaggerated conditions. Some minimized them. Some reports were found on investigation to be absolutely lacking in foundation. These erroneous reports are often—generally in fact—forwarded in perfectly good faith. The value of questionnaires appears when they are secured promptly and forwarded directly to the investigator in the field to be used as suggestions of points of contact, or lines of investigation.

14. The time has come when the investigation of earthquakes in the field must be planned in advance of the shock. If the work is to be of any use to the engineer (and it is but a reasonable requirement that it should be) some sort of seismoscope must be devised which shall be so cheap that it can be produced for, say, ten or fifteen dollars, and which shall be capable of indicating the horizontal component of the direction of motion of the first movement of a given acceleration. If it can also record the maximum acceleration and maximum amplitude, so much the better.

These seismoscopes are to be set up in secure positions at many points of vantage in the area to be studied, the basements of schools, churches, meteorological stations, etc. and given into the care of those capable of restoring them to normal conditions of level and adjustment from time to time at regular intervals of inspection. The observers should be instructed as to a set manner of adjusting the seismoscopes and of checking the effects of an earthquake upon them.

Besides these cheap instruments there should be recording seismographs at various points in the seismic area. These should be capable of withstanding the shocks to which they are likely to be subjected, and of recording the various effects of these shocks—their period, amplitude, acceleration, and duration.

There is a real need for a reasonably priced instrument, perhaps such as that recently devised by Prof. K. Suyehiro as reported in the following papers:

(*a*) "On the Nature of Earthquake Motions Examined by a Seismic Vibration Analyser," *Proceedings of the Imperial Academy of Japan*, Vol. 2, No. 6, Tokyo, June, 1926.

(*b*) "A Seismic Vibration Analyser and the Recording Obtained Therewith," *Bulletin of the Earthquake Research Institute, Tokyo Imperial University*, Vol. 1, 59-64, August, 1926.

(*c*) "On the Nature of Earthquakes Studied by Means of the Seismic Wave Analyser," *Bulletin of the Earthquake Research Institute, Tokyo Imperial University*, Vol. 7, Part 3, 467-470, December 1929.

Seismographs designed to record the acceleration of an earthquake movement are desirable. It is quite possible to make instruments capable of registering such a record and of continuing to operate throughout a severe earthquake.

It should be possible to inaugurate such a complete field investigation for an area of frequent earthquakes. The experience gained would tend to indicate the most efficient and economical means of preparing for the investigation of the less-frequently disturbed seismic areas. The result obtained would be of inestimable value in pure seismology and also in its applications to engineering and insurance.

APPENDIX A.

The Rossi-Forel Scale of Earthquake Intensity*

(1) Recorded by a single seismograph or by some seismographs of the same pattern, but not by several seismographs of different kinds; the shock felt by an experienced observer.

(2) Recorded by seismographs of different kinds; felt by a small number of persons at rest.

(3) Felt by several persons at rest; strong enough for the duration or direction to be, appreciable.

(4) Felt by several persons in motion; disturbance of movable objects, doors, windows creaking of floors.

(5) Felt generally by everyone; disturbance of furniture and beds; ringing of some bells.

(6) General awakening of those asleep; general ringing of bells; oscillation of chandeliers, stopping of clocks; visible disturbance of trees and shrubs; some startled persons leave their dwellings.

(7) Overthrow of movable objects, fall of plaster, ringing of church-bells, general panic, without damage to buildings.

(8) Fall of chimneys, cracks in the walls of buildings.

(9) Partial or total destruction of some buildings.

(10) Great disasters, ruins, disturbance of strata, fissures in the earth's crust, rock-falls from mountains.

