

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

NO. V.—THE GLASGOW EARTHQUAKE OF 14TH DECEMBER, 1910.
Presidential Address. By J. W. GREGORY, D.Sc., F.R.S.,
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[Delivered on 12th January, 1911.]

THE Midland Valley of Scotland has been formed and its chief geographical features determined by an intricate network of faults. Faults separate the Midland Valley from the Highlands to the north and the Southern Uplands to the south; upraised fault-blocks form some of the most conspicuous features in the scenery, such as the Campsie Fells and the Fintry Hills; and coalfields preserved in basins due to down-faults have been the main factor in the economic development of the country. These faults doubtless extend to a great depth beneath the surface; for not only are the Carboniferous rocks immediately beneath Glasgow intensely faulted, but it may be inferred from the older rocks at their nearest outcrops that the Glasgow district had been much faulted even earlier than Carboniferous and Devonian times. The geological principle is now well established that later movements in the earth's crust tend to follow the lines of older movements. Hence we might reasonably expect that faulting is still in progress in the Glasgow district; and several geographical features indicate that some fault movements are of comparatively recent date. It is not surprising that small earthquakes are frequent along

the Highland Boundary Fault, which separates the Midland Valley from the Southern Highlands, and the interesting catalogue of earthquakes ranging from 1570 to 1889, published by Dr. David Murray in the *Glasgow Herald* of 20th December, 1910, shows that noticeable earthquakes in this district are not uncommon. The earthquake of 14th December appears, however, to have been the most severe in living memory.

Earthquakes in big cities cannot be safely ignored. The study of an earthquake, which in a Highland district may be only of academic interest, is of practical importance in a city underlain by a plexus of water pipes, sewers, gas pipes, and electric mains. For an earthquake shock may start leaks causing costly waste and serious injury to public health.

The many correspondents who have so kindly sent me a statement of their observations have therefore done useful service by contributing a collection of personally recorded facts which serve to show the origin and path of the recent earthquake. Their letters will be preserved in the University library, so as to be available for detailed comparison with future earthquakes.

The recent earthquake was one of a world-wide series, which began on the morning of the 14th December, 1910, with a powerful earthquake along the eastern coast of Africa at 11.40 a.m. Greenwich mean time. It was followed by such severe shocks elsewhere that, according to the *Times* of 19th December, Dr. J. J. Shaw, of West Bromwich, described the week including the 14th December as "the most disturbed week he ever knew." Dr. J. Milne has recorded in *Nature* a succession of large earthquakes, including those on 14th December in East Africa, on 16th December in New Guinea, on 17th December in the West Indies, on the 18th one at 4 a.m. in Java and one at 5.49 a.m. in the West Indies. Each of these shook half the world. Others followed in the new year, culminating on 4th January in the disastrous earthquake around Tashkend, in Central Asia.

The Glasgow earthquake probably had no direct connection with the others, but they may all have had a common cause. It was claimed by Perrey that earthquakes are especially numerous near the times of full and new moon when the tidal strain on the earth's crust is at its greatest. The evidence

quoted in support of this view has been shown by Professor Knott to be unconvincing; but it has been reaffirmed in 1906 from the Greek seismic observatory,* and, as the first group of the recent series happened near full moon, and the second group near new moon, they add to the list of such approximate coincidences.

The local series began on the evening of 14th December with a very faint shock at Ayr between 6.45 and 7 o'clock. Evidence of this earthquake has been kindly reported to me by Dr. Morton [84].† At 8.54 p.m. the Glasgow district was shaken by a sharp shock, which was followed by some fainter earthquakes, of which two were recorded on the Paisley seismograph at 9.26 and 9.29 p.m. They were barely perceptible in Glasgow, though felt by a few people. Secondary shocks were noticeable at Rosneath and Kilcreggan; at Cathcart at 9.10 p.m.; at Swinton, Easterhouse, near Coatbridge, at 9.46 p.m.

The main shock occurred at 8.54, and it was most powerful in the north-western suburbs of Glasgow, and was felt by various observers to distances of about 10 miles from its centre.

It is unfortunate that there was no seismograph in the district that would give information about earthquakes of local origin. The Coats Observatory at Paisley has a Milne horizontal-pendulum seismograph, the instrument which has done so much to advance modern seismology. It was designed to record and interpret the tremors transmitted from far distant earthquakes, but it gives little information about shocks of local origin. The Paisley Observatory also has a Ewing seismometer, which interprets the movements of local earthquakes, but this instrument was not in action at the time.

The recent earthquake can be best tracked to its centre of origin by use of the Rossi-Forel scale of earthquake intensity, which is the scale most useful for the study of slight and

* "Étude des Séismes survenus en Grèce pendant les années, 1900-1903." By D. Eginitis. "Annales de l'Observatoire National d'Athènes," 1906, vol. iv., pp. 135-145. *Fide* an abstract by Mr. Belinfante in Trans. Inst. Min. Eng., vol. xxxii, 1908, p. 582.

† The thick Nos. in brackets refer to the list of letters in Appendix II.

moderate shocks. Earthquakes are divided by this scale into ten grades—from No. 1, the slightest, to No. 10, the most severe. The classification is based on such simple observations and experiences as are not likely to vary much with the imagination of the observer, and can be collected after the earthquake. The different divisions are not sharply defined and they are of unequal value; and the characters have to be used with discretion, or an earthquake may be unduly promoted owing to the peculiar elasticity of jerry-built houses. Care is especially necessary in a mining district, where buildings may stand above abandoned coal pits, and the collapse of old workings may exaggerate the earthquake effects. Thus in three localities near Glasgow a house was so badly shaken that the inmates left in alarm, a character that would indicate an earthquake of intensity No. 6. Yet in one of these cases people in an adjacent house did not even notice the earthquake. Again, the shock was very feeble at Cathcart, yet the worst cracking of the plaster in ceilings was caused in a house there by the slight secondary shock at 9.10 p.m. Such exceptional cases may be explained by local weakness in the foundations.

For the scientific comparison of earthquakes numerical estimates are most important, but I have not obtained any reliable data as to the velocity or size of the earthquake waves. I have therefore added to the table of the Rossi-Forel scale Professor Holden's estimates of the intensities as determined by the accelerative effect, for these numbers afford some measure of the relative intensities of the different degrees on the scale.

The recent earthquake appears to have attained the rank of about $5\frac{1}{2}$ or between "moderate" and "fairly strong" in the area most affected. It was therefore milder than the earthquake at Colchester in April, 1884, which must have reached the degree of 8.5, and of those at Inverness in September, 1901, and at Pembroke on 18th August, 1892, both of which, according to Dr. Davison, reached grade No. 8. Nevertheless, thanks to the improvements in the sensitiveness of seismographs, our earthquake appears to have beaten the British record in one respect, for, according to Dr. Milne, it was recognised at a greater distance than any other earth-

quake of British origin. Dr. Milne has kindly informed me that the earthquake was recorded in his observatory at Shide, in the Isle of Wight, and also by seismographs at Guildford. The movement of 9.26 was also felt at Shide, Bidston (Liverpool), and Stonyhurst. The movements were all very slight, and in a letter received this morning he says, "It was a great surprise to me to find that your earthquake had travelled as far as the Isle of Wight. The first British earthquake ever recorded took place in the year 10, when the castle at Edinburgh was shaken. Your last one has beaten all others for distance. Scotland for ever."

THE ROSSI-FOREL SCALE.

