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Earthquake of April 28, 1913

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EARTHQUAKE OF APRIL 28, 1913.

BY OTTO KLOTZ, LL.D., F.R.A.S.

On the evening of Monday, April 28, 1913, at about 7.30 p.m. an earthquake shock was felt by probably most people in Ottawa. It was interpreted by most that felt it as an earthquake. While some were alarmed others were quite indifferent to the small disturbance. In some instances windows rattled as well as dishes on the supper table. As for the direction in which the movement took place the opinions differed nearly as widely as the points of the compass itself; similarly the duration was estimated from 3 to 20 seconds. As for sound accompanying the quake, the comparison was generally made as resembling that of a heavy waggon or dray drawn along the street, and the motion more or less undulating. No damage of any description, such as cracking of plaster, or loose brick falling from chimneys, was done.

As the papers of the following day brought despatches that the quake had been felt as far as 70 to 100 miles away, numerous printed forms for such an occasion were sent to postmasters to answer and return, with the object of determining the epicentral region. Fully 100 replies were received, and of those which said that it had been felt, there was considerable uniformity in them, particularly to the answer: What effect? The almost universal answer was, windows rattled. However, from Iroquois and Morrisburg, both situate on the north shore of the St. Lawrence, it was stated that chimneys had fallen. In consequence, the writer visited both places, and the following are the notes taken at the time:

May 9, 1913. Took train to Prescott, distant 52 miles on the St. Lawrence, at 7.30 a. m. and from there drove along the river road 15 miles through Johnstown and Cardinal to Iroquois, where I was for 1½ hours, returning to Prescott by train.

Shortly after leaving Prescott I noticed rock exposure, presumably limestone, in horizontal layers. The blacksmith at Johnstown I questioned. He felt the quake very distinctly, being outside at the time on the grass. He said he felt as if standing on boards that gave. His wife was in the house, and felt the floor shake and move, and stove-lids rattled. He said that there was no rock at the house, while a few hundred feet to the west it disappears.

A farmer———, lot 18, felt it very distinctly, he was milking at the time. No rock visible about this place. Before reaching Cardinal I passed a gully and a pit therein, where horizontal layers of limestone were exposed. Getting to Cardinal I accosted Mr.——— and wife (he is 66 years old), both felt it distinctly. She was in the country two miles back, and was lying on a couch when she was startled by the quake. He was outside of his house, and felt it very well, and as he said "I knew it was an earthquake for it reminded me of the great earthquake in Naples about 40 years ago." Where were you then?, I asked. "Right here or back on the farm," was the answer. Then you felt the Naples earthquake here, I remarked. Certainly, he said, to which I made no comment. He told me that the rock here was down about 50 ft., also that a few loose brick on chimneys in Cardinal fell to the ground.

In Iroquois. Saw postmaster first and he gave me some names of people where damage, or if not damage, at least where something had happened. Mr. ———, whose store has since been burned told me how one end of his show-case had been broken. In his show-case there was a loose glass shelf. When the shock came he was so alarmed that he ran out of doors; when he came back, he found that the glass shelf had moved and jarred sufficiently to hit the end of the case and break the glass. Then I went to the tin-shop of Mr. ———, where I found his son. On that Monday eve he was at home and felt the shock most distinctly and sharply, and immediately thought of the tin-shop, whither he then went. The watchmaker was at the time fixing the clock in the tin-shop which is full of stoves and tin-ware on shelves. The shock came, and a tin bath tub about 4 ft. long, hanging on a nail on the wall, fell on a stove, making a great racket, scaring the watchmaker badly, and he ran outside. But otherwise there was no displacement or falling of tin-ware. Young Mr.——— told me that he has several requests to remove brick that fell down and into chimneys by the quake. They were all loose brick. At the Central hotel a man told me he was sitting at the time of the quake where we then were, and he was looking out of the window on to the street. When the shock came he saw the corner of a ruin on the opposite side of the street fall off, and to the north and east, the corner being more or less loose stone and brick. Spoke with Mr.———, opposite the hotel. He had much to say. Apparently everybody in Iroquois felt the quake, and very markedly. Some women screamed. People rushed out of doors, some thought of the San Francisco catastrophe, and the report was spread that the town-hall had collapsed. A lady in his house, was at the time phoning to Ottawa to her sister, she dropped the phone and ran out. When she resumed her phoning, her sister told her she had heard and felt nothing at Ottawa. Some loose brick fell from his chimney too. Blind trooper—— considered the "bang" worse than any cannonading he had experienced in South Africa. A man was cutting some limbs from trees near which were a series of telegraph wires, and as an effect of the shock, he said, they (the wires) were "breathing" *i. e.*, swaying to and fro. Another man was fixing his wire clothes-lines, which were pretty taut, and they oscillated very markedly during the shock. The general impression is that the shock came from the north or northwest.

Prescott. Felt generally but not nearly so much as in Iroquois. Mr. —— of the Alexandra hotel said that he was in the back of the house and his impression was that the noise and motion were from an automobile, and he said to his wife "Perhaps we'll have to get supper for these people", as he thought the car was coming down the side street at the hotel.

At Iroquois, I was told that it was thought that the quake was more severe at Kemptville, so in passing through Kemptville on the way to Ottawa, I asked a number of people about the quake, but none found it severe, simply a quake, and not all people felt it. There was rattling of some windows; evidently far less intense than at Iroquois.

May 12, 1913. Left at 7.50 a. m. for Cornwall, 46 miles distant on the St. Lawrence. Just before reaching Cambridge I saw exposed horizontal layers of limestone.

At Cornwall. The clerk of the King George hotel neither heard nor felt the quake while walking on the street. He was accosted by a lady who felt it in the second story of the house, and was badly scared; others too told him of it. No damage of any kind done. Quake was stronger to the west.

Mr. —— of the "Standard" felt it, sitting reading in the story above the "Standard" office, first thought was of an auto, but there being *no* noise concluded it was an earthquake. The building is on quicksand as so many in Cornwall are (*e.g.*, English church which shows effects thereof by one wall out of vertical; Catholic church spent many thousands for pile-driving to secure good foundation). As far as the "Standard" could gather there was no damage, nothing fell down in the shops, only rattling of windows and in some cases of dishes was experienced. Mr. —— imagined the motion to come from the west. The motion he thinks was undulatory and continued for quite a time, perhaps as long as 30 seconds.

At Cornwall station. Met Mr. ——, merchant from Osnabruck, not far from Cornwall, who told me that the quake broke one of the mantles of the gasoline lights in his store. These mantles are very fragile and sometimes break in his store when there are many people in the ice-cream parlor above. Mr. ——, school inspector from Finch, said that the quake was felt there but otherwise nothing particular was noted.