APPENDIX B

Previous Seismic Record of the Saint Lawrence Valley

Persistent investigation of every indicated source of information of historical references to the seismic conditions in Quebec has yielded, to date, a list of some 325 earthquakes which have taken place during the past 300 years in Eastern Canada and in New England. Special mention may be made of the following earthquakes, all centering in Eastern Canada, and comparable in intensity with the shock of 1925. They are as follows: February 5, 1663; September 5, 1732; December 6, 1791; October 17, 1860; and October 20, 1870. Adding the quake of 1925 we have a list of six earthquakes arranged roughly at five (taking account of the 1860 and 1870 shocks coming so close together that they may be counted as one place in the cycle) intervals of about 60 years. The earthquake of 1663 (see "The Probable Epicentre of the Saint Lawrence Earthquake of February 5, 1663". *Journal of the Royal Astronomical Society of Canada.* Vol. 22, No. 8, 325-334, October, 1928) may have been worse than any of the others, or it may be that accounts were exaggerated because of the difficulties involved in investigating reports received at the scattered posts. None of the others, unless perhaps it may be that of 1860, seems to have been less severe than that of 1925.

** From "A Manual of Seismology," by Charles Davison, Cambridge University Press, 1921. (A bibliography of this scale is there given: it was published first in 1883).*

The following notes with regard to each of the five earthquakes mentioned in the preceding paragraph will serve to indicate the nature of each and also the various sources of information.

February 5, 1663

Although a most severe earthquake occurred on this date it was but one of a series which terrified the early settlers and the Indians during the spring and summer of 1663. The accounts, as reported in various publications, are based for the most part on two records, namely:

"Histoire et description générale de la Nouvelle France avec le journal historique d'un voyage fait par ordre du roi dans l'Amérique septentrionale." Pierre François Xavier Charlevoix, S.J., Paris, 1744.

"The Jesuit Relations and Allied Documents, Travels and Exploration of the Jesuit Missionaries in New France, 1610-1791" (Presented in the original French, with the English translation on facing pages throughout 75 volumes). Edited by Reuben Gold Thwaites, Secretary of the State Historical Society of Wisconsin. Published by the Burrows Brothers Company, Cleveland, Ohio. Edition limited to 750 sets. A complete set may be found in the reference room of the Carnegie Library, Ottawa.

The reference given in the section immediately preceding ("The Probable Epicentre, etc.") discusses the data available for study of this earthquake and presents the following conclusions:

"The study of the documentary evidence thus far would lead to certain tentative conclusions which are being critically examined in the light of each added bit of evidence. Although recited dogmatically in the following tabulation, they are not by any means completely established by the evidence to date. We are led to believe, however, that:—

"(1) The actual seismic intensity of the earthquake of February 5, 1663, was not incomparable with that of the disturbances of September 5, 1732; December 6, 1791; October 17, 1860; October 20, 1870; or that of February 28, 1925. That is to say, it was not markedly greater.

"(2) The documentary reports, while undoubtedly coloured by the excitement and terror of the early settlers, may be accepted to a much greater degree if we consider the possibilities of landslides.

"(3) Landslides are obviously aggravated by a previous wet season. It becomes, therefore, a matter of extreme importance to examine carefully all available accounts with a view to establishing the meteorological conditions in Canada during the fall of 1662. This evidence would have considerable bearing on the question of whether the reported disturbances (if real) were due to landslides or to unusually severe seismic tremors.

"(4) The reported devastation near Trois Rivières and in the valley of the Saint Maurice does not, in all probability, indicate a separate focus there, but was due to a landslide of major proportions in that valley.

"(5) There seems to be a reasonable basis for the assumption that the epicentre of the earthquake of February 5, 1663, lay below the city of Quebec, near that of the earthquake of 1925. We read, for example, from the writings of Francis Mercier (1665) that ' . . . Two highly trustworthy Frenchmen, who have traversed the whole coast of Malbaie (down to Tadoussac is indicated), made the assertion that the Relations of the year 1663 (Lalemant) had only half described the ravages wrought by the earthquake shocks of that region'."

At this point it would seem best to present an hypothesis regarding the reported disappearance of the waterfall at Les Grès on the Saint Maurice river between Trois Rivières and Shawinigan Falls which seems much more probable than any heretofore advanced. Indeed, it seems to offer a reasonable explanation of all the records of destruction in that valley by the earthquake of 1663. It was suggested by Mr. Julian C. Smith, of Montreal, who has made a very considerable investigation of the records of that earthquake.