Grade of Intensity.	Characteristics.	Description.	Corresponding acceleration according to Prof. E. S. Holden.
1.	Recorded by delicate seismographs	Imperceptible.	per sec. 20 mm.
2.	{ Recorded by all seismographs; felt by occasional people at rest - }	Extremely feeble.	40 "
3.	{ Felt by several people at rest; direction and duration appreciable }	Very feeble.	60 "
4.	{ Felt by people in motion; movable objects disturbed; ceilings cracked - - - }	Feeble.	80 "
5.	{ Felt by everybody; furniture disturbed; light bells rung - - }	Moderate.	110 "
6.	{ Most sleepers awakened; most bells rung; trees visibly shaken; some people leave their houses - - }	Fairly strong.	150 "
7.	{ Objects overthrown; church bells rung; general panic - - - }	Strong.	300 "
8.	{ Chimneys overthrown; walls of buildings cracked. - - - }	Very strong.	500 "
9.	Some buildings destroyed - - -	Violent.	1200 "
10.	Complete devastation - - -	Catastrophic.	—

From the epicentre the shock diminished quickly in strength to Nos. 4 and 3, dying away as a barely imperceptible shock of grade No. 2 at Bowling or perhaps Dumbarton [1] in the west and Glenboig in the east. The area over which the earthquake had an intensity of No. 2 and upwards was therefore about 20 miles from west to east and 15 from north to south,

and, allowing for the irregularity of its margin, it affected about 300 square miles. Some occasional records may be expected outside the area included in the above estimate. Thus the earthquake was appreciably felt in the Rosneath peninsula [2], which is crossed by the Highland Boundary Fault from Rosneath to Kilcreggan; and the account of the shock there, which has been sent me by Miss H. Story, would indicate an earthquake with an intensity above No. 2. Its recognition there was probably due to the imperceptible earth wave breaking against the Highland Boundary Fault, and thus causing a secondary local vibration.

The distribution and varying strength of the earthquake are shown on map (Fig. 1), based on the information received in the correspondence catalogued in Appendix No. 11. and from that published in the Glasgow newspapers.

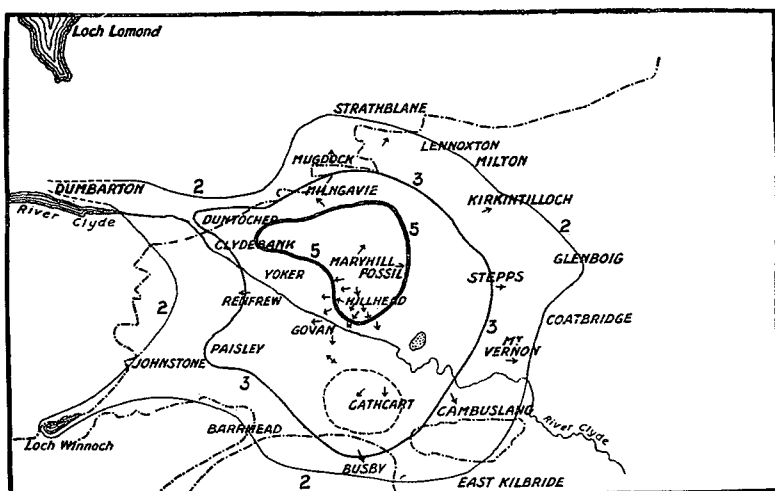


FIG. 1.—Lines of Equal Intensity (Isoseists). Nos. 2-5 are the degrees on the Rossi-Foré Scale. The dotted line around Cathcart shows the area of the earthquake at 9.10 p.m. Scale—1 inch = about 8 miles.

In the north-western suburbs of Glasgow the shock was felt by most people except those who were busily engaged. It woke up a few sleepers; it rung some bells in Hillhead; it occasionally disturbed furniture; it overthrew some dishes and pottery that were in insecure positions; and it widened or made

a few cracks in plaster. But as there are no reports of several of the characters of intensity No. 6, it seems not to have reached that degree in the Rossi-Forel scale.

The earthquake decreased to the intensity of No. 4 in Milngavie, around Glasgow Bridge, and in Govan; to intensity No. 3 at north Milngavie, to the north of Clydebank, at Renfrew, Partick, west Govan, Pollokshields, Cathcart, Rutherglen, Stepps, and west of Kirkintilloch; to intensity No. 2 at Mugdock, south Lennoxton, Milton of Campsie, Glenboig, Lenzie, Mount Vernon, Cambuslang, Barrhead, and Lochwinnoch. It was apparently a little less than 2 at Dumbarton and East Kilbride; and it was not felt, as far as the records go, at Killearn, Kilsyth, Airdrie, Coatbridge, or Greenock.

As it travelled outward from its epicentre the effect changed. In the central area the shock emerged very steeply from below the ground. It was felt as a short, sharp vibration, and the sounds heard were compared to a rumbling, an explosion, or the fall of a heavy body on the floor overhead. It lasted for from less than one to about two seconds. A little further from the centre a double shock was felt; the two parts, however, followed one another almost immediately. The first of the two was due to the normal wave of compression caused by the direct forward thrust of the earthquake; the second was the transverse or torsional wave, which always travels more slowly than the other, and therefore soon lags behind. Further from the centre the whole wave became much longer, and the horizontal effect became more marked than the vertical, and the shock lasted for several seconds, the estimates varying from five to ten. In the outer zones down to No. 3 a horizontal thrust was sometimes felt before an uplift. Thus Miss Tina Smith, who was in bed at Stepps, described her bed as having been first pushed eastward, brought backward, and then jerked upward [No. 80 received through Mr. Fleck]; this description would accurately represent the probable nature of the movement at that locality. The increase of the horizontal component was shown by the fact that occasionally clocks stopped in the outer zones affected, as at Lennoxton and in south-eastern Glasgow.

The gradual outward fading of the shock enables the position of the epicentre to be determined approximately. A more

definite localisation requires more detailed consideration of the evidence from different localities. The first reports showed that the movement at Hillhead was along a north and south line, and it was recognised as having had the same trend at Mugdock and Lennoxtown. But to determine whether the wave travelled from the north or the south is more difficult.

It is often inferred that an object displaced by an earthquake would be inclined or fall away from the earthquake centre. A person on a chair who feels himself pushed westward usually concludes that the movement came from the east; but it would probably have come from the west, for as the floor is jerked eastward the inertia of the weight on the chair would cause it to incline or fall westward. Hence any heavy body in firm contact with the ground, and with its centre of gravity well raised above its base, would usually incline towards the direction from which the shock came. Light objects, however, which may be jerked upward from the ground, would be thrown away from the epicentre. Further, a body so placed that when shaken it swings to and fro, may fall in either direction. Pictures on a wall parallel to the path of the advancing earthquake wave might be tilted, while those on a wall at right angles to the direction would swing outward from the wall, and might fall back to exactly their original position.

The sounds that accompany an earthquake are also used to track it to its source; but in a large city this evidence seems to me less reliable. It is notoriously difficult to determine the direction of sound, and it may be impossible to distinguish the sound due to the passage of the wave through the earth from that made by the structures shaken. Hence the same earthquake may sound like thunder to a man near an iron shed; like the wind to a man beside a forest; or like a rumble to an observer who hears the actual vibration of the ground. The apparent direction of a sound may be misleading, unless allowance be made for the relative velocities of the earthquake and the sound which it has produced. The velocity of sound in Glasgow at 9 p.m. on the 14th December would have been about 1100 feet per second. An observer at the northern end of a room would hear the windows there rattled before those at the southern end if an earthquake coming from the south

were travelling at a greater velocity than 1100 feet a second. He would probably conclude that the earthquake was travelling from north to south; but the southern end of the room would have been shaken first, although the shaking of the northern windows first reached his ears. A map showing the homacoustic lines, illustrating the distribution of the different sounds, is given as Fig. 2.

