THE ACADIAN-NEWFOUNDLAND EARTHQUAKE OF NOVEMBER 18, 1929.—By J. H. L. JOHNSTONE, PH. D., Department of Physics, Dalhousie University, Halifax, N. S.

(Presented 12 February 1930).

ABSTRACT.

Field data obtained by some observers in Nova Scotia and Newfoundland are given. The seismograms of three of the aftershocks recorded at Halifax are discussed. The first part of the P Wave to reach Halifax was a compression. The seismogram obtained at the Island of St. Helena is briefly referred to. The Tsunami or tidal wave caused by the earthquake is discussed and a copy of the tide gauge record obtained at Halifax is shown. The damage to cables is briefly discussed and photographs of broken cable ends found at N. Lat. 43°26′54″ and W. Long. 56°12′54″ are given. No exhaustive investigation has been undertaken as this is being carried out by the Dominion Observatory, Ottawa, and by the United States Coast and Geodetic Survey.

There are records that 325 earthquakes[1] have occurred in Northeastern United States and Eastern Canada in the period 1638-1929. According to Heck[2], 104 were of intensity 5 or greater, (Rossi-Forrel scale). The epicentres occur in the region N. Lat. 40°.6 to 47°.6 and W. Long 64°.8 to 79°.6. Seven of the earthquakes, viz. those of 1663, 1732, 1755, 1791, 1860, 1870 and 1925 had intensities from 8 to 10. It is probable that eighteen of these tremors were felt in Nova Scotia and New Brunswick. An earthquake of intensity 7 to 8 was felt in New Brunswick, Nova Scotia and Maine on Feb. 8, 1855, being most noticeable at Moncton, N. B. and Dorchester, N. B.; the epicentre is placed at N. Lat. 46°.2 and W. Long 64°.8. Five epicentres have been located at N. Lat. 45° and W. Long. 67°.2 approx., (near Maine and N. B. border). Information concerning the earthquake of March 21, 1904 is published in these Transactions[3].

1 Hodgson, *Trans. Roy. Soc. Can.*, **4**, 151, (1927).

2. Heck. *Earthquake History of U. S.*, U. S. Coast and Geodetic Survey Serial publication No. **149**, 13.

3. Woodman, *These Transactions*, **11**, Pt. 2, 227 (1904).

Field Data.

Halifax, N. S.—The writer, who was on the first floor of his residence, felt the house vibrate at 4:34 p. m. A.S.T. At first the motion seemed to be caused by the vibration of the engine of a motor truck near the house. The intensity of the vibration then increased, and it seemed to become more vertical in direction, as if originating in the basement of the house. It felt as if the water in the furnace were boiling with much bumping, and "water hammer" effects. The time of maximum motion was noted to be 4:34±20 seconds, A.S.T. Similar sensations were experienced by many in Halifax. Several people in the Science Building at Dalhousie University thought that the fan motors on the top floor had become loose and were bumping around. Several stenographers who were on the upper floors of the Metropole Building felt the building sway from side to side and rushed down the stairs to the street in semi-panic. The rattling of dishes and water pipes was general throughout the City of Halifax. At about 5 p. m. a strong southeast wind commenced to blow accompanied by rain and sleet; this continued until after midnight and caused interruption of the City light service. There is no evidence that any chimneys were broken in Halifax or vicinity. The barometer and thermometer readings at Halifax on Nov. 17, 18 and 19 are shown in Table V.

Lunenburg.—The buildings shook as though some heavy printing press was being operated. Radiators shook.

Bridgewater.— Fire bell rang. Several parked autos moved a few feet on the road.

Yarmouth.—Small articles were dislodged and broken. People on the street did not notice the vibration.

Annapolis Royal.—Pictures swayed from side to side. Buildings trembled. A rumbling sound was heard.

Windsor.—Chimneys were noted swaying from side to side. Two distinct shocks were noticed. The second shock was the more intense. The tops of chimneys seven feet high seemed to sway six or seven inches. Charles Scott, Esq., Head Master at King's Collegiate School, states that a chimney

about seven feet high was broken through entirely, the bricks side stepping about $1\frac{1}{2}$ inches in a direction approx. 30° east of south. On the following day this chimney had to be entirely demolished as it was unsafe. Aftershocks were felt at Windsor at approximately 7 p. m. and 10 p. m.