We have only to accept the assumption that the original waterfall at Les Grès was of moderate proportions—15 to 20 feet in height or even a little more, which is not incompatible with the original accounts. It would offer, even so, a serious interruption to navigation and so would find place in the chronicles of voyages up the Saint Maurice. Below Les Grès, the banks of the river are more than 100 feet high. They are of clay and are subject to frequent landslides. The earthquake may be supposed to have caused slides of major proportions in this clay, which completely dammed the river, raising the water to a height sufficient to back up to the level of the top of the falls, thus temporarily "destroying" them. The clay in the river bed would provide the series of rapids which early writings indicate to have been found below the vanished waterfall.

This explanation finds support in the geology of the region, a support which has been lacking for any explanations previously offered. It agrees with the reports that the river "ran white with mud" for the following summer. It is in accord with the fact that, until a hydro-electric power dam was built in about this same position, and with the same effect of destroying the waterfall, such a waterfall existed in recent times at Les Grès, having been restored when the mud of the slides had been eroded.

September 5, 1732

The records of earthquakes in eastern Canada and New England were collected by the late Dr. J. W. (Sir William) Dawson and published in a series of papers which appeared in *The Canadian Naturalist and Geologist* as follows:

"A Chapter on Earthquakes", Old Series, Vol. 1, 189-196, May 1, 1856.

"Notes on the Earthquake of October, 1860", Old Series, Vol. 5, 363-372, October 17, 1860.

"The Earthquake of April, 1864", New Series, Vol. 1, 156-159, April 20, 1864.

"The Earthquake of October 20th, 1860", New Series, Vol. 7, 282-289, October 20, 1870.

In the Report Concerning Canadian Archives for the Year 1904 (4-5 Edward VII, Sessional Paper No. 18) on pages 176-178 the following references to the earthquakes are given:

1733: April 21 . . . . . Is happy that the earthquake felt in Montreal did not do much damage to the town walls. (pg. 176)

1733: May 6 . . . . . Does not think the damages of the earthquake in Montreal were large enough to be worth aiding. (pg. 178)

1735: April 12 . . . . . Cannot grant to the Recollets the sums they ask for the losses suffered by them during the earthquake. (pg. 212)

In the second of the four lists published by Sir Wm. Dawson, he states: "1732, September 5, Canada, New England, and as far as Maryland, buildings injured."

A paper entitled "Les tremblements de terre de Québec," was published by Mgr. J.-C. K. Laflamme, (Proceedings and Transactions of the Royal Society of Canada, Third Series, Vol. 1, Section IV, 157-183, Ottawa, May, 1907). He presents the following note with regard to the earthquake of 1732: "Le séisme de 1732 n'ayant affecté que la région de Montréal ne rentre pas rigoureusement dans le cadre de ce travail. Nous en dirons quelques mots cependant pour faire voir que, si les séismes montréalais ont, en général, moins d'intensité que ceux de la région inférieure de la province, ils peuvent cependant atteindre un certain degré de violence.

"La Mère Duplessis de Sainte Hélène, supérieure de l'Hôtel-Dieu de Québec, après avoir parlé, dans une lettre du 20 octobre 1732, de l'incendie de Montréal qui avait détruit 190 "corps de logis," ajoute: 'Depuis un mois c'est un tremblement de terre qui y jette une consternation qu'on ne peut exprimer. De la première secousse qui ne dura que deux ou trois minutes, plus de trois cents maisons ont été endommagées, quantité de cheminées tombées, des murailles fendues, des personnes blessées, une fille tuée, des grêles de pierres qui se répandaient partout et qui semblaient être jetées par des mains invisibles, enfin un effroi si universel que les maisons sont désertes, on couche dans les jardins, les bêtes même privées de raison jetaient des cris capables de redoubler la frayeur des hommes. On fait des confessions générales de tous les côtés: les dames ont quitté leurs paniers, les prêtres leur ont fait signer une promesse. Plusieurs ont fui et sont venus à Québec pour n'être enseveli sous les ruines de cette pauvre ville. Le fâcheux est que tout celà n'est pas fini. Il n'est point de jour qu'il ne se fasse sentir; il y a des puits qui ont été extrêmement taris, des chemins boulversés.'