Bearing these considerations in mind, the evidence available indicates that the earthquake was travelling in the directions of the arrows marked on the map (Fig. 1). Thus, for example, at Woodlands Terrace a statue was seen to incline northward, showing that its base was pushed southward [51]. One of the University janitors—Scott—saw a stink cupboard on a southern wall in the Mining Department jerked northward. Miss Hannan Watson has collected various items of evidence, including the overthrow of bottles and the oscillation of liquids in them, all pointing to a southward movement in Hillhead. A light ornament was thrown from a mantelpiece on a north and south wall in the residence attached to the Anatomy Department of the University, and fell to the south or south-south-east. Our member, Mr. W. A. Buchanan [41], saw a picture on the north-north-east wall of a room in 18 Bute Gardens swing outward from the wall, and he remarks that the shock was "quite alarming," and that "I am perfectly certain it came from the north."

Miss Macbeth tells me [40] that in the room in which she was sitting the northern wall was first shaken, and the wave distinctly passed from north to south.

The southward course of the wave in the centre of the city is shown by several records. Thus Mr. W. R. Smellie reports the fall northward of "some short, squat ornaments not more than 2 or 3 inches high, and standing on four legs," at Messrs. Dykes Bros.' shop in Royal Exchange Square. They all fell in the one direction, and such objects would probably fall towards the direction from which the shock came. An observer in Gordon Street is reported in the *Glasgow Herald* of the 15th December to have heard a rumbling, then felt a shock, and heard the noise pass southward across the Central Station. My own experience also pointed clearly to a movement from

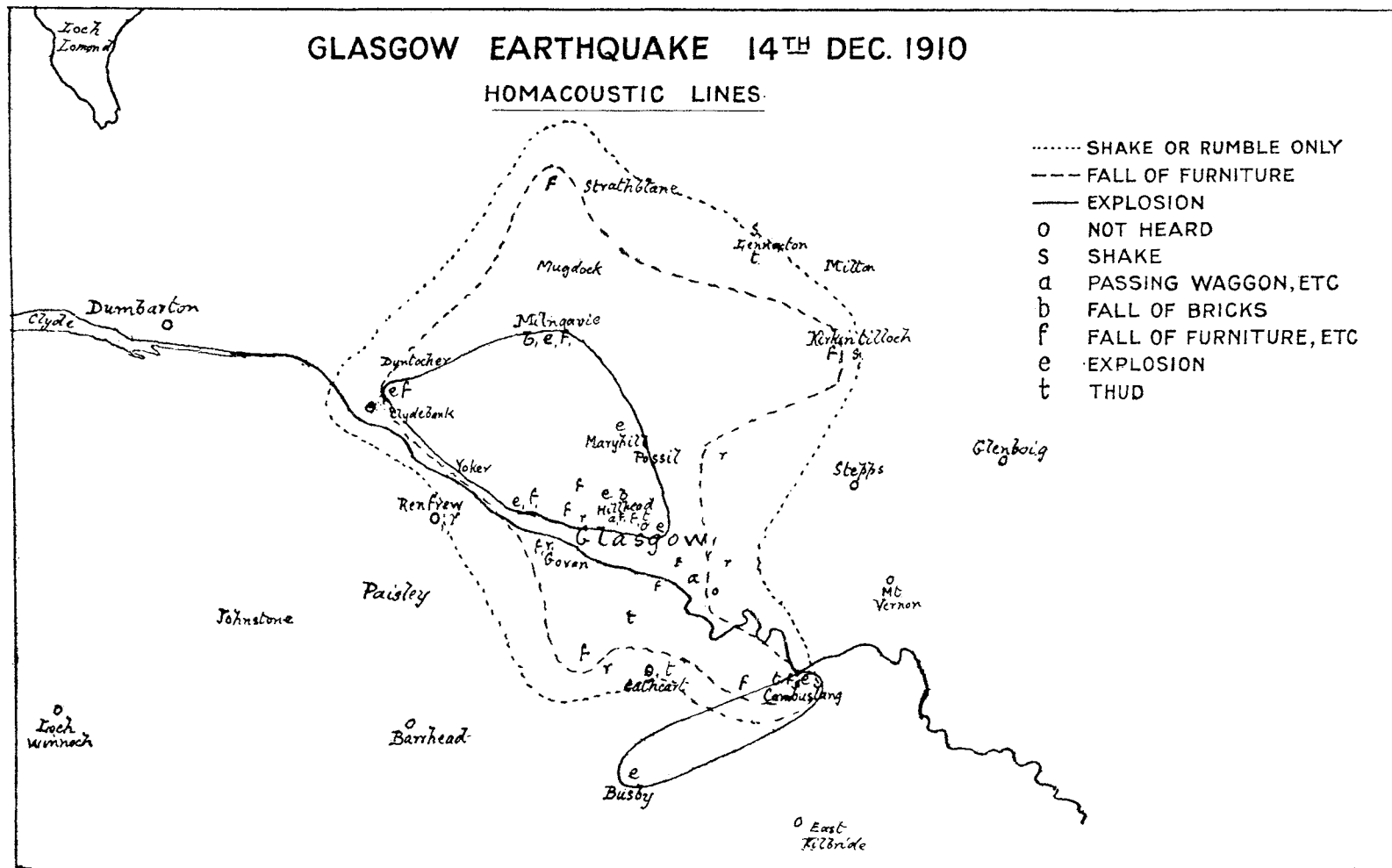


Fig. 2.

Scale, 1 inch = 4 miles.

north to south at West End Park. I happened to be standing facing east examining some maps on a long table running north and south, and the sensation was that of a sharp jerk upward of the northern end of the room, and its slower fall as the wave passed on, rattling the kitchen pans on the southern wall of the house. The shock lasted less than two seconds, and was so sharp that I feared it might have overthrown a wardrobe standing against the northern wall of my daughter's room, and so, after looking at the time, I rushed there to see that nothing had fallen. The door in a long north-and-south wall, which I had closed only a few minutes before, had been jerked open. Out of ten pictures on a north-and-south wall six were tilted with a slope downward to the south, indicating again a jerk upward from the north.

That the earthquake arose to the north of Glasgow rather than in central Glasgow is also indicated by the fact that it was less severe around the three main railway stations and along Argyle Street than in the northern suburbs. At the Technical College it was noticed by Mr. Boyle, who said it felt as if something had fallen on the roof. Mr. J. W. Reoch, on the other hand, tells me that, although he was "doing microscopic work there at the time, and should therefore have felt any special vibration under the then existing conditions of absolute quiet, when any unusual disturbance that might occur would hardly have passed unnoticed, yet neither I nor any one in my neighbourhood in the class-room observed anything, either of a shock or of a noise." Miss Hughes, who was in the Chemical Laboratory of the same college, also felt nothing, and was accordingly surprised to see some chloroform in a bottle begin to sway to and fro, while fluids of average specific gravity were much less affected. The intensity at the Technical College was therefore scarcely above No. 2. Moreover, the earthquake was unnoticed in several streets near the Trongate and in Bridgeton. Thus, according to the *Glasgow Herald* of 15th December, it was not felt in Marlborough Street or Stevenson Street, near Bridgeton Cross; it was noticed as a faint tremor by some of the men in the Eastern Police Office, and they attributed it to a passing traction engine. A correspondent, who was at the time in a house in Gallowgate,

opposite Kent Street, heard a noise like the fall of furniture in the room below; but he found, on inquiry of his neighbours in the adjacent parts of London Street, that none of them had noticed anything unusual. The *Glasgow Herald* of 16th December records the stoppage of a clock in the eastern end of the city at 8.54, which showed that the vibrations had become longer and more horizontal in that district than near the epicentre.