Wolfville.—Movement was more violent here than in Halifax according to reports.

Canso.—Mr. H. A. Rice reports as follows: "I was in my office which is on the end of the wharf. It seemed as though a large steamer had bumped into the wharf and the bumping continued as though the engine and propeller were still going.

Pictou.—Dishes rattled and a stove moved. A low rumbling sound was heard. People on the street did not hear it. A car with brakes on rocked back and forward terrifying the occupant. A stove and stove-pipe was seen in vibration.

Dundee, Richmond County, N. S.—A road was cracked in several places. This is discussed by D. S. McIntosh[4].

Ross Ferry, C. B.—A slight landslide occurred.

Ingonish, C. B.—Simon Brewer reports having seen two cups upset on the table and further states that a window glass was broken. A concrete door sill was put out of alignment so the door did not close properly.

Sydney, N. S.—Mr. R. W. Mackinnon, City Engineer of Sydney, N. S. gives the following report: "A number of chimneys which had very little mortar between the bricks came down, or had bricks shaken off the top. The rumbling noises of buildings, together with the swaying of telegraph and telephone wires, made things seem weird for a few minutes. Several leaks in the water mains were noted on Nov. 19. These mostly occurred at the joints between the lead and iron pipes."

Magdalen Islands.—A stove was reported as having been moved about a half inch along the floor.

Sable Island.—The earthquake was felt at about 4:30 p.m. and lasted for three minutes. Houses trembled. The lighthouse keeper reported that some mercury was spilt from a container. The shock was felt more at the ends of the Island. Positively no tidal wave here.

4. *These Transactions*, 17, Pt. 4, 216, (1930).

Cape Race, Nfld.—The light-keeper reports that about five pounds of mercury were spilled from the revolving light.

Grand Bank, Nfld.—Mr. Howard Patten, Pharmacist, reports as follows: "I was in a general store which shook and the noise was likened unto an engine, high power, running on a loose base. When I observed people running out into the street from other buildings the thought occurred that an earthquake tremor was being experienced. The vibration was little felt outside the building. It was unnoticed by many walking along the street. No chimneys were broken."

Burin, Nfld.—Magistrate Hollett gives the following account[5]: "I was in the house when it began, about five o'clock and went out into the garden. The land trembled so violently that I could hardly stand, and the garden gate rattled as if in the wind. The sensation was similar to that felt when one stands in the stern of the ship which suddenly reverses its engines from ahead to full astern. The people had just got over the terrible fright occasioned by the earthquake when about half past seven the harbour suddenly ran out nearly dry. Immediately this was followed by the first tidal wave which came roaring in the moonlight, for it was a clear, bright and calm night. Where the land was low, like at Taylor's Bay, houses were washed inland by the first wave and carried back by the undertow. The worst damage was caused at points where the land rose rapidly, houses were washed to sea by the receding wave or thrown back by each of the succeeding waves."

At Sea.—Capt. James, S.S. Nerissa, when in N. Lat. 44°57′ W. Long 61°16½′ proceeding from St. John's to Halifax, felt the ship tremble violently at 4:35 p.m. A.S.T. This lasted for about one and a half minutes. It felt as if the main engine had suddenly been put astern. The ship fell off her course 10 degrees to port. The motion felt was similar to the effect the propeller has on the ship when it is racing in a heavy sea. However, at that time the sea was very smooth.

The estimated intensity of the shock (Rossi-Forrel Scale), at different places in Nova Scotia and Newfoundland is given in Table I.

5. This account is taken from the *Daily News*, St. John's, Nfld., Jan. 15, 1930.

TABLE 1.

	Intensit
Halifax	4-5
Lunenburg	4-5
Bridgewater	5
Yarmouth	4
Annapolis Royal	4-5
Windsor	5
Wolfville	5
Canso	5
Pictou	5
Dundee, N. S.	5-6
Ingonish	5-6
Sydney, N. S.	5-6
Magdalen Islands	5-6
Sable Island	5-6
Burin, Nfld.	6
Grand Bank, Nfld.	4-5

INSTRUMENTAL DATA.

Halifax:

Dalhousie University Seismograph—

North Lat. 44°38′

West Long. 63°36′

Instrument: Small Mainka Pendulum (horizontal) 139.9 Kg. Clock drive. Smoke paper records.