"D'autre part, l'ingénieur de Léry écrit au ministre pour lui annoncer qu'il y a eu un tremblement de terre à Montréal. Le 3 octobre 1732, l'intendant Hocquart apprend au Ministre la nouvelle de ce tremblement de terre, et, le 12 avril 1735, le Président du Conseil de Marine écrit à l'intendant Hocquart qu'il ne peut accorder aux Récollets la somme qu'ils demandent pour les pertes subies par eux dans le tremblement de terre."

It is desirable that further references to this earthquake be sought, in order that it may be established whether an earthquake of such intensity centred near Montreal or, if not, the position of its epicentre.

The fact that the first tremors lasted "only two or three minutes", would indicate that Montreal was not the centre of this earthquake. It is just possible that later references. may establish an epicentre much farther down the Saint Lawrence.

December 6, 1791:

The paper by Mgr. Laflamme, quoted in the case of the earthquake of 1732, has the following note regarding the earthquake of 1791: "Le tremblement de terre de 1791 fut un de plus violents qui ait jamais été ressentis dans notre région. C'est surtout dans le comté de Charlevoix qu'il fit les plus grands ravages. Nous avons l'avantage de posséder le récit d'un témoin oculaire de ce terrible phénomène. Au moment de la catastrophe, ce témoin,—une fillette,— avait douze ans. Plus tard, sur la fin de sa vie, elle écrivit ses notes et l'abbé A. Mailloux les a insérées telles quelles dans son 'Histoire de l'Île-aux Coudres' publiée en 1879. En lisant ce récit que nous reproduisons plus loin, on verra que la jeune personne savait observer avec une rare perspicacité, car les détails qu'elle nous donne sont en parfaite conformité avec ce que l'on sait se passer dans tous les tremblements de terre un peu violents . . . . . "

Then follows an account covering five closely printed pages and detailing the effects of the earthquake. A map is included. The centre of the earthquake is given as the lower Saint Lawrence—Baie Saint Paul, Malbaie, and the vicinity. The last paragraph of the quotation may be given in full, followed by the comments of Mgr. Laflamme in concluding his references to the earthquake: " 'Plusieurs vieillards remarquent que depuis plusieurs quarts de siècles, il y a eu des tremblements de terre semblables à celui-ci qui ont duré quarante jours. On trouve que leur retour est passablement exact de 25 ans en 25 ans à une année ou deux de variation et que le présent est le troisième qui, à leur souvenir, est arrivé dans la même saison, à la différence d'un mois ou deux.'

"A ce propos, nous nous permettrons d'ajouter que, depuis 1791, les paroxismes séismiques semblent se répéter plutôt tous les quarante ans, ou à peu près. Si cette règle était vraie, nous devrions nous attendre à avoir des perturbations plus violentes que celles de tous les jours vers 1911. On peut cependant en douter, car ces répétitions périodiques à dates précises, sont toujours très incertaines."

If we limit the earthquakes included in a deduction of the cycle period to those which were felt over Eastern Canada and New England we have the following, according to the card index of earthquakes for this region on file at the Dominion Observatory. (There is some evidence of a great earthquake in 1534 or 1535, which is added for what it may be worth.)