The Rev. John Alexander tells me that some prisoners at Duke Street, who were awake in bed at the time, heard and felt the earthquake. They described the building as having been distinctly shaken. The beds are placed north and south, and the feeling was that of a movement from west to east and of a movement like the swaying eastward of the outer eastern wall. The noise was described by some as a rumble, and by others as resembling a distant explosion. The evidence of people lying in bed is especially useful, as they are sensitive to slight movements, the direction of which can often be reliably determined. The evidence from Duke Street is most consistent with a wave travelling eastwards.

The earthquake seems to have originated a little north of Hillhead and Port Dundas, but to the south of Milngavie and Bishopbriggs; for to the north of Maryhill the evidence points to a movement of the earthquake wave from south to north, and the evidence for this direction is still more definite at Mugdock Castle [12] and Lennoxtown. The earthquake was probably not due to a wide movement along a fault, for the movement was radial from a restricted locality. Thus at Kirkintilloch it was travelling from the south-west; at Colston, south of Bishopbriggs, the evidence indicates a movement from a little south of west; at Stepps from the west; in Duke Street Prison from the west; at Jordanhill from north or east; at Maryhill and Hyndland (T. B. Baillie), and Renfrew, from the east. The centre from which the wave spread was probably not more than 2 miles in length.

The evidence of direction is not always consistent. Thus at Copland Street, Govan, one reliable observer records the movement as from east to west, whereas other records from parts of Govan a little further east represent the movement as from

north to south. Similarly in Anderston and Overnewton, though the general evidence is of a movement from north to south, there are some clear impressions of a movement from east to west. These differences may be explained by the fact that the movement there was from between north and east, and the apparent direction depended as to whether the house could vibrate more readily to the west or south.

Such differences in the record of directions are not limited to personal observers. As Professor Milne has pointed out, instruments which give identical records when placed side by side give very different records when placed 800 feet apart.* The movements of the actual ground at any place will vary with a series of very complex and variable factors, and it is therefore necessary to trust for the main direction to the average evidence of many observations.

Reliable evidence as to time would give the most conclusive evidence as to direction, but there is very little evidence available as to the time at which the earthquake passed different localities.

The time records are, however, not very consistent. The most precise record is that of the seismograph at the Coats Observatory at Paisley, where three slight earthquakes were recorded. Their times are recorded by Mr. Donald Maclean as 8 h. 53 m. 42 s., 9 h. 26 m., and 9 h. 30 m. 12 s. They were only tremors with amplitudes of .15, .2, and .3 mm. respectively. (See Figs. 3 and 4.) The Glasgow earthquake was felt only as a tremor, which was by far the faintest of the three. The 9.26 and 9.30 tremors were more powerful, and they have been identified by Dr. Milne as due to an earthquake off the south-eastern coast of Africa.

The slightness of the Paisley record is surprising. There must have been an earthquake at Paisley at about 8.54 p.m., with an amplitude of more than a millimetre, for it was felt by many people; it caused the displacement of some furniture, and, according to the evidence collected by Mr. J. M. B. Taylor, split a block of stone at the insertion of an iron railing,

* J. Milne. "On 387 Earthquakes observed during two years in North Japan, October, 1881—October, 1883." *Trans. Seismol. Soc. Japan*, vol. vii., part 2, 1884, p. 5.

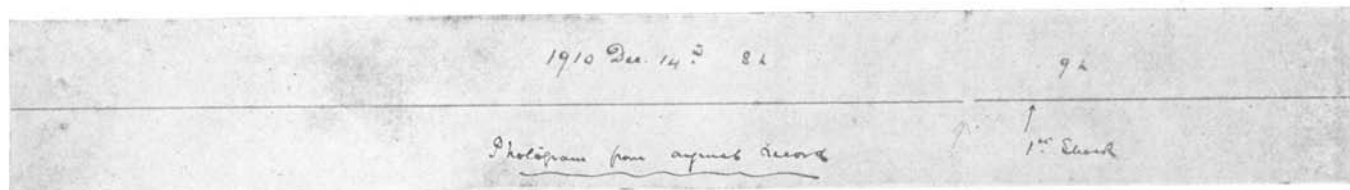


Fig. 3.—The Seismogram from the Milne Seismograph, Paisley—Mr. D. Maclean.

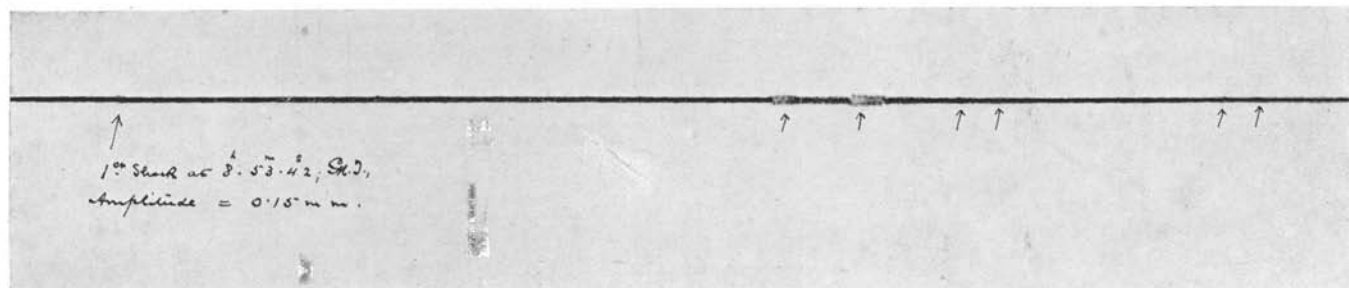


Fig. 4.—Enlarged photograph of part of Fig. 3.

cracked plaster, and threw door frames out of plumb. These effects are hardly likely to have been produced by a wave with an amplitude of only a tenth of a millimetre or $\frac{1}{250}$ of an inch. According to Dutton, an earthquake is sensible to the feeling if it have an amplitude of half a millimetre with a period of a fifth of a second. The smallness of the Paisley record may be appreciated from the comparison that the Tashkend earthquake of 4th January produced a movement on the Edinburgh seismograph of an amplitude of 29 mm., or nearly two hundred times as much as that caused by the Glasgow earthquake at Paisley.

The vibrations of the Tashkend earthquake at Edinburgh were, of course, slower, and the sensible shock depends on the combined amplitude and velocity.