Period: 10.0 Secs. N. S. component

7.5 Secs. E. W. "

Magnification: 110

The record of the earthquake obtained at Halifax is of little scientific value. For some time previous to Nov. 18, 1929 the clockwork drive of the seismograph had been giving trouble and unfortunately it stopped some three hours previous to the earthquake. The earth motion, however, was sufficient to start the motor, but not soon enough to record the preliminary waves altho the later phases are recorded. Records of the "aftershocks" on Nov. 18, 19 and subsequently were

obtained and the times of arrival of the phases are given in Table 2. It is found that the maximum amplitude of the P wave in the after-shock records is much greater on the E. W. component than on the N. S. component. It is also noted that the first movement is towards the west. It is to be concluded therefore that the first part of the wave to reach Halifax from the focus of the "aftershocks" was a compression.

TABLE 2.

Halifax.	Aftershocks of main earthquake. h. m. s. (G.M.T.)				
Nov. 18	eP_e	23	03	17	
	eP_n	23	03	20	
	i_n	23	04	10	
	i	23	04	15	
	i_n	23	04	44	Felt at Burin, Nfld., and
	i_E	23	05	02	Guysboro, N. S.
	MN	23	05	26	
	M_E	23	05	29	
	F	23	13		
Nov. 19	0	(2	01	38)	
	eP	(2	02	42)	
	eS?	2	03	44	Distance = 500 km. Felt at
	i	2	04	30	Burin and Guysboro
	F	2	05	45	
Dec. 6	e	17	43	00	
Dec. 7	e	1	40	00	
Dec. 7	e	4	22	00	Felt at Mulgrave, N. S.
	eP	11	20	45	
	eS?	11	21	37	Distance = 500 km. Felt at
	i	11	22	15	Guysboro, N. S.
	F	11	24	00	

TABLE 3.

Time of Origin	Arrival of "P" Wave	Arrival of "S" Wave	Δ in degrees	Station.
h. m. s.	h. m. s.	h. m. s.		
20 31 55	20 35 18	20 37 40	12.7	Ottawa.
	20 35 11	20 37 37	12.7	Fordham.
	20 35 50	20 38 48	15.3	Buffalo.
	20 35 54	20 39 04	16.4	Georgetown.
	20 36 07	20 39 37	17.4	Charlottesville
	20 36 30	20 40 18	19.3	Ann Arbor.
	20 37 06	20 40 14	22	Milwaukee.
	20 37 06	20 41 18	22.2	Loyala.
	20 37 34	20 41 51	24.8	St. Louis.
	20 38 59	20 44 24	33.7	Saskatoon.
	20 38 09	20 42 20	40.5	New Orleans.
	20 38 48	20 43 42	34.3	Denver.
	20 40 08	20 46 37	42	Tucson.
	20 40 06	20 46 33	42.3	Hohenheim.
	20 40 49	20 47 52	47.6	Berkeley.
	20 47 (?)	20 58 (?)	78.6	St. Helena.
	20 50 (?)	—	—	Kobe, Japan.

TABLE 4.

St. Helena. Nov. 18, 1929.

h. m. (G. M. T.)

S. ? e 20 54
e 20 57½
L. ? e 21 08
e 21 14
e 21 24½
e 21 52 Distance 8700 km.

TABLE 5.

		Barometer.	Thermometer.
Nov. 17	9 a. m.	29.99 ins.	43°F.
	9 p. m.	30.16	40
Nov. 18	9 a. m.	30.42	33
	9 p. m.	30.05	40
Nov. 19	9 a. m.	29.60	50
	9 p. m.	29.75	44

A copy of the record obtained on the seismograph operated by the Eastern Telegraph Company at St. Helena was very kindly supplied to the writer by Mr. J. C. Hagen, Supt. of the Halifax and Bermuda Cable Co., Halifax, N. S. The arrival times of different phases are given in Table 4. Owing to the great distance of St. Helena from the epicentre the phases are not well defined on this record. If 20 hr. 54 min. is taken as the time of arrival of the S Wave, the distance to the epicentre is calculated by the Klotz Tables to be 8700 km. This value accords with the tentative position of the epicentre, i. e. N. Lat. 44°30′ and W. Long. 57°15′ as given by the Dominion Obervatory, Ottawa. If 21 hr. 8 min. is taken as the time of arrival at St. Helena of the surface wave, its velocity is found to be 4.0 km. per second. This value agrees with the velocity of waves over Pacific paths as found by Neuman.[6]

Table 3 shows the arrival times of the P and S waves at various stations, and the respective distances to the epicentre. The data given are taken from various reports[7]. From the above data it should be possible to determine the average velocity for these waves at various distances from the epicentre. This will no doubt be published by others.