Date of Earthquake	*Interval*
1534–35	
	129 years
1663	
	69 "
1732	
	59 "
1791	
	69 "
1860	
	10 "
1870	
	55 "
1925	

The evidence seems to indicate a cycle greater than 25 or even 40 years. There is, however, evidence of periodicity of a sort. If prediction is ever to be safe for this region it must be based on a long-continued study of the fore-shocks and after-shocks of one of the great quakes. Immediately following the earthquake of 1925, steps were taken to establish a seismograph in the region of Sainte Anne de la Pocatière, with the object of recording the after-shocks of the earthquake and to continue the observations. It was soon found that the instrument used was not suited for such work. Since then, two stations, using instruments specially designed for recording local shocks, have been established in the province of Quebec, one near Shawinigan Falls, the other near Beaupré, for the purpose of recording the shocks which affect eastern Canada, the Sainte Anne station being discontinued. To completely fulfil the purpose for which they have been established, it will be necessary that the observations be continued up to and beyond the next great shock. When it will occur, we cannot tell. It would at least seem a fair assumption that it will not be later than 70 years after the last one, that is to say, before 1995. It is possible that it will happen much sooner than that.

October 17, 1860

The best account of this earthquake is that given by Sir William Dawson in the second of the papers to which reference was made on page 429. He writes: "On the 17th October, Canada and the Northern States of the American Union were visited by an earthquake vibration of a more general and impressive character than any that has occurred for many years, and we propose to present to our readers such reports as have reached us with respect to its distribution, time, and local intensity, and to add for comparison and future experience a summary of the earthquakes that have occurred in Canada since its colonization, and some remarks on the laws of these phenomena as far as they have been ascertained.

"In Canada the earthquake of the 17th was experienced in its greatest intensity in the lower part of the river, and with diminished force as far west as Hamilton. In the United States, in like manner, it was most violent on the Atlantic coast and extended westward apparently with less intensity as far as Troy. Between Hamilton and Father Point it was felt throughout the whole of (Upper and Lower) Canada. At Rivière Ouelle and other places in the lower Saint Lawrence it was so violent as to throw down chimneys and damage walls, and several severe shocks were felt. In Upper Canada there appears to have been but one shock and this comparatively feeble. We have at present no information as to the extension of the vibrations to the north of Canada and to the south of the Northern States. (It was felt in New Brunswick also.)

"The following list of places in which observations were made of the time and intensity of the shocks has been compiled chiefly from the newspapers, to which much credit is due for the careful and intelligent manner in which they have collected and recorded the facts.

"The places have been arranged in the order of their longitudes from east to west, and it will be observed that the time is earlier in eastern localities, but on comparing

Bic and Belleville nearly nine degrees of longitude apart, it will be seen that the difference of time is only a little less than that due to the difference of longitude. The Hamilton observation would give an earlier time, but as the shock was slight and the testimony of only one observer was recorded there may be an error. The shock thus appears to have been nearly simultaneous throughout Canada." (In view of the velocity with which the seismic tremors are propagated and the evidently inaccurate time checks used, this conclusion is not warranted—E.A.H.)

Then follows a list of reports from Bic to Hamilton. The author continues: "The following graphic account of the phenomena as observed at Rivière Ouelle appeared anonymously in a Quebec paper, and is the most detailed statement we have seen of the effects of the earthquake in those localities in which it was most evident.

Rivière Ouelle, 17 octobre, 1860

'Ce matin trois fortes secousses de tremblement de terre sont venues jeter la frayeur au milieu de nos populations.

'Les bâtisses situées de chaque côté de notre rivière ont souffert généralement. Une cheminée chez E. Chas Tetu, deux chez M. C. Casgrain, une chez M. Frenette, une chez Auguste Casgrain, une chez Madame Frs Casgrain, et chez une dizaine d'autres personnes ont été renversées. La croix de notre église et le coq qui la surmontait sont à terre; *les murs de notre belle église sont lézardés.* Les secousses étaient effrayantes, la première, la plus violente, a commencé à six heures et quart et a duré quatre minutes et 40 secondes, très violente durant dix secondes et s'affaiblissant graduellement; la secousse la plus faible à six heures et vingt minutes, a duré trois à quatre secondes, et la troisième a commencé à six heures et demie, et n'a duré que deux à trois secondes; mais, comme la première, c'était un choc saccado faisant danser les meubles, décrochant les cadres, les horloges, etc.

'*Les secousses ont été plus faibles sur les hauteurs, que dans les plaines,* de sorte que mes bâtisses se sont trouvées à l'abri des accidents.