It may be suggested that the boom of the Paisley seismograph was exactly at right angles to the earthquake wave, so that it was shaken but not displaced; but that explanation is inadequate, for the evidence shows that the wave must have traversed Paisley obliquely to the seismograph boom.*

The other time records indicate a disturbance at about 8.54. Professor Gray felt it at the University within a few seconds of 8 h. 54 m. 20 s. The most hopeful sources of reliable time records are the railway signal boxes, where the clocks are correlated, and a note is made of any unusual experience. Mr. T. W. Pettigrew, of the Caledonian Railway Company, has kindly sent me a note of the times at which the earthquake was noted at its signal boxes (see Appendix I.). The effect was described as "very violent" at Dawsholm, Maryhill, Maryhill East, Possil, and Springburn, the district which all the other evidence indicates as the probable source of the earthquake. The time is recorded as 8.54 in the area including Possil, Maryhill, Kelvinbridge, Partick, Partick East, Anniesland, and Paisley. Outside this area the time is generally recorded as 8.55, as to the west of Glasgow at Blackstone, Bishopton, Partick West, Scotstoun, and Scotstoun West and Bowling; also to the east of Glasgow at Springburn, Buchanan Street, Balornock, Robroyston, Germiston, Parkhead, London Road, Clyde

* Answers to subsequent personal inquiries show that the earthquake was less severe in Paisley than in Glasgow, and also less than in Renfrew.

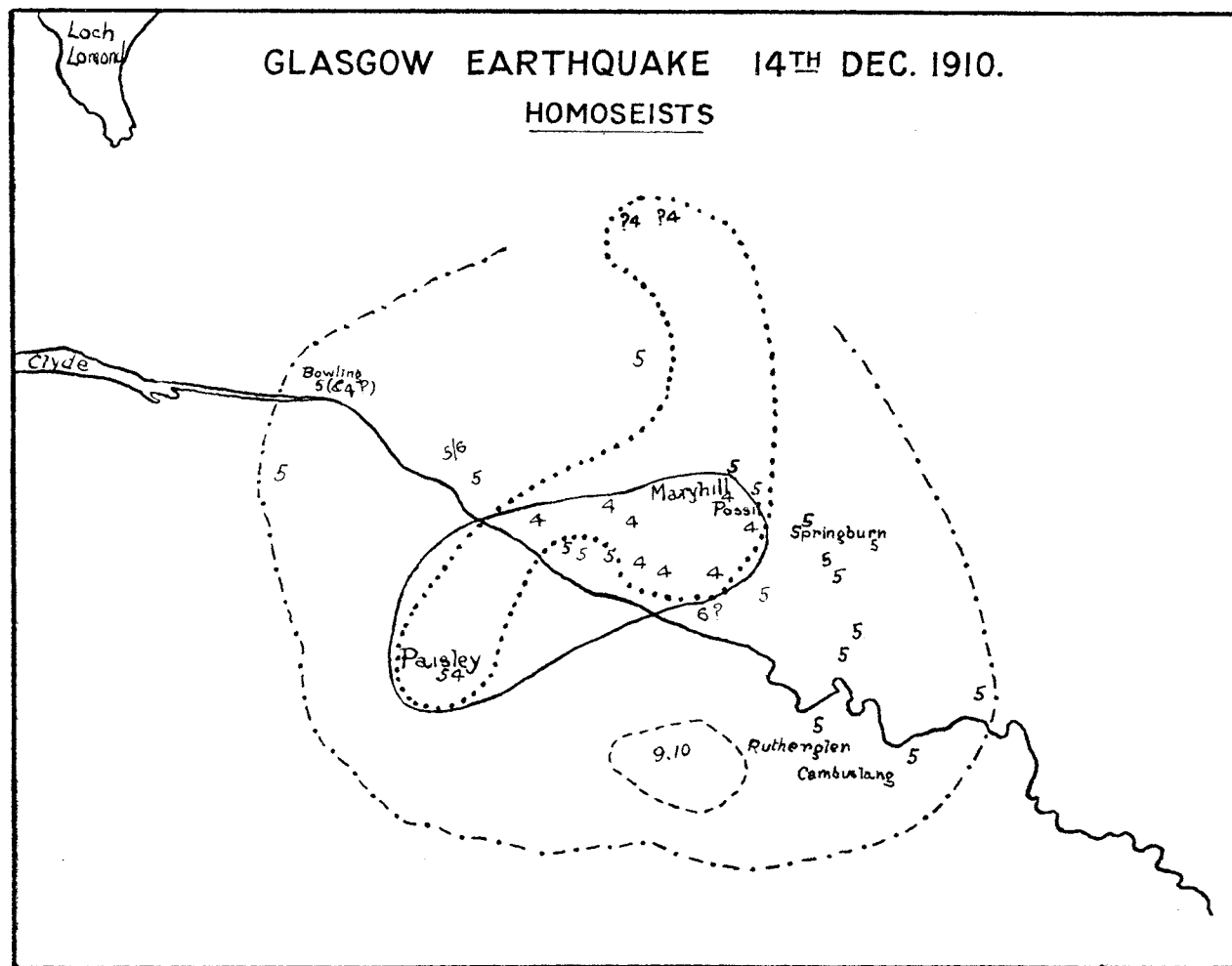
Bridge Steel Works, Cambuslang, and Rutherglen. The time was recorded at 8.56 at Stobcross.

Mr. J. C. Christie has kindly collected a record of the times on the various signal stations on the North British Railway. Mr. Christie states that most of the men who heard a rumbling noise in their signal cabins attributed it to the passage of a train somewhat heavier than usual, and that none of the electric instruments in any of the cabins were put out of working order by the earthquake. According to his report, the earthquake was felt at Bowling, Strathblane, and Blanefield at 8.54. It was felt like a distant explosion at Clydebank about 8.55; at the same time at Milngavie; and at Singer at 8.55 or 8.56. Further to the west it was felt slightly at Dumbarton, but the time there is uncertain. It was not felt at Cardross nor at Helensburgh. To the north and east of Glasgow it was felt at Kirkintilloch and Lenzie, but not at any other point eastward on the North British main line to Edinburgh, nor was it felt at Torrance or Lennoxtown.

The time records are not fully consistent, but it must be remembered that the difficulty, except in two cases, is due to a difference of a minute, and an error of a few seconds near the half-minute would lead to the inconsistent results. It seems most likely that the times are slightly too early at Blanefield and Strathblane, and that at Stobcross a minute or two late. The railway record at Paisley agrees as to the minute with that at the Observatory, which is probably some seconds too soon. Reference to the copy of the seismogram (Figs. 3 and 4), which I owe to Mr. Maclean, shows that determination of time can hardly be relied on within a few seconds. The slight inconsistencies in the time records prevent them throwing any certain light on the precise centre of origin. The earthquake time was probably some seconds after 8.54.

A map showing the homoseists is given as Fig. 5, and it points to the neighbourhood of Hillhead, Maryhill, and Possil as the epicentre.

Mr. Pettigrew's records show that a secondary earthquake was felt at 9.10 at Pollokshields, Langside, and at three stations in Cathcart. The shock at Dumbarton Junction was



4 — 8.54 p.m. 5 — 8.55 p.m. 6 — 8.56 p.m.

Scale, 1 inch = 4 miles.

Fig. 5.—The line of round dots encloses the area, which includes all the 8.54 records, with the exception of the one record at Bowling. The more probable course of the homoseist separating the 8.54 and 8.55 areas is along the continuous black line, which is based on the assumption that the 8.54 records in the Blane Valley and the 8.55 records at Scotstoun are a minute wrong. The area enclosed within the 9.10 secondary earthquake at Cathcart is based on the records from the Caledonian Railway.

recorded at 9 o'clock, and the only other record from Dumbarton gave the time as shortly after 9, so that Dumbarton was apparently outside the area in which the main earthquake was perceptible.

The general evidence points clearly to the district to the north of Glasgow between Bishopbriggs and Maryhill, and especially near Ruchill and Possil, as the locality where the earthquake started. It doubtless began along a fault, as was suggested by Mr. Macnair in an article in the *Glasgow Herald* of 16th December. A map which I prepared for a recent paper* shows that the longer axes of the areas affected by many of the British earthquakes trend from north-east to south-west; hence it was natural at first to consider whether the Glasgow earthquake might be due to a movement along a fault with this trend.