Cable Breaks.

The Atlantic cables off the Nova Scotia coast were severely damaged as a result of the earthquake. The cables were broken at the ends of the black lines shown in Fig. I. The numbers indicate the approximate depth of the water in fathoms. The positions are plotted from data obtained from the Western Union, Commercial and French Cable Companies. They extend from N. Lat. 39°29′ to 45°06′ and from W. Long. 52°10′ to 57°56′ and the area covered is approximately 60,000 square miles. In many cases the cables were found buried in mud and gravel. The ends appear as if the cable were sheared

6. Neuman, *F. Bull. Seis. Soc. Am.*, **19**, 63.
7. *Dominion Observatory, Ottawa, Seis. Report*, Nov. 1929.
Central Station Jesuit Seis. Ass. Special Bull., 1929.
Seis. Ber. Der. Wurtt. Erd. Hohenheim Und Ravensburg, 2 Halbjahr, 1929.

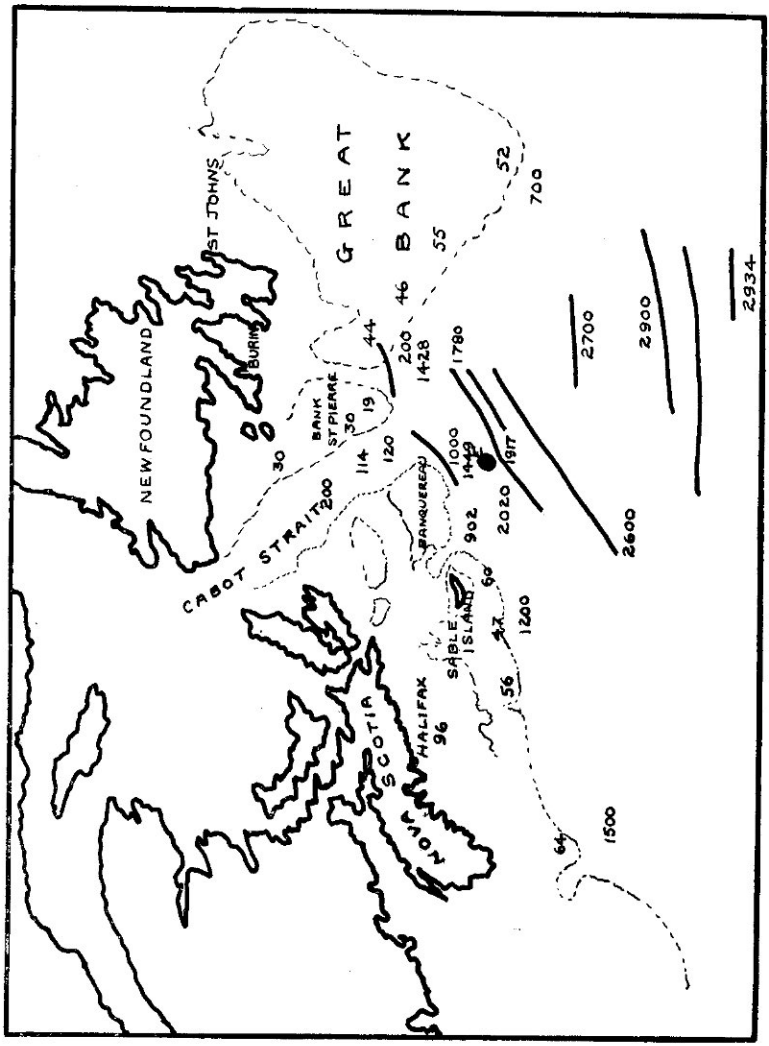
GREAT BANK
ST JOHNS
BURIN
NEWFOUNDLAND
BANK ST PIERRE
CABOT STRAIT
SABLE ISLAND
HALIFAX
NOVA SCOTIA
52
700
55
46
44
200
1428
1780
2700
2900
2934
30
19
30
114
120
200
1000
1449
1917
2020
2600
902
60
1200
56
64
1500
96

Fig. I.