Morrisburg. At 1 p.m. at the St. Lawrence Hall. Interviewed Mr. ——, storekeeper; he took me to his house to see the damaged chimney. The house stands on a side street running N.W.–S.E., and the house parallel thereto. There are two brick chimneys on the ridge running N.W.–S.E. The northerly one was damaged. The northerly side of the three-layer crown of the chimney, the brick being loose judged by those remaining, was thrown down, the brick falling on the roof and rolling down. The most fell towards the western side. He was in his garden at the time and the ground seemed to move, but he is not sure. The quake startled him as an explosion and he thought of an explosion of a gas-buoy, of which he had some knowledge or experience some years ago. With the crash the chimney brick fell. Everybody in town heard and felt the quake; he thinks the shock came from the west or southwest.

Interviewed the harness-maker, Mr. ——, whose chimney also was said to have been damaged. However, learned from him that that was done weeks ago by an ice and sleet storm that blew down a tree which hit the chimney in its fall.

Miss ——, of the "Leader", compared the quake with an explosion which made windows and dishes rattle. Similarly as at the storekeeper's, some brick fell from another chimney, the house being northwest from the other damaged one above, and on the road to the station.

Mr. ——, of the St. Lawrence Hall, was sitting in his hotel, when the shock came. To him it seemed as an explosion in the cellar, but the furnace was out and there was nothing to explode. He said he had experienced quakes in California, Arizona and Mexico, but this one resembled none of them, as there were no "premonitory tremors" as he named them. He showed me the chimney at the east end of the hotel, pointing out a small opening or crack in the crown, about 3 bricks deep, which was not there before the quake. The brick of the crown appeared to be loose. As to the direction of the quake his mind was quite blank. His clerk was washing himself at the moment of the quake, preparatory to going fishing. But he was so startled that his fishing trip was abandoned. Some thought that a car of dynamite had exploded on the Grand Trunk railway track, about half a mile to the north.

This ended my Morrisburg evidence, showing that of the many places from which I have reports, the quake was most severely felt at Iroquois and Morrisburg.

In my data collected at Iroquois last Friday, I forgot, I think, to mention that the phone operator there, after the quake was over, phoned to the station Wales, 22 miles to the west on the railway, "Did you feel the earthquake?" The reply was "No," so Iroquois said, "Well, look out, it's coming!"

The area with which we have to deal, lying north and south of the St. Lawrence, comprises formations almost wholly of the Cambro-Silurian period, and in which the Calciferous and Trenton predominate, as shown on R. W. Ell's sheet No. 120 of the Geological Survey of Canada. The only fault lines shown are in the vicinity of Ottawa, and from the evidence obtained do not appear to play any part in the above quake. The total thickness of the formations from the Lorraine to the Potsdam sandstone is estimated at from 1,600 to 2,000 ft., of which about one third is occupied by the Trenton.

The area in which the earthquake was felt covers about 25,000 square miles, and is roughly an elongated figure running northwest–southeast, fully 200 miles long and its greatest width about 150 miles.

In the following is given a condensed statement of the answers received to the printed forms alluded to above:

Station.	Duration.	No. of shocks.	Nature of Shock.	Effect.	Sound.	Ground.
1 Archer	10 secs.	....	Wave motion.	Windows and dishes rattled.	Rumbling	No rock.
2 Arnprior	3 "	1	Wave motion.	Windows rattled	Rumbling noise.	No rock.
3 Aultsville	50 "	1	Wave motion	Windows rattled, rolling wave.	Rumbling noise from E.	Hilly.
4 Avonmore	15 "	1	Heavy rumble.	Windows and dishes rattled.	Rumbling sound	Clay & sand, no rock.
5 Berwick	12–14 "	....	Jerk	Windows rattled, bottles on shelf shook.	Like truck on plank platf'm	Clay.
6 Brockville	30 "	1	Motion	Windows rattle	Like auto passing.	Rock.
7 Burritt Rapids	Several, say 20, secs.	1	Wave motion	Windows rattled	W to E	Clay, no rock.
8 Canton, N.Y.	10–20 secs.	1 max. 2 min.	Horiz. rolling	Windows rattle	Very little, not explosive.	Gneiss.
9 Cardinal	10 secs.	1	Wave motion.	Windows rattle	Rumbling, heavy waggon on frozen ground	Sandy.
10 Carleton Place	2 or 3 secs.	1	Slight tremor	Dishes rattle slightly	Slight dull so'nd	Soil, little rock.

Station.	Duration.	No. of Shocks.	Nature of Shock.	Effect.	Sound.	Ground.
11 Charleville		1	Wave motion	Dishes shook, lamp rattled, ran out of house, could feel ground tremble, hear rumble for several minutes.	Roaring noise, like thunder, dies away to S.	Deep soil.
12 Chelsea	5 secs.	1		Nothing noticed	Rumbling noise, auto.	Clay.
13 Cornwall	15 "	1	Wave motion	Windows rattled	Terrible, loud, rumbl'g noise	Sandy soil.
14 Dundee, Que		1	Wave motion	Windows rattled	No sound	Flat, no rock.
15 Elizabethtown, N.Y.				Shaking		
16 Elma	Few "	1		Rattling things in store	Like thunder	
17 Embrun	2–3 "	1	Wave motion	It came like a strong wind.		No rock.
18 Glen Smail	60 "	1	Wave motion	Rattled some goods in store.	Rumbling noise.	Clay, no rock
19 Gouverneur, N.Y.	10 "			Windows rattle		
20 Groveton	30 "		Rocking	Tinware and stove rattled.	Heavy roaring noise.	Rolling gr'nd.
21 Harkness, N.Y.	1–2 "	1	Wave motion	Windows rattled but not general.	Like distant thunder.	Soil, rock 14 feet down
22 Hawkesbury	60 "	2	Wave motion	Chandelier rocked	Slight rumbling noise.	Gravel.
23 Hoasic	15 "	1 & 2 (slight)	Jerky, up and down.	Windows did not rattle, but stove-lids did, milk-can vibrates violently.	Like thunder before and after shock.	Clay, no rock
24 Howick	12–15 "	1	(?)	Windows rattle, more noticeably in stone or brick building.	Some noise.	Clay.
25 Huntingdon				Felt only by some people.		
26 Hyndman	5 mins.	1	Wave motion	Windows rattled and everything shook.	Like thunder	Soil, no rock.
27 Iroquois	15 & 5 s.	2	Jerky, jarring	Parts of chimneys fell, loose brick.	Noise like thunder.	Clay, rock 15 feet down
28 Johnstown	10 secs.	1		Dishes rattled	Sound heard	No rock.
29 Keeseville, N.Y.				Direction varies to all parts of compass.	Some thought of heavy wagon passing.	
30 Kemptville	5 secs.	1	Wave or rocking.	Windows rattle	Low sound like thunder, h'rd shock 2 secs. before shock felt.	Gravelly, no rock.
31 Lanark	4–5 "	4	Jerky	Four movements of bed in a S.W. and N.E. position.		House partly on rock.
32 Lancaster	11 "	1	Wave	Glass in boxes rattled.	Roll, like cog wheels.	Clay, no rock
33 Lansdowne	15 "		Wave motion	Door trembled which I was painting.	Steady rumble, like train.	Heavy clay.
34 Lyn			Wave motion	Windows rattled	Slight	Rock.
35 Manotick	20 "	1	Wave motion	Windows rattle	Rumbling noise.	Gravelly, no rock.
36 Massena	15 "	1	Jerk	Windows rattled	Rumbling sound	No rock.