This view would be consistent with some of the time records. Thus, the earthquake was recorded at 8.54 at localities extending from Paisley north-north-eastward to Strathblane, and in intervening places from Bowling and Clydebank to the University. If the Blane field time record be correct, it would suggest that the earthquake was due to movements along a deep-seated fault running from south-south-west to north-north-east from Paisley to Blane field. The greatest extension of the earthquake area being east and west from Helensburgh to Glenboig might be explained as due to the more ready passage of the surface waves in that direction along the Carboniferous rocks of the Clyde basin or along the east and west faults. This hypothesis would, however, be inconsistent with the time records from Partick, Scotstoun, Clydebank, and Milngavie, and with the 8.56 record at Stobcross. The balance of the evidence seems to me opposed to the origin along a north-east to south-west fault. Mr. Macnair was probably correct in referring it to one of the faults that trend east and west across the Glasgow area.

The evidence available is most consistent with the epicentre of the earthquake being an area not more than 2 miles in length beside one or both of the two step faults which pass through

* "The Glasgow Earthquake of December 14th, 1910, in Relation to Mining." *Trans. Inst. Min. Eng.*, vol. xli., part 1, 1911, pp. 55-63, pt. ii.

Possil and Maryhill (Fig. 6). The southern of this pair of faults passes to the south of Possil, and further east it throws the Millstone Grit against the Coal Measure series near Gartloch and Gartcosh. The northern of the two faults passes through Maryhill and Colston, and further east it brings the Millstone Grit against the rocks of the Carboniferous Limestone series.

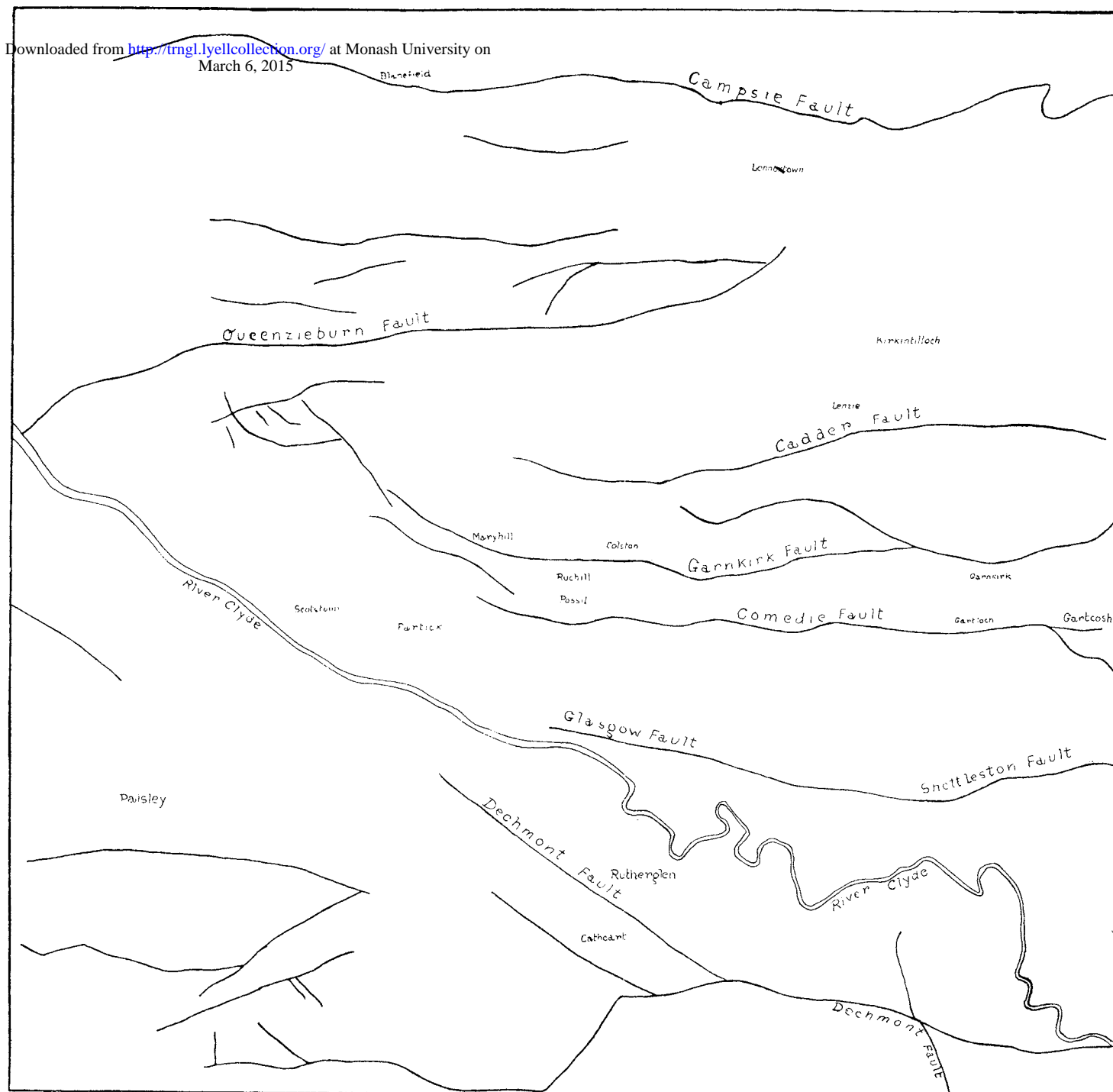
As the evidence was received it soon pointed to an origin somewhere between the faults between Maryhill and Bishopbriggs. I subsequently received striking evidence of a severe and vertical disturbance in that area. Thus Dr. Brownlee, of Ruchill Hospital, tells me that "the earthquake was felt all through the hospital, but nowhere produced any special directional effects. . . . In my own room the shock was fairly severe, but seemed to be absolutely vertical, as I have decorative plates resting almost vertically on ledges on each of the four walls, and there was no disturbance, not even as regards shaking."

The direction of movement at Colston, half a mile south of Bishopbriggs, was regarded as nearly vertical by Mr. J. M. Lindsay, who records his experience as follows:—"My wife and I were sitting reading when the shock came. There was not the slightest sensation of undulation, just a startling thud. We both said that whatever it might be the disturbance was immediately below us. So sharp and quickly past was the disturbance that we had no chance to see how anything in the room moved. So very distinct, on this occasion, was a downward movement that I looked rather anxiously next morning at the brick and rubble gable of the house; and if some one had authoritatively told me that the ground was several inches nearer to sea-level than before I should not have been much, if any, surprised.

"A second thud was also felt, but it was of the slight nature above referred to, so that if we had been moving about it would probably not have been noticed at all.

"I never thought of earthquake over a considerable area. The sensation was so very sharp—having a duration, I should think, of less than a second—that a feeling of merely local

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Scale, 1 inch = about 2 miles.

Fig. 6.—The Chief Faults in the neighbourhood of Glasgow. The Earthquake is assigned to movement on the Garnkirk or Comedie Faults, near Possil.

disturbance was experienced. The sound also gave an impression of nearness. The vibrations in air were not felt nor prolonged as in the case of an explosion at some distance. There was no rumble or reverberation. One could not distinguish between shock and sound, so quickly did the latter cease."