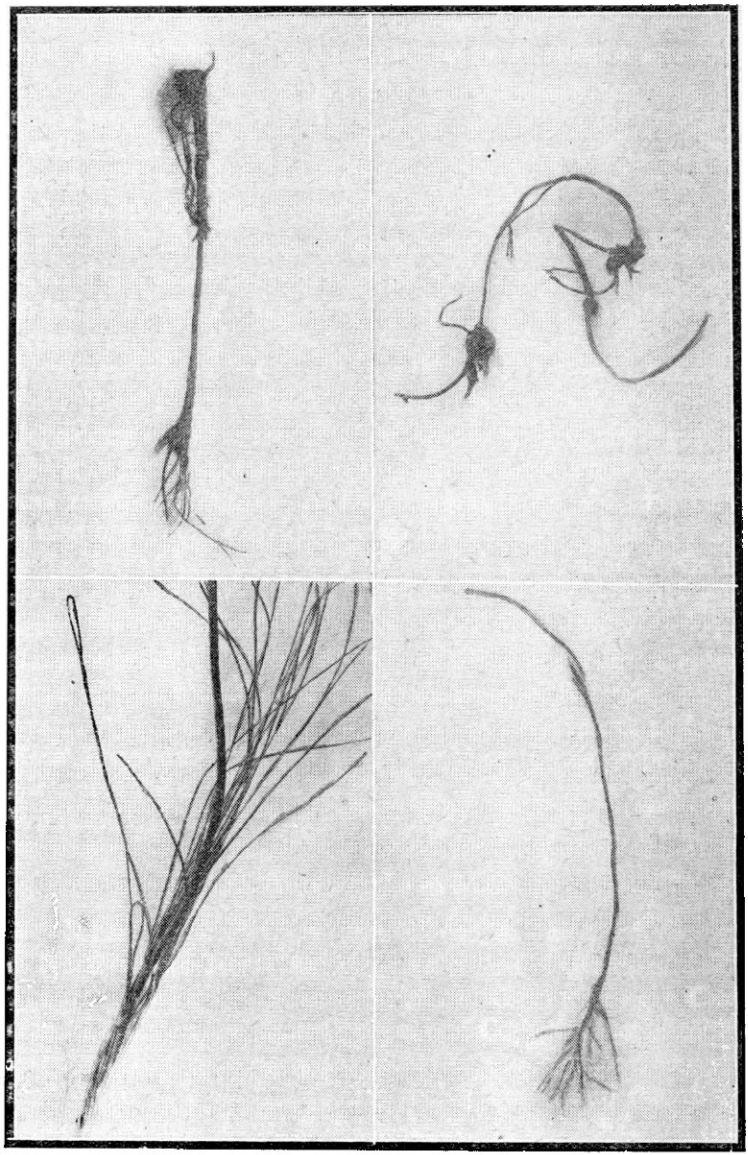

Fig. II.

off by a dull pair of heavy scissors, except at one place, where their appearance is very different. Photographs of these unusual breaks are shown in Fig. II. These ends were found by the Cable Ship Lord Kelvin[8] at N. Lat. 43°26′54″ and W. Long. 56°12′54″ in 1995 fathoms. At this location the cable was found broken up in short lengths and the core twisted around the sheath. The wires of the sheath were bent back on themselves two and three times, wound around the core and the latter twisted about the heavy galvanized steel wire sheath. To distort the cable in this manner would require the application of a very large force. I am assured that this could not be done by the grappling hook used to bring them to the surface. It seems, therefore, that this part of the ocean bed was subjected to very great vibratory and oscillatory forces, and as no other breaks show the above characteristics, it would appear that the epicentre was not far distant from the position given above, viz. N. Lat. 43°27′ and W. Long. 56°13′.

The Tidal Wave.

As is usual in the case of submarine earthquakes a water wave or Tsunami was generated by the sub-aqueous disturbance. Several studies of Tsunami have been published. Sezawa[9] in a theoretical paper shows that gravity waves are excited in deep water by seismic waves. In spite of the very small displacements of the compressional waves in the neighbourhood of the origin the waves excited in the water have relatively large amplitudes. The generated surface waves are chiefly the ordinary gravity waves, and their velocity is given by the expression $V = \sqrt{g \times h}$ where g is the acceleration due to gravity and h is the depth of the water. When the disturbance occurs at a moderate depth, however, the velocity of the surface wave is not constant, and therefore dispersion occurs.