Station.	Duration.	No. of Shocks.	Nature of Shock.	Effect.	Sound.	Ground.
37 Martintown........	15 secs.	1	Jerky..........	Windows rattled......	Like rolling furniture, West to East.	No rock.
38 Maxville..........	15–20 "	1	Wave motion..	Windows rattle.......	Rumbling......	Sandy, no rock.
39 Merrickville.......	2–3 "	1	Vibration......	Slight rattling........	Slight rumbling.	Rock exposure.
40 Monkland Station..	18 "	1	Wave motion..	Windows rattled on N. side of house.	Like train of cars from NW. to S.E.	Gravelly soil
41 Montreal..........	4–5 "	1	Wave motion..	Just before quake dog in garden made unusual noise, suggesting fear.	None noticed...	Clay.
42 Morrisburg........	10 "	disputed.	Tremors.......	Two chimneys have loose brick fall.	Rumbling (explosion).	No rock.
43 Munroe Mills......	12–15 "	1	Wave motion..	Windows rattled.	Rumbling noise.	Loam, no rock
44 Napierville........	3 "	1	Jerk..........	....	....	No rock.
45 North Augusta.....	8 "	1	Wave motion..	Windows rattled......	Rumbling noise.	Sandy loam and rock.
46 North Gower......	30 "	1	Wave motion..	Table moved back and forth.	Rumbling like waggon.	Clay, no rock
47 Ogdensburg, N.Y...	10 "	....	....	Windows rattle, house shaken. Billiard balls roll in all directions.	....	....
48 Ottawa...........	10 "	1	Wave, smooth..	Some heard windows rattle.	No distinct.....	Clay, rock 10 feet.
49 Ormstown.........	3–5 "	1	Wave motion...	Shaking of house and crockery.	Rumbling, increasing to loud.	Heavy clay, no rock.
50 Osnabruck Centre..	15 "	1	Wave motion...	Slow rumbling noise..	....	No rock.
51 Pembroke.........	10 "	1	Wave motion...	Window and shutter rattled.	No noise.......	Sandy loam.
52 Potsdam, N.Y......	15 "	....	....	Shaking buildings.....	Rumbling......	....
53 Plattsburg, N.Y....	5 "	....	Wave motion...	Shaking, windows rattle.	Deep rumble...	Till 10-20 ft. on Trenton.
54 Prescott...........	10 "	1	Wave motion...	No windows rattle....	Rumbling noise.	No rock.
55 Quyon............	6 "	1	Jerk..........	Everything rattled....	No............	Clay & limestone.
56 Renfrew..........	1 min.	1	....	....	Rumbling sound	Clay.
57 Rigaud...........	10-15 sec.	1	Wave.........	Thought it a railway train.	No sound......	Stony, blue clay.
58 Roebuck..........	30 secs.	....	....	Shed jarred, pails rattled.	After..........	Sand, no rock
59 Saranac Lake, N.Y.	4 "	2	Undulating.....	Rattled dishes, more noticed on hill than below.	Thunder, heavy waggons.	....
60 Shanly...........	....	2, 1 small	....	Shook shop, windows rattle and loose brick fall from chimney.	Yes, light......	Gravelly, clay
61 Spencerville........	15 secs.	1	Wave motion..	Windows rattle.......	Like thunder rolling before the shock.	Gravelly some rock
62 Ste. Agathe des Monts.	10 "	1	Rocking.......	Everything rattled....	No noise.......	Rocky.

Station.	Duration.	No. of Shocks.	Nature of Shock.	Effect.	Sound.	Ground.
63 Smiths Falls.......	6 secs.	1	Wave motion..	Windows rattled, coils creaked in brackets.	Noise increased and rock died out from S. to N.	....
64 Stittville..........	8 "	1	Short jerks....	Windows rattled, table moved.	Rumbling.....	Sandy, no rock.
65 Strathmore.......	Very short.	1	Wave motion..	Whole house shook...	Heavy clap of thunder.	Clay loam.
66 Waddington, N.Y...	30 secs.	2 small, distinct.	Jerk..........	Dishes fell, lamps put out.	Rumbling noise	....

Places addressed, and from which the reply was, that the earthquake was not felt.

Actonvale,
Arthabaska,
Batiscan,
Berthier en haut,
Brighton,
Chesterville,
Cobourg,
Drummondville,
Duhamel,
Farnham,
Gracefield,
Hemmingford,
Kamouraska,
Kazabazua,
Kilmarnock,
Kingston,
Labelle,
L'Islet,
Laprairie,
Levis,
Longueuil,
Lotbinière,
Louisville,
Maniwaki,
Murray Bay,
Oshawa,
Peterborough,
Plessisville,
Portneuf,
Sharbot Lake,
Sorel,
St. Apollinaire,
St. Valier,
Three Rivers,
Trenton,
Wakefield.

It will be observed that in New York state the quake was felt in the archaean region, the Adirondacks, as well as to the west and east thereof. We have no data from the heart of the Adirondacks, and possibly the disturbance that was noted on their edge may have been communicated from the Silurian formations that hold this archaean island in their grasp. Another point to be noted is that although the quake was felt in Montreal, overlying the Trenton formation, yet across the St. Lawrence at Longueuil and Laprairie which are over the next higher formation, the Utica, the quake was not felt.

Passing westward from Brockville along the St. Lawrence we reach Kingston, 50 miles distant, and in the narrow archaean (Laurentian) belt that crosses the

St. Lawrence to New York state to expand into the Adirondacks, there was apparently no disturbance. At Kingston the quake was not felt. The most westerly point on the St. Lawrence where the quake was felt, as far as could be determined by correspondence, was Lansdowne, 20 miles from Brockville.

Again, going northward from Ottawa along the Gatineau river we soon enter the archaean of gneiss and granite with a few outcrops of crystalline limestone, and find that at Wakefield only 22 miles distant nothing was felt, while at Pembroke 100 miles to the westward, on the edge of the Cambro-Silurian it was felt, although the epicentral area lay to the southward of Ottawa as will be referred to later.