Mr. Lindsay, however, tells me that the experiences of a neighbour were not quite the same, as he heard an approaching rumble, apparently from south of west, and then felt the swaying of his bed on an east and west line, or perhaps between a little north of east and south of west.

As the neighbourhood of Possil was formerly an important mining centre, this position of the epicentre may appear to support the suggestion that the earthquake was due to a collapse of some old mining excavations. This view, however, seems to me impossible, as the earthquake must have originated at far too great a depth.

The Edinburgh earthquake of 18th January, 1889, was very similar to ours in range and intensity; it was felt over an area of 30 miles north and south by $26\frac{1}{2}$ miles east and west; its intensity at the epicentre was No. 6 of the Rossi-Foré scale. According to Dr. Davison,* its probable focus was at the depth of about 8 miles. As the intensity in the Glasgow earthquake decreased more rapidly from the epicentre, the depth was probably less, but still it can hardly have been at a less depth than several thousand feet. If it had been caused by the collapse of mine workings it should have shown a rapid decrease in intensity near the sunken area, but the most marked fall in the intensity occurred about 2 miles from the probable centre.

The evidence from the fall in intensity is unfortunately too indefinite for Dutton's method of determination of the depth of the focus to give reliable results. The angle at which the earthquake emerged at the surface in Hillhead, as shown by the cracked plaster at the University, is also too slight for any satisfactory conclusion as to depth, even if that method were reliable. The evidence, however, so far as it goes, suggests that the earthquake originated from at least several thousand feet beneath the surface.

* C. Davidson. "Geol. Mag.," 1891, p. 66.

The connection between the distribution of the shock and of the geological formations also gives interesting indications as to its probable depth. The earthquake as a sensible shock was practically confined to the sedimentary rocks of the Carboniferous Limestone series, and barely extended on to the volcanic rocks of the underlying Calciferous Sandstone series. Thus it was felt northward throughout the area of the Carboniferous Limestone series to Milngavie, and was noticed by occasional observers at Mugdock and Lennoxton, but not on the Campsie Fells. At Barrhead it was faintly noticed on the lower slopes of the Fereneze Hills, but further to the south-west the records are confined to the Carboniferous Limestone series, along which it extended as far as Lochwinnoch. Its extension to that locality may have been due to the faults by which the Carboniferous Limestones have been faulted down between the Calciferous Sandstone lavas to the north and south (Fig. 1).

It may be suggested that, if the earthquake originated beneath the Calciferous Sandstone series, the various outcrops of that formation should have been more affected by it; but unless the earthquake originated below the Calciferous Sandstones it would have been started at the depth of less than 2000 feet, and that depth is inadequate to account for the widespread distribution of the shock in proportion to its limited strength at its epicentre. It must, therefore, have originated at a much greater depth, and its restriction to the Carboniferous Limestone series must be due to its more ready transmission through those bedded rocks than through the more compact and massive underlying lavas.

The question of depth is of some importance as bearing upon the suggestion that has been made that the earthquake was due to the overloading of the surface by the heavy buildings of this city; but if it originated at the depth of several thousands of feet the weight of buildings would have been comparatively insignificant, while the earthquake came from the north-western suburbs, where buildings are lighter and fewer than in the city.

The question of most general practical concern in regard to earthquakes is the probability of their recurrence, especially as to the likelihood of an area affected by a moderate shock

being visited by one of a more mischievous kind. The slight earthquakes which have been repeatedly recorded in Glasgow will doubtless continue to happen at irregular intervals; but the evidence of the recent earthquake affords ground for the belief that they are not likely to occur with a serious increase of severity; for tectonic earthquakes are generally followed by a series of after-shocks due to the gradual readjustment of the ground after the main movement. There have been no after-shocks since the 14th December. It may fairly be inferred from their absence that the rocks underneath Glasgow are now so stable in arrangement that there is no probability of any earthquake here more serious than the moderate shocks which have been often felt, but have done little material damage.

APPENDIX I.

List of Signal Cabins on the Caledonian Railway and the various times at which the shock was felt—

8.54.	8.55.	8.56.	9.0.
Dalmuir.	Bowling.	Stobcross.	Dumbarton.
Kilbowie.	Scotstoun.		Bowling Swing
Clydebank.	Scotstoun W.		Bridge.
Yoker.	Partick W. Junc.		
Partick N. Junc.	Buchanan St.		
Crow Road.	Sighthill Station.		
Bellshaugh Junc.	Maryhill E.		
Kelvinbridge.	Springburn Park.		
Dawsholm.	Balornock Junc.		
Maryhill.	Germiston Junc.		
Paisley (St. James)	Blochairn.		
	Parkhead Iron Wks.		
	London Rd. Junc.		
	Rutherglen Junc.		
	Cambuslang.		
	Clyde Bridge		
	Steel Works.		
	Bishopton.		
	Blackstone.		
	Robroyston W. Junc.		
	Possil.		
9.10.	9.13.	9.25.	
Pollokshaws East.	Anderston Cross.	Milton.	
Langside.			
Cathcart.			
Cathcart W. Junc.			

APPENDIX II.—SUMMARY OF CORRESPONDENCE *re* EARTHQUAKE OF 14TH DECEMBER, 1910.

(Some of the letters deal with more than one area.)

I. WESTERN DISTRICT.	TIME.	SOUND.	DIRECTION.	
	Shortly after 9.			
1. Philips, Mrs. L. M., Cemetery Lodge, Dumbarton,				
2. Story, Miss H., 30 Lilybank Gardens,			E. to W. or N. to S.	Earthquake felt.
At Rosneath,				
At Anderston,				
3. Sharp, J. H., Parkhill, Dalmuir, 1 mile north of Canal,	8.54.	Explosion or fall of furniture above. Window rattled.		Not felt.
Beside the Canal,				Duration, 5-6 secs.
4. Ferrie, Robert (of 195 Crow Road, Partick), <i>re</i> S. Barr Estate,	8.54-8.55.	None except straining of walls.		
5. Miller, Thomas M., Sandycroft, Sandy Road, Renfrew,	Before 9.	None.	E. to W.	Duration, 2 secs.
6. M'Clelland, Rev. Robert, All Hallows, Inchinnan, Renfrew,		Rumble.	E. to W.	
7. Taylor, J. M. B., Laboratory of Science, 5 County Place, Paisley,				Collected many observations and records at Paisley.
8. Maclean, Donald, Coats Observatory, Paisley,				Seismograph records.
9. Dewar, Peter, Cross, Lochwinnoch,	8.54.			
II. NORTHERN DISTRICT.				
10. Fleming, T. L., 4 Kinnoul Terrace, Milngavie,	8.50-8.51.	Explosion or fall of furniture.		Felt as one shock; vibration under foot.
11. Learmont, R., Rockbank, Milngavie,		Noise like load of bricks.	S.E. to N.W.	
12. Reid, Col., Mugdock Castle, Milngavie,			S. to N.	Felt by a few.