8. The writer is much indebted to Capt. M. H. Bloomer, Cable ship Lord Kelvin, for drawing his attention to these cable ends and for permission to photograph and publish them.
9. Sezawa, *Bull. Earthquake Res. Institut. Tokyo Imp. Univ.* **6**, 19; **7**, 15.

Fig. III is a copy of the tide gauge record[10] obtained at Halifax for Nov. 17, 18 and 19, 1929. It is seen that the first wave reached Halifax at 7:30 p. m. A.S.T. (almost three hours after the time of origin of the earthquake) and the tide reached its maximum height (eight feet three inches) at 11:00 p. m. A.S.T. The average speed of the first water wave was therefore approximately 165 km. per hour or 46 meters per second, assuming the distance from the epicentre to Halifax to be 500 km. Using the formula $V = \sqrt{g \times h}$, and assuming no dispersion, the average depth of the water over which the wave passed is found to be 250 fathoms, which value is not out of reason.

Tidal oscillations continued until noon Nov. 19. These are very complex in character and a harmonic analyser should be used to determine the components. A cursory examination, however, shows superimposed on the fundamental tide oscillation components which have periods of 6, 15, 29 and 150 minutes respectively. Tide gauge records of Japanese Tsunami show similar peculiarities. According to Dawson[11] secondary undulations are present at Halifax at all times, and their amplitudes may be as great as 1.5 feet. In Jan. 1899 components appeared on the tide gauge records which had periods of 6, 12, 18 and 28 minutes. In 1863 the undulations had periods of 5 to 25 minutes. At St. John, N. B., the usual period is 40 minutes. It appears, therefore, that some of the periods of the secondary undulations of Nov. 18 and 19, 1929, are characteristic of Halifax Harbour. Yamaguti[12] mentions the period of the secondary undulations of the Bay of Tokyo as 222 minutes.

The tidal oscillations were very apparent to the Captain of the Dartmouth Ferry Boat in his usual trips across Halifax Harbour. At times during the morning of Nov. 19 the currents were so variable that great difficulty was experienced in docking the ferry boat.

It is unfortunate that there are no accurate data concerning the arrival time of the wave at points on the Nova Scotia

10. The author wishes to thank the Chief Hydrographer, Dept. of Marine and Fisheries, Ottawa, for the copy of this record so kindly supplied, and for permission to publish it.
11. Dawson, *Trans. Roy. Soc. of Can.* Seriei III. 1895, 25; 1899, 23.
12. Yamaguti, *S. Bull. Imp. Earthquake Inv. Comm.*, 9, No. 3, 95.