From these observations one is led to conclude that the hypocentre, or hearth, or origin of the earthquake was not in the archaean formation.

It was stated that the archaean region to the north of Ottawa was practically unaffected by the earthquake. There seems to be, however, a notable exception, which appears as an anomaly, being the case of Ste. Agathe, 65 miles northwest of Montreal. I found on the return of the printed forms that the postmaster of the place had crossed out the time 7.30 p.m., which I had written in for the approximate time of the quake, and in its stead was written 7.45 p.m., railroad time, which is of course standard time. It scarcely seems possible that the railroad clock, even in the backwoods, should be out 15 minutes. That the first quake should set off another, 15 minutes later in this archaean region borders on impossibility. Considering then that the clock was in error, one asks why the earthquake should have been felt at Ste. Agathe and not in the neighborhood? Examining a geological map we find that Ste. Agathe lies about centrally in an island of intrusive igneous rocks of anorthosite of Laurentian age. With this bald statement of the case we have to leave it, as no explanation offers itself to interpret the phenomenon of Ste. Agathe.

In the latter part of the table are given many stations to which the printed forms had been sent and from which a negative reply was received. The reason that stations rather far afield or distant were communicated with was to ascertain whether the quake had anything to do with the great St. Lawrence or Champlain fault, extending from Lake Champlain to Levis and then down the bed of the St. Lawrence into the Gulf, and which played so prominent a part in the greatest of Canadian earthquakes in 1663, and described in my official annual report of 1909. As is seen from the replies there was no disturbance felt along this fault line.

The instrumental record. There are only three seismograph stations from which records were probable,—in their order of distance from the epicentral area, Ottawa, Albany and Boston (Harvard). Ottawa and Harvard got records, while at Albany there was no record as the instrument was dismounted for removal to another location. At Harvard, there are two Bosch-Omori horizontal pendulums with mechanical registration. At Ottawa, there are two Bosch horizontal pendulums with photographic registration and a vertical seismograph of Spindler and Hoyer with mechanical registration, smoked paper. The horizontal pendulums at each station are mounted in the N-S, and E-W directions respectively. Below is the record of these two stations, the times given being transcribed into eastern standard time which is 5 hours slow on Greenwich time, in which latter time earthquake stations otherwise always express their times, for ready comparison with international stations.

Ottawa.						Harvard.		
Component.	Phase.	Time.	Period.	Amplitude.	Δ	Time.	Period.	Δ
		h. m. s.	s.	μ	km.	h. m. s.	s.	km.
V	*P*	7 29 07·2	·3	3	...	...	...	...
E	*P*	29 08·7	1·5	1	60	7 30 02	·8	435
N	*P*	29 09·5	1·0	1		30 03	·7	
E	*S*	29 14·8	3·0	6		30 50	...	...
V	*S*	29 15·0	2·0	20	...	...	...	...
N	*S*	29 15·2	...	13		30 53	·5	...
V	*M*	29 16·6	3·5	30	...	...	...	...
N	*F*	30 00	...	...	...	33 34	...	...
E	*F*	30 00	...	...	...	33 34	...	...
V	*F*	31 15	...	...	...	...	...	...

Explanatory to the symbols in the above which are those of the International Seismological Association we find for the Ottawa record, in the first column—component—which refers to the pendulum, vertical, N-S, and E-W. Under—phase—we understand particular characteristics of an earthquake record. The first wave to arrive from the hypocentre is a longitudinal wave, a wave of compression or dilatation, similar to a sound wave, and is designated by *P* (primus). This is generally of very short period, a second or less. The next different waves to arrive are the transverse or distortional ones, propagated like the waves of light and designated by *S* (secundus). These are of a longer period than the preceding ones. Both the longitudinal and transverse waves are propagated as spherical, or nearly so, waves through the earth, while the last waves to arrive are the surface or long waves, designated by L, and the greatest deflection or amplitude occurring with the long waves is designated by M; F signifies the end. These long waves, however, for near-by earthquakes are merged in the S waves. The third column—time—is self explanatory, being the time of arrival of the different waves as read on the seismogram. It may be stated that 15 mm. (about $\frac{3}{5}$ of an inch) are equivalent to one minute or 60 seconds on our records; the fourth column gives the amplitude or half range in microns, one thousandth millimetre, of the actual movement of the earth particle; while in the last or fifth column is given under Δ the distance in kilometres, of the epicentre from the seismograph station. It may be noted that the distance from Ottawa to Boston (Harvard) is in round numbers very nearly 500 km., while the sum of the distances from Ottawa and Harvard to the epicentre as seen from the above record is 495 km., which is strong evidence that the epicentre lies not only between these two stations, but also near the line joining the two places, as will be pointed out to be the case from other evidence.

Instrumentally the severity of an earthquake is not measured simply by the displacement or amplitude produced, but, this combined with the period; in short, it is dependent upon the maximum acceleration produced. Two earthquakes might produce the same amplitude, *i.e.*, the range (double the amplitude) of the motion of the earth particles might be the same, yet if their periods were not the same, the intensity or destructiveness of the earthquakes would be different.

In an earthquake we have the impulse converted into elastic vibrations in the medium through which the rays are propagated. The elementary expression for acceleration for the harmonic motion of the earth particle with which we have to deal is $\frac{v^2}{A}$ in which v is the velocity and $= \frac{2\pi A}{T}$; A is the amplitude of the earth particle, and T its period. Hence the acceleration becomes $\frac{4\pi^2 A}{T^2}$. As π^2 is very nearly equal to 10, the acceleration may be written as $\frac{40A}{T^2}$.

The amplitude A is however not read directly from the seismogram, for the amplitude that the record gives is dependent upon the free or undamped period of the horizontal pendulum, the period of the earth particle, as well as upon the degree of damping that obtains for the pendulum. The records of undamped pendulums are practically useless for the determination of acceleration on account of their continued own swing when once set in motion, and this motion may be much aggravated if their natural period falls near that of the earth particle. Before then, we can find A we must know the necessary constants of the instrument, which are the undamped period of the pendulum and the damping ratio. It may be mentioned that one of our horizontal pendulums has air damping, the other magnetic damping, effected by having a thin aluminum vane at the end of the pendulum moving between the poles of a heavy wolfram-steel horse-shoe magnet, while the vertical seismograph has air damping also. All seismographs have a theoretical magnification of the motion imparted to them, and Professor Wiechert in his investigation of the theory of the seismograph has deduced a formula for the actual magnification dependent upon the theoretical magnification, the free period of the pendulum, the period of the earth particle, and the damping ratio. This formula we have plotted for various ratios of the two periods, and various values of the damping ratio, so that from the resulting curves the actual magnification can readily be taken. It may be observed that a damping ratio of about 5 to 1 deviates but little from the theoretical magnification when the ratio of the above two periods does not exceed unity. When the damping is little, or the ratio small, say 1·5 to 1 or 2 to 1 then the magnification is much increased over the theoretical up to the ratio of the two periods of 1 to 1. The accompanying diagram will illustrate this clearly. For the first sharp impulse of an earthquake, the *P* waves, we may apply the theoretical magnification, but not so later when the period of the pendulum comes into play.