'Jamais de mémoire de nos habitants, nous n'avons eu des coups aussi forts. Je suis demeuré devant mon horloge tout le temps pour m'assurer de sa durée, afin de pouvoir computer avec d'autres endroits la marche de ce grand et terrible phénomène.

'Un bruit sourd et fort nous a d'abord averti et ensuite sont venus les secousses et les craquements.'* . . . . . "

The author continues with observations about earthquakes in general and the one of 1860 in particular and finally gives a list of earthquakes felt in Canada and New England since colonization.

The italics in the above French quotation are inserted to mark two comments which are of interest in view of the observations in the case of the earthquake of 1925. The church,—*notre belle église,*—whose walls were damaged in 1860 was presumably rebuilt. The one wrecked in 1925 had been built in 1872, indicating that it was again wrecked in the earthquake of 1870. Yet in 1925 it was again rebuilt in the same spot, of the same stone, in the same design,—and with every prospect of having the same destiny.

The second part italicized in the quotation was so printed to draw attention to the fact that, as in 1925, the disturbance differed markedly in intensity on the heights to the south and in the plains beside the river.

October 20, 1870

The earthquake of 1870, as described by Dawson in the last of the four publications mentioned on page 429, was less severe than that of 1860 except at Baie Saint Paul and, presumably, nearby points. Except for one rather lengthy description by the parish priest of Baie Saint Paul the reports of the earthquake effects are short. The tremors were felt over the whole of Eastern Canada and New England, as far west as Sault Sainte Marie, the north shore of lake Superior, and Dubuque, Iowa. It was felt as far south as Richmond, Va.

A detailed account of meteorological conditions at the time of the earthquake at various points in Canada is furnished by Dr. Smallwood of McGill University, Montreal.

Three direct quotations may be given:

"As usual with Canadian earthquakes, this was felt most severely in the Lower Saint Lawrence, more especially at the junction of the Lower Silurian and Laurentian formations in the vicinity of Baie Saint Paul, Malbaie, and the Saguenay."

"Other correspondents mention the opening of chasms in the ground, from which streams of water and sand burst forth. This phenomenon arises from the landslips produced in the terraces of post-pliocene clay which in that part of the country rest against the steep sides of the Laurentian hills. These are ready to slide downward with any slight movement of the earth, and to press the water out of the sandy layers associated with them or give outlet to hidden springs and streams."

"It is also stated that a mass of rock 400 feet in length fell from the face of the cliff at Cape Trinity, in the Saguenay. Cape Trinity is a cliff of Laurentian gneiss, presenting to the river a vertical front abour 1,500 feet high." (Capes Trinity and Eternity are on either side of the mouth of Eternity river which flows into the Saquenay about 30 miles above the confluence of the Saguenay and Saint Lawrence rivers.) The article by Mgr. Laflamme (*see* page 430) devotes 5 closely printed pages to a description of this earthquake.

Besides the greater earthquakes of 1663, 1732, 1791, 1860, 1870, and 1925, there have been some outstanding shocks during historic times which were of secondary, though still considerable, intensity, or which appear to have centred off the Atlantic coast, and which were felt over considerable areas in Eastern Canada and New England. Without going into details for these records, it may be of value to record the dates on which they occurred. The complete index includes, at the present date, a total of 242 earthquakes up to and including the one of 1925 (but not its after-shocks) of which the following (in addition to the ones discussed in detail) were strongly felt over considerable areas:

Date	*Remarks*
1534–35	Les Eboulements, Que. reported to have been so named from the effects of an earthquake which occurred between the two voyages of Jacques Cartier.
1638	Eastern Canada and New England, apparently with centre in Canada.
1727, Nov. 9	Centred near Newbury, Mass. and followed by after-shocks which continued for nearly a year.
1755, Nov. 18	New England and Eastern Canada, particularly Nova Scotia. Felt as far south as Maryland. 1,200 chimneys destroyed in Boston. Epicentre may have been under ocean.
1831, July 14	Malbaie, Beauport, Kamouraska. Houses damaged. (One authority reports very similar details for an earthquake on May 7-8 of the same year: it is not certain whether there were two dates of shock or not.)
1842, Nov. 8–9	Montreal and Trois Rivières.
1864, April 20	Felt over considerable area in Eastern Canada. Reported in a special paper by Sir Wm. Dawson.
1897, March 23	Montreal, over Eastern Canada and New England. This was the first earthquake registered in Canada according to McLeod and Callendar. Felt over an area 300 miles by 100 miles.
1904, March 21	Felt over about 300,000 square miles. Eastern Canada and New England.
1924, Sept. 30	Widely felt over Eastern Canada and New England. Located at practically the same epicentre as that of 1925.

The references consulted in preparing the card catalogue of earthquakes in Eastern Canada and New England have been brought to the attention of the writer by many individuals at various times. There have been three outstanding sources, however, to which reference should be made:

(*a*) The bibliography and catalogue entitled "The Earthquake Record in New England," prepared by Hollis Godfrey, Kirtley F. Mather, and Katherine Hampson, presented as a paper at the Second Annual Meeting of the Eastern Section of the Seismological Society of America, and published by the Engineering Economics Foundation of Boston. The bibliography, as furnished the writer by Dr. Mather, in manuscript form, lists 56 references. The catalogue tabulates the Year, Day, Hour and Minute, Epicentre, Intensity (on Rossi-Forel scale) at Epicentre and at Boston, Limits of Appreciably Shaken Area, and Sources of Information.

(*b*) Notes and records by the late Professor Woodworth of Harvard University, who, for many years, made a continued study of the records of earthquakes in New England. The bibliography compiled from his notes furnishes 15 additional references.

(*c*) The "Earthquake History of the United States, Exclusive of the Pacific Region," by N. H. Heck. Special publication No. 149 of the U.S. Coast and Geodetic Survey, Washington, D.C. Comdr. Heck lists a total of 28 references, only a few of which are included in the two sources (*a*) and (*b*).

In concluding his paper on "Les Tremblements de Terre de Québec," Mgr. Laflamme writes: "De ce trop long travail nous nous permettrons de tirer une conclusion pratique. Étant donné l'âge très ancien de nos terrains québécois, il n'y a aucune raison de craindre qu'ils soient jamais le siège de perturbations séismiques violentes, comparables à celles des régions séismiques proprement dites. Nous n'aurons donc guère au Canada que ce que l'on pourrait appeler des tremblements de terre de laboratoire. Mais cela n'enlève aucun intérêt à leur étude.

"Par conséquent, l'installation de séismographes à la Baie Saint Paul ou quelque part dans les environs, donnerait des renseignements de la plus haute valeur, surtout si les appareils inscrivaient la composante verticale en même temps que les composantes horizontales.

"L'entreprise vaut d'être tentée, et nous soumettons respecteusement cette suggestion aux fervents de la science séismique. On arriverait ainsi à faire une étude aussi complète que possible de nos tremblements de terre et à déterminer à la fois, et la position exacte de la ligne épicentrale, et sa profondeur au-dessous de la surface du sol."

Some small start has been made toward this instrumental investigation of the seismicity of Quebec. As has been indicated on page 432, short-period seismographs are now operating under ideal conditions at two points in Quebec. At present only one component, short period, horizontal instrument is installed at each station. As advocated by Mgr. Laflamme, it would be desirable to have both horizontal components and also a vertical at each station. For the present, all that can be determined is the number of small shocks occurring in the province and their relative intensity. Some slight indication is also given of their location. To obtain all the information desired it will be first necessary to perfect the time-recording arrangements and then to add the other horizontal component and the vertical at each of the stations. The seismic history of Quebec, as sketched in this appendix, serves to show that there is a field of investigation here which, when fully and carefully cultivated, should yield much valuable information in seismology, pure and applied.

DOMINION OBSERVATORY,
OTTAWA, August, 1930.