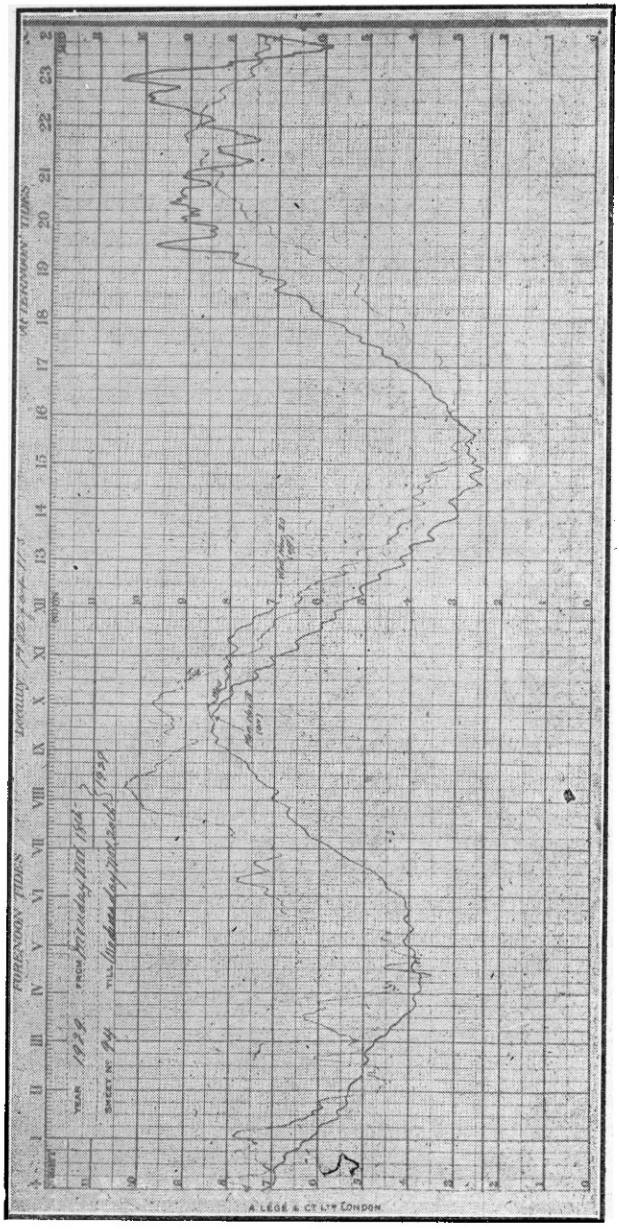

Fig. III

coast, except Halifax. The Captain of the Strait of Canso Ferry reports that the wave reached its top at Mulgrave at 9:30 p. m. A.S.T. The arrival time of the first undulation at the Newfoundland coast is known approximately. Mr. Howard Patten of Grand Bank, Nfld., informs the author that the wave arrived at Burin and Lamaline at nearly the same time, viz. 7:25 p. m. A.S.T. It reached St. Lawrence (between Lamaline and Burin) at 7:15 p. m. so that the telegraph operator at St. Lawrence was able to warn Burin before the telegraph office at the former place was washed away. This would indicate that the epicentre may be further to the east than is supposed. At Burin and at St. Lawrence the water at first receded until it seemed that the harbour was going dry and then the water returned to cause the great destruction of property and life in this vicinity. The first undulation reached Burin and Halifax at approximately the same time. If we assume the same average depth of water between the epicentre and Burin and Halifax it may be interred that the epicentre is approximately equidistant from these two places. The location 43°30′ N. Lat. and 56°15′ W. Long. approximately satisfies the above condition. The charts however show a greater depth of water between Burin and the epicentre than between Halifax and the epicentre; moreover, there is a deep channel between the banks in line with Burin and the epicentre. There is thus evidence that the origin of the wave was south and east of the tentative epicentre previously given.

The large amplitude of the wave at St. Lawrence and Burin (the tidal bore is reported to have been 40 ft. high) can be accounted for by the narrow deep channel through which the water passed, and the possibility that a reflected wave from the Cape Race side arrived along the Burin Peninsula in phase with the direct wave. The small amplitude of the wave along the Nova Scotian coastline is probably the result of the damping action of the comparatively shallow bottom. The Sable Island and Banquereau Banks probably protected the Nova Scotian coast. It is of interest to note that no tide oscillations were observed at Sable Island. It was well protected by the surrounding sand banks.

The destructive effects at Burin and vicinity are reported by Magistrate Hollett as follows: 26 lives were lost, 32 dwellings destroyed, 27 badly damaged and others slightly damaged; 34 fishing boats, 44 power dories and 100 small dories were sunk or destroyed. In addition practically all the fishing gear of the village of this neighbourhood was washed away. Property damage is estimated at approximately $1,000,000.

Position of Epicentre.

The fact that the arcs drawn with different seismograph stations as centres are found to intersect over a considerable area and that cables were broken at different places widely separated indicates that the epicentral area was quite large or that it extended along a line. The tentative position given by the Dominion Observatory, Ottawa, is N. Lat. 44°30′ and W Long. 57°15′ and is shown at E on Fig. I. The arrival times of the water wave at Halifax and at points on the Burin peninsula, Newfoundland, indicate the epicentral area to be somewhat south and east of the above position. The location at which the peculiar cable ends, were found, viz., N. Lat. 43°27′ and W. Long. 56°13′ supports this conclusion. A more careful examination of the "seismograph arcs" will no doubt throw more light on this point.*

In conclusion the writer wishes to thank the many persons who supplied much of the information discussed in this paper.

*Since this was written, F. A. Hodgson and W. W. Doxsee in a paper presented to the Eastern Section of the Seismological Society of America, state that seismograph data seem to point to a location near N. Lat. 44°.5′ and W. Long. 55°15′.