Reverting now to the Ottawa record, we find that the greatest acceleration was produced by the first or *P* waves where the period was ·3 seconds, and the amplitude 3 microns or 3 one-thousandths of a millimetre. Hence the acceleration is 1,333 microns per second per second, or 135 milligals. The term milligal is used in seismology, and as it is of comparatively recent introduction, a word of explanation may not be out of place. The unit of force is called the dyne, being the force which, acting upon a gramme for a second, generates a velocity of a centimetre a second; and the unit of acceleration, called a gal, is the acceleration of a body whose velocity increases in every second by a centimetre per second. Hence gravity, or *g*, is expressed approximately by 981 gals or 32 ft. per second per second. A milligal is the thousandth of a gal or roughly the one millionth of gravity, or is the acceleration of 10 microns per second per second. We may therefore write our approximate formula for acceleration as $\frac{4A}{T^2}$, which will thus express the acceleration in milligals.

The acceleration we have obtained above for the vertical component of 135 milligals is one-seven hundred and thirtieth that of gravity, undoubtedly a small quantity. This means, that a person weighing for instance 200 lbs. would momentarily—at the moment of the shock—weigh five ounces less, for by that much the force of gravity was reduced on the mass. This was the acceleration at Ottawa; at the epicentre it was considerably greater, for which the evidence is only direct observation and experience, and not instrumental. It may be noted that we are dealing with pretty small measurements on our seismogram both as regards A and T, particularly so with T in determining the period of a fractional part of a second of time, so that a small change in either, particularly in T, as the acceleration varies inversely as the square of T, would easily double the acceleration.

There is an empirical scale of earthquake intensity, the Forel-Mercalli scale, which numbers from I to XII, the first indicating an earthquake only instrumentally noticeable, while XII expresses the most awful catastrophe. On this scale the earthquake at Ottawa would be indicated by II, and in the neighborhood of Iroquois and Morrisburg between IV and V.

If the interior of the earth were homogeneous or isotropic, we might with confidence look to the instrumental record of two horizontal pendulums mounted at right angles to each other for obtaining the direction of the ray; and when to this is added the record of a vertical instrument, the ambiguity of direction of 180° is removed. We certainly know that the upper crust of the earth is not homogeneous, say to a depth of about 2 km., so that one has reason for having grave doubts whether the path of the ray lies wholly in the plane passing through the observing station, hypocentre, and centre of the earth.

It must be admitted that Prince Galitzin has been successful in many cases in obtaining satisfactory results for direction from instruments of his own design, although this does not gainsay the geophysical disabilities under which other stations may be placed. A marked case may be noted in support of the last statement. In the south German quake of Nov. 16, 1911, the epicentre was located with a fair degree of accuracy, so that the relative movements in the N-S and E-W components for any recording station could be pretty well foretold. Now Professor Schmidt in his report, referred to again hereafter, tells us that at Hohenheim and Biberach, where for the first place a strong N-S movement was expected, and for the second place a strong E-W movement, the seismograms showed just the reverse to be the case. My own experience with different distant quakes in interpreting direction has not been very satisfactory. If we take for instance the west coast of South America where earthquakes are frequent, and which is almost due south of Ottawa, we would expect the E-W component to be very small indeed compared with the N-S component. Although the ratio is not reversed as at Hohenheim and Biberach, yet it is not in the theoretical ratio. We may repeat what was said about obtaining A in determining the acceleration, applies also here for getting the values for the N-S and E-W components in order to deduce the resultant direction from the parallelogram of forces. Although we speak very glibly of the period of the earth particle which enters into our determination of the actual magnification that we must apply to our seismogram measurement, it is not always an easy matter to see or measure or properly interpret it on the record. Any uncertainty in it, is reflected in the direction or azimuth of the epicentre.

When a quake records the first impulse by a very sharp offset, which is not always the case, then there is less uncertainty about magnification. When the recorded amplitudes are small fractions of a millimetre and our recording line, made either by a stylus on smoked paper or by a spot of light on sensitive paper, is a tenth of a millimetre, to which we may add a certain uncertainty of our base or zero line from which we measure, it is obvious that uncertainties of many degrees in azimuth may arise thereby.

From our record of the quake of 28 April, it will be seen from the data above given that the first impulse gave a deflection of 1 micron for both horizontal components, the N-S one to the south, and the other to the east, indicating that the ray came either from S. 45° E. or N. 45° W. The direction of the amplitude of the vertical seismograph showed that the wave was one of compression, and therefore the direction of the ray must have been from the S.E. which agrees with the record of distances for Ottawa and Boston. Had it been from the N.W. the Harvard distance would have to be increased by about 120 km., a quantity quite inadmissible for the Harvard time record. The direction Ottawa-Harvard is S. 48° E., and the direction from Ottawa to the approximate position of the epicentre, that is, in the neighborhood of Iroquois and Morrisburg is roughly S. 30° E. In any event, all the evidence, three independent methods, point to the epicentre as lying southeast of Ottawa.

To answer the question not only of where was the earthquake, but also of how deep down was the hypocentre or hearth?, we are plunged into a sea of trouble. To answer this question with any degree of assurance would require numerous satisfactory instrumental records in or about the epicentral region, where we have only one. Even then our answer would lie between pretty wide limits as shown by the earthquake in southern Germany on Nov. 16, 1911. That quake was considerably more severe than ours of April 28, and in an area more densely populated than we have here; besides there were records of many seismographs at stations within the disturbed region, yet the geographical co-ordinates given for the epicentre by the investigators Lais and Sieberg are given with a probable error of 15 to 20 km. (say 9 to 12 miles), while the co-ordinates for the same quake by Professor A. Von Schmidt differ from the above by a minute in latitude and 13 minutes in longitude or 10 miles.

One of the first things one thinks of in considering the location of an epicentre is to enquire whether and where there is a line of weakness—a geological fault—in the area; for evidently the adjustment of equilibrium, brought about by the quake, of the stresses took place along the line or lines of least resistance. Examining Ell's geological map, above referred to, failed to show any fault line anywhere near where the quake was felt the most, hence we may conclude that there is possibly a hidden fault. Between Iroquois and Morrisburg, 6½ miles apart, there is a line of contact between the Calciferous and Chazy shales, and again about two miles north of Morrisburg we enter upon the Chazy limestone formation. As far as the formations are concerned the whole area under discussion is but a very shallow trough in the archaean, and there may have been horizontal displacement in the formations causing the quake, without any superficial fault line.

From the evidence obtained over the 25,000 square miles that were shaken, one concludes that the epicentre was in the neighborhood of Iroquois and Morrisburg, probably nearer the former place, and consequently the hypocentre or actual fracture some distance beneath there. From the data obtained by corespondence it was quite impossible to draw a series of isoseists or lines of equal intensity, which should be more or less concentric and thereby indicate the epicentre. More reliable are the homoseists, or lines along which the times of arrival of P and S waves are respectively equal. These lines can only be laid down by instrumental records, but there are none except of Ottawa.

The fact that local conditions, as to the nature of the ground, may affect the effect of a quake in its apparent intensity has not been overlooked. It does not necessarily follow that where the most damage was done is an indication of the epicentre.

Attempts to determine the depth of the hypocentre of an earthquake were first made by Mallet in 1862 for the Neapolitan quake in 1857, and based on ocular observations of the direction of cracks in buildings from which the direction of the impulse was deduced. This of course was found to be unsatisfactory. Later in 1873, Seebach attempted to find the depth from the times of arrival at different places of the impulse, and Dutton from the intensity. Seebach assumed the impulses to proceed in straight lines and ignored curvature of the earth, both leading to erroneous results, aggravated by an earthquake which affected very large areas. We must recollect that up to this time there were practically no instrumental records of earthquakes at all, and the rate of propagation of earthquake waves almost unknown. Although the determination of the depth of the hypocentre is still unsolved, yet theoretical considerations have been developed that point towards a solution. One of the difficulties is the measurement of some of the quantities in the theoretical formulae, among which may be mentioned the angle of emergence of the ray or direction of impulse. From the hypocentre, spherical waves are supposed to issue.

From the increasing density and elasticity as we penetrate the earth, it follows that these spherical waves must be eccentric, the centres shifting from the hypocentre towards the earth's centre. As the ray is always perpendicular to the wave front, its path will be a curved line concave to the surface of the earth. The angle which the ray makes with the surface of the earth is called the angle of emergence. The ray from the hypocentre to the epicentre will be the first to reach the surface, and for other places the time of arrival will be a function, but not a direct linear function, of the distance from the epicentre. From the times of arrival of say the first wave at different places we obtain the apparent velocity of that wave on the surface of the earth, not its velocity from the hypocentre through the earth. This rate of propagation upon the surface of the earth is always greater than the propagation of the waves within the earth. A little consideration will show that this apparent velocity at the epicentre must be infinity. As the distance from the hypocentre to the epicentre differs but minutely from that of near-by rays, the times of arrival of waves along such rays and the one to the epicentre are almost simultaneous and hence the apparent surface velocity approaches infinity, but soon decreases until it reaches a minimum at the point where the ray issuing from the hypocentre at right angles to the diameter of the earth passing through the hypocentre, emerges at the surface. The area comprised within the circle having the epicentre as centre, and radius equal to the distance from the epicentre to the above emergent ray is called the epicentral area. Beyond this area the apparent velocity of the spreading wave slowly increases. The velocity curve, rather incorrectly called hodograph, has a point of inflection corresponding to the minimum velocity, and is tangent at the point representing the epicentre.

Reverting to the earthquake of Nov. 16, 1911, in southern Germany which serves our purpose for discussing the question of depth, Professor Schmidt determines from the instrumental records the distance from the epicentre to the line of minimum velocity. This is found at 460 km.

We have the fundamental expression for a ray $\frac{v}{r \sin i}$ = a constant, where v is the velocity at any point of its path, r its radius vector reckoned from the centre of the earth, and i the angle made by the radius vector with the ray at that point. The angle of emergence α at the surface of the earth is the complement of i there. A simple geometrical relation shows that the ratio of the surface velocity at the point of emergence is to the velocity of the emergent ray as 1 to $\sin i$. $\operatorname{Sin} i$ becomes a maximum, when i is 90°, that is at the hypocentre. At the surface r becomes R, radius of the earth, and at the hypocentre r becomes $R-h$, where h is the depth of the hypocentre. If v_o is the velocity of the wave at the hypocentre, where $i = 90°$, c_o the surface velocity at the point of emergence of the ray we have the relation $c_o = v_o R : (R-h)$ for a sphere, and $c_o = v_o$ for a plane surface, also $h = e \sqrt{(c_o - v_1) : (c_o + v_1)}$ where e is the radius of the epicentral area and v_1 the velocity along the path of the ray at the point of emergence.

We have thus a simple expression for finding the depth of the hypocentre treated as a mathematical point. On the right-hand side of the equation we have three quantities whose numerical values must be known before we can find h. We can obtain a fair approximation to the value of e when we have numerous instrumental records and by comparing them find where the surface velocity reaches its minimum, As already stated Schmidt found for that quake $e = 460$ km. Similarly the value of c_o is deduced from the records and found to be 7.1 km. per second; but for v_1 there is a difficulty in obtaining a satisfactory value. If the angle of emergence could be observed, then v_1 would readily follow, but so far this has not been accomplished. The velocity that is sought is that in the upper layer of the earth's crust. Schmidt has recourse to the record of an earthquake at Aachen in 1911, reported by Professor Haussmann, and which for good reasons is supposed to have been very shallow, that is, its hearth had but little depth, so that the velocities found for comparatively near places to the epicentre would give a pretty fair value of the velocity of propagation in the outer crust of the earth. This value he finds to lie between 5 and 6 km. per second. Substituting for e 460 km., and for c_o 7·1 km., we find for h when we take v_1 as 5·5 km., $h = 164$ km.; and for v_1 as 6·0 km., $h =$ 133 km., as given by Schmidt. This on the face of it appears as a pretty good depth, the greater of the two being just over a hundred miles. It is only within comparatively recent years that we have learned anything definitely about the interior of the earth, and that there has been some mathematical and observational basis to deal with the interior of the earth. The independent investigations of Helmert and Hayford in quite another field, have brought to light the isostatic layer at a depth of about 120 km., and the new science of seismology is daily penetrating deeper and deeper into the mysteries of the earth's interior. We have not yet got accustomed to depths beneath the surface of the earth, as we are with heights and distances above. If in the above formula we write $v_1 = \cos c_0$, it reduces to $h = e \tan \frac{\alpha}{2}$, where α is the angle of emergence.

For the purpose of bringing to the attention the depths of earthquake hypocentres, the following are taken from a recent valuable paper by Professor Pilgrim:

South German	quake	16 Nov.	1911	110 km.
Calabrian	"	23 Oct.	1907	170 "
Indian	"	4 April	1905	50 "
Mexican	"	14 April	1907	140 "
Guatemalan	"	19 April	1902	170 "
Calabrian	"	8 Sept.	1905	140 "
Colombian	"	31 Jan.	1906	170 "
San Francisco	"	18 April	1906	140 "
Agram	"	8 Oct.	1909	75 "
Cephalonian	"	24 Jan.	1912	90 "

Looking over the figures one is struck by the fact that they are of the order of the depth above given for the isostatic layer, or layer of compensation.

Rudzki's formula for the determination of the depth of the hypocentre given in his work " Physik der Erde " (1911), $l = \frac{2R \sin \frac{1}{2}\gamma \sin \epsilon}{\cos(\frac{1}{2}\gamma - \epsilon)}$, in which $\sin \epsilon = \frac{2 \sin \frac{1}{2}\gamma}{\gamma} - \cos \frac{1}{2}\gamma$ is inapplicable, as it is based on untenable assumptions. The values found by this formula are far too small. In the above l stands for depth, R for radius of the earth, γ for radius of epicentral area, expressed in arc, and ϵ an auxiliary angle.

As this is the first local earthquake that has given occasion to report thereon somewhat fully, it was thought desirable to digress somewhat, as has been done above, in order to introduce some elementary and fundamental considerations that enter into seismological investigations at present.

Reverting now to our quake of April 28 and the question of hypocentre and its depth beneath the surface ; we have no instrumental nor other data to give us a definite answer to the question. However we may volunteer a conclusion from the evidence gathered, and that is, that the hypocentre is not in the archaean, for had it been we would have expected the quake to have been felt in places over the archaean, like Kingston, Wakefield and the Gatineau valley, which are closer to the epicentre, of the position of which we are fairly confident, than numerous other places, where the quake was felt and that are considerably more distant, notably Pembroke. This conclusion would then restrict us to a depth not exceeding 2,000 ft., less than half a mile. The effect of the quake being wide spread, and yet not a very marked difference shown in the effect over a large area, seems to point to a disturbance not emanating from a centre, nor from a vertical fault line, but rather suggests the horizontal movement of a block or layer with accompanying rupture. This latter must have been very minute, otherwise the instrumental amplitude would have been greater. To recapitulate then, the most we can say is that the epicentre is in the neighborhood of Iroquois and Morrisburg and the hypocentre at a depth not exceeding 2,000 ft. The quake had no connection with the Great Champlain fault line of the St. Lawrence.

Some remarks may be made upon the replies given to the printed forms sent out. There are six places, Saranac, Iroquois, Hawkesbury, Hoasic, Shanly and Canton, that report two distinct shocks following each other closely. These would represent the arrival of the longitudinal and transverse waves or the maximum, which would almost be merged in the preceding waves. Saranac estimates the time interval between the two shocks as between 12 or 15 seconds, which agrees very well with the theoretical value. The Iroquois estimate points to its proximity to the epicentre. The evidence from Hoasic that the motion felt was "jerky, seemingly up and down" is significant, showing that it was near the epicentre, a conclusion in harmony with other evidence. In Saranac the quake was felt more on the hill than in the lower parts of the village, an experience just the reverse of what happened generally in the south German quake. The question is essentially one of the nature of the ground on which buildings are erected; if on rock, the effect is slight, if on alluvium it is apt to be great. The effect in an upper story is obviously greater than in the lower story of the same house, as was found to have been the case here. One correspondent adds to his report from Montreal, "Just before the earthquake, our dog which was just outside in the garden, made some unusual noise suggesting fear." It is a common belief in earthquake countries, which we must take with reserve however, that many animals and living creatures, show signs of the coming quake in various ways, and in advance of the event, ranging from minutes to many hours. Amongst these animals, dogs and cats play a prominent part. Cattle and even snakes seem to be hyper-sensitive. After the south German quake spoken of, reports of such premonitory signs from animals were received. Some of the premonitions were long enough in advance that people could have migrated to foreign parts.

Light phenomena in the form of fire-balls, light streaks and flames, have been observed, in connection with earthquakes but not with ours, so that there appears to be really a causal connection, and the coincidence not fortuitous. So far no satisfactory explanation has as yet been offered for their appearance. The release of gases from the earth has been suggested, electric ignition through friction, however nothing has been proven.

Sound was heard at most places where our earthquake was felt, but not at the most distant place, Pembroke, 100 miles. Sound is produced by waves of condensation and rarefaction in the air. The lower limit of audibility requires at least 30 vibrations per second. These vibrations in case of earthquakes must come from the elastic vibrations in the rocky medium of the earth along the ray of the impulse. As the rate of propagation in air is very much less than in rock there will be refraction at the surface, with the result that the direction of the sound waves will be nearly vertical, as pointed out by Professor Knott. Areas overlain with a thick bed of alluvium will naturally be less affected by the phenomenon of sound than those with rock close to the surface, on account of absorption in the former case. This absorption takes place too in deep-seated quakes by the viscosity of the rocky material, so that a wide-spread quake of small intensity, as obtained with the quake of April 28, combined with the fact that it was accompanied by sound would again point to a hypocentre of no great depth, a conclusion we had already arrived at for other reasons. In general, the description of the sound was low-rumbling, the rolling of distant thunder, or of a heavy vehicle, indicating vibrations of low frequency. Evidence of sound of an explosive character was only obtained at Iroquois and Morrisburg, which as stated above are near the epicentre, and consequently suffer less by absorption of the original energy.

Although we know that audible sound requires a frequency of the air-waves of at least 30 per second, yet such frequency or period we can not measure on the seismogram as the period of the earth particles which create the vibrations in the air, remembering that a millimetre on the seismogram represents four seconds. It is desired to point out that the explanation of the phenomenon of sound in connection with earthquakes is inferred, but is not deduced from or correlated with actual instrumental or seismograph records. Sounds emanating from the earth have been noted in different parts of the world, not only in connection with earthquakes, but otherwise also, and the phenomenon goes under different names in different countries, such as Mistpoeffers in the Netherlands; Guns of Barisal in India; Rombo, Marina and Balza in Italy; Bramido in Mexico, and so on. Their complete explanation has not yet been found.

Beneficial effects of earthquakes are seldom noted so that the case cited by Professor Schmidt of the quake of Nov. 16, 1911, may well be given. On the preceding day a farmer was using 6 horses for plowing to a depth of 20 to 22 inches, and had to rest his horses every 40 or 50 yards. However on the following day he found that 4 horses could easily do the same work and with fewer intervals of rest. This fact the farmer attributed to the loosening of the heavy ground by the quake, and the explanation seems plausible.

In conclusion let me say that the earthquake of April 28 last was a very minute manifestation of the pent up energy of the earth, although to us, small crawlers on the surface, it aroused fear and trembling in some quarters. The earth is always under strain and from various causes. Some of these causes are periodic like the daily squeezing, and to the very core, that the earth undergoes by the attraction of the moon in its path around the earth. Again, in the upper crust we have a bulge following the daily heating by the sun. The cooling of the earth, which we assume but cannot prove as existing at the present time, produces strains of a cumulative nature; so does the action of the elements, (rain, snow, water, wind, frost), ceaselessly wearing down here, building up there; ever changing the distribution of matter upon the surface of the earth; lessening the pressure in one place, increasing it at another; mountains rising, sea-bottoms sinking, minutely but continuously day by day, year by year, until at times the strain becomes greater than the rocky crust can resist, and then this big 8,000-mile sphere gives a little jerk, perhaps only of an inch, to have its coat fit more snugly, when suddenly the crawlers shout,—an earthquake—, while the earth is scarcely conscious that she did anything.

In our part of Canada, in fact over the greater part of Canada we need have no fear of any disastrous earthquake, we are too near the primeval rock, we have too few formations beneath us in which the compression and adjustment take place. The weak line of the surface of the earth in eastern Canada, an old wound that is not perfectly healed, and that would be the first to open afresh, if strains were to become excessive, is the Great Champlain fault running down the bed of the St. Lawrence from Levis to the Gulf, and already referred to.

We may rest in peace, we are not in a seismic area.

The accompanying map, being a small section of the standard map of Canada on a scale of 35 miles to an inch, 1:2,217,600, shows the area within which the earthquake was felt, and is indicated approximately by a red dotted line. Not all the small places given in the table of the text are shown on the map. Along the northwestern edge of Vermont the quake is said to have been felt too.

The following is the Forel-Mercalli scale for estimating the intensity of an earthquake, referred to in the text, to which is added Cancani's equivalent in absolute measure taken from Sieberg's "Erdbebenkunde."—

Intensity.	Effect.	Maximum acceleration in mm. per second per second.
I	Only instrumentally noticeable	Less than 2·5
II	Very light, but felt	2·5 to 5·0
III	Light	5 to 10
IV	Moderately felt	10 " 25
V	Fairly strong	25 " 50
VI	Strong	50 " 100
VII	Very strong	100 " 250
VIII	Destructive	250 " 500
IX	Disastrous	500 " 1,000
X	Very disastrous	1,000 " 2,500
XI	Catastrophe	2,500 " 5,000
XII	Awful catastrophe	5,000 " 10,000

NOTE.—To convert the last column to milligals, we simply multiply by 100.

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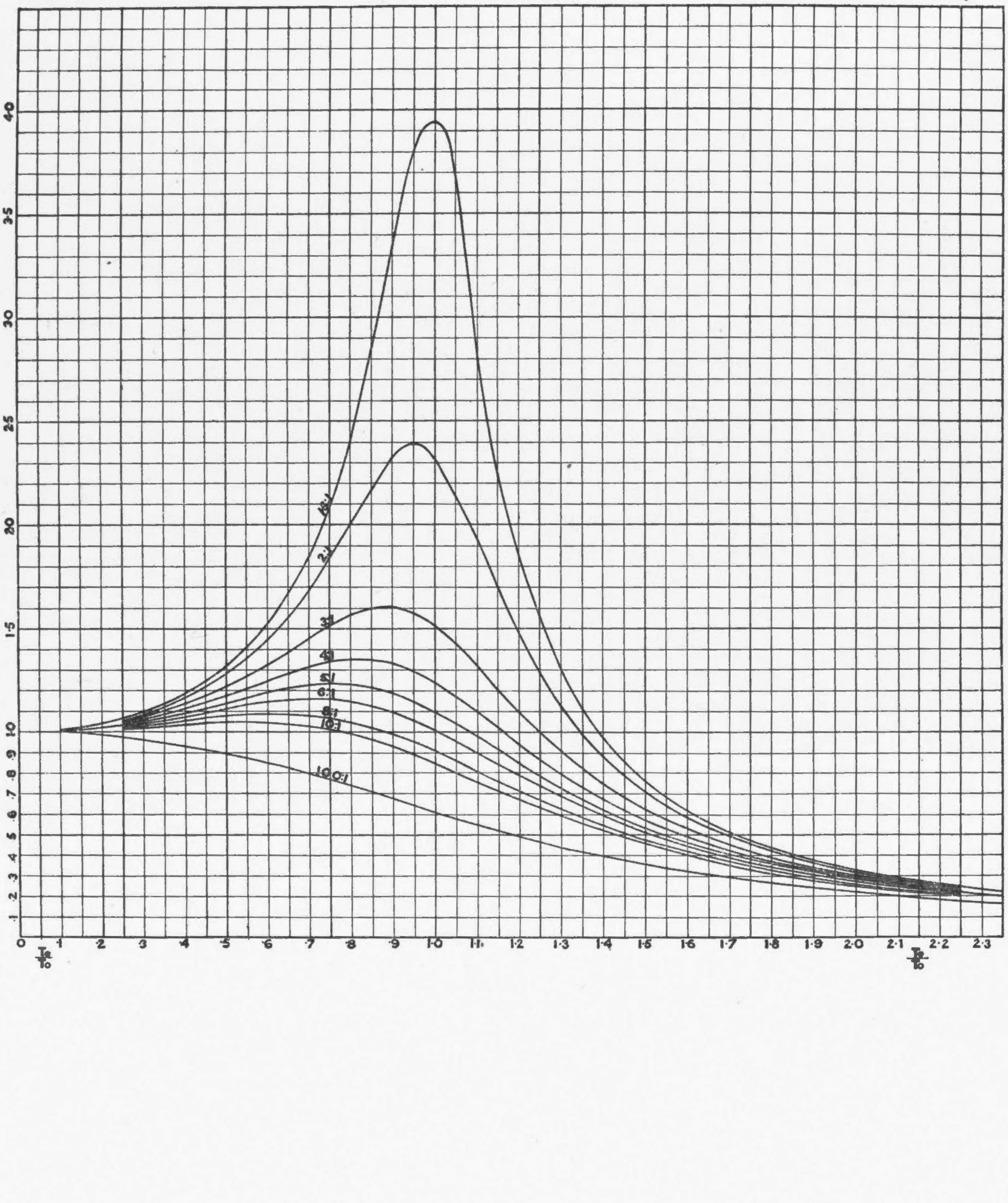
DOMINION OBSERVATORY,
June 17, 1913.

MAGNIFICATION CURVES



Scale, 35 Miles to an Inch