WESTERN DISTRICT— <i>continued</i> .	TIME.	SOUND.	DIRECTION.	Felt.
13. Barns-Graham, Allan, jun., Craigallian, Milngavie,				Felt.
14. Smith, Miss A. L. Guthrie, Achnagowen, Killearn,				Not felt there.
15. Coubrough, John, Blane field,	8.55.	Fall of heavy furniture.		Not felt in kitchen; severe at U.F. Manse.
16. Murray, Adam, Southfield, Lennoxtown,		Thud and then shake.	North-north-eastward.	
17. Davidson, Rev. W. S., The Manse, Lennoxtown,		Rattling of a stick.		Not felt.
18. Robertson, John S., 176 St. Vincent Street,			N.N.E. to S.S.W.	
At Lennoxtown,	8.55 clock stopped.			
III. WESTERN SUBURBS.				
19. Balfour, T. A. R. (<i>re</i> E. & N. of Victoria Park), 45 Bishop's Road, Broomhill,		No rumble but loud report like explosion.		
20. Drysdale, Wm., Southbrae Drive, Jordanhill,		Heavy fall below.	E. to W.	
21. Staig, R. A., 16 York Avenue, Jordanhill,	8.55.	Heavy but momentary.	N. to S.	
22. Reoch, J. W., 22 Montgomerie Street, Kelvinside,		Fall of furniture.		Like bed lifting.
Crow Road,		Heavy fall.		Do.
Queensborough Gardens, Technical College,		Fall of furniture.		Not felt.
23. _____, White Street, Partickhill,		Explosion and fall.		
24. Browne, John, 31 Rowallan Gardens, Partick,				
At Jordanhill,	9.	Noise above.		Not felt.
At Bearsden,				People fled from one house, but not felt in the next.

WESTERN SUBURBS— <i>continued.</i>				
	TIME.	SOUND.	DIRECTION.	
25. Rogers, Mrs. H. J., 3 Lancaster Terrace, Kelvinside, W.,		Loud; fall of heavy furniture.	E. to W.	Shift of petrol house.
26. Macfarlane, J. E., 2 Montgomerie Crescent,				Miscellaneous records.
27. Wordie, J. M., <i>re</i> Bardonald, &c.,				
28. Collins, Charles M., Kelvinside Paper Works, Maryhill, At Highfield Farm,				Door burst open, faces E. 30° N. Two shocks; duration, 3 secs. Slight tremors.
29. Baillie, Thomas B., 29 Polwarth Gardens, Hyndland,	8.54.	Rumbling noise and oscillation.	E. to W.	
30. Shaw, George C., 26 White Street, Partick,	9.28.	Noise of grinding stones.	N.E. to S.W.	
31. Stevens, Alex., 17 Dalnair Street, Overnewton,	8.54.		N.N.E. to S.S.W.	Swaying of lamp and movement of oil.
32. Meikle, Miss, 41 Blackie Street, Overnewton,		Strange noise.		Bad shock; house heaved.
33. Mackinnon, R., Weights and Measures Department, Town Hall, Govan,	8.54.	Fall and rumble.	Westward.	Ground gave a distinct wobble.
34. Hamilton, D., 18 Barrington Drive, At Drumgoyne Drive, Govan,			N. to S.	
35. Rosie, J. G., Albert Street, Govan,				Cups thrown northward from a shelf east and west.
IV. HILLHEAD AND WEST END PARK.				
36. Stevenson, Mrs. M., 24 Wilton Gardens,		Distant explosion.	E. to W.	Sinking of west end of room.
37. Stevenson, John G., 2 Doune Gardens,	8.55.		S.E. to N.W.	
38. Stewart, John A., 3 Carlton Gardens,	After 9.	Rumbling like cart of bricks.		Violent trembling.

HILLHEAD AND WEST END PARK—continued.	TIME.	SOUND.	DIRECTION.	
39. Becker, Prof. L., The Observatory,	8.54 m. 30 secs.		N. to S.	Door north to south wall opened. Wave-like feeling.
40. Macbeth, Miss Ann, Queen Margaret Hall,				
41. Buchanan, W. A., 14 Hillhead Gardens, At 18 Bute Gardens,	8.55.		N. to S. or N.E. to S.W.	Pictures swayed forward.
At 5 Lilybank Gardens,	10.	Door slamming.		Less severe than at Bute Gardens; bells rung. Reports record there.
Re Fereneze Braes, Barrhead,				
42. Sloan, Dr. Hugh R., Sutherland Terrace.			N.W. to S.E.	
43. Paterson, Mrs. Janet S., 31 Kersland Terrace, At Belmont Church,		Heavy motor.		
44. Watson, Miss M. A. H., Laurel Bank School,		Fall of furniture. Fall above.	N. to S.	Bottles fell.
45. Drummond, R. H. T., 7 Rupert Street,		Heavy train.		
46. Wright, R. H., 109 Great Western Road,			N. to S.	Cupboard door N. & S. opened Eastward. Pushed up.
47. Bost, T., 12 Burnbank Terrace,		Thud.		
48. Robertson, M., 114 South Woodside Road,		Fall of furniture above.	N. to S.	
49. Wilson, A. N. A., 9 Park Quadrant,		Fall of furniture above.		
50. Anderson, J. W., 23 Woodside Place,		No sound.	W. to E. or S.W. to N.E.	2 secs. duration.
51. Bryce, Mrs. Agnes D., 11 Woodlands Terrace,			N. to S.	Statue swayed Northward.

V. NORTHERN SUBURBS.	TIME.	SOUND. Explosive.	DIRECTION. S.W. to N.E.	
52. King, Robert, Strathview, Calder- cuilt Road, Maryhill,	About 9. and 9.15.			Doors swung.
53. Wright, Miss A. C., 26 Lands- downe Crescent, At Gairbraid Avenue, Maryhill,				Do.
54. Brownlee, Dr. John, Ruchill Hos- pital,				Vertical effect.
55. Lindsay, J. B., 166 Buchanan Street, At Colston, S. of Bishopbriggs,		Sound and shock together.		Vertical effect less than one sec.
56. Boyle, J., jun., 24 Forth Street, Port-Dundas,	After 9.			Felt.
VI. CITY.	9.30 ?	Explosion.		
57. Frame, W. A., 1 Ford Place, Fin- nart Street, Greenock, At Theatre Royal,				
58. Smellie, W. R., Mayfield Villa, Mossend, At Messrs. Dykes Brothers, 11 Royal Exchange Square,			N. to S.	Topheavy objects thrown northward.
VII. SOUTH OF CENTRAL GLASGOW.				
59. MacBrayne, John, 72 Houston Street, S.S.,		Sound after shock.	N. to S.	3 secs. duration.
60. Barr, M. G., 20 Apsley Place,	8.54.	Fall on roof.		
61. Wallace, Matthew, 19 Keir Lane, Pollokshields,		Fall in lobby.	W.N.W. to E.S.E. or <i>vice versa</i> .	Two motions.
62. Maclaren, W. B., Willowbank, Giffnock,	8.54.	Rumbling heard.	S.W. to N.E.	Bed heaved.
63. Watson, G. C., 478 St. Vincent Street, At Giffnock Quarries,	9.26.		N.E. to S.W.	Material thrown.

SOUTH OF CENTRAL GLASGOW— <i>continued.</i>		TIME.	SOUND.	DIRECTION.	
64. Black, E. A. T., Aldouran, Newlands,		About 9.		N. to S.	Photo and ornaments fell Southward from North mantelpiece; billiard ball moved S. 30° E.
65. Donaldson, Alex., 67 Durward Avenue, Shawlands,			Noise with rocking.	N.W. to S.E.	Dishes rattled and gazogene rocked.
66. White, Robert, 279 Holmlea Road, Cathcart,		9.20 or 9.25.	Concussion on roof.		8-10 secs. Ceiling cracked in every direction.
67. Wood, David J., 46 Phannan Road, Cathcart,		8.54.	No noise.	N. to S.	Vibration of trays; not heard by others.
68. Gartshore, Alex., Duntulean, Cathcart,		About 9.	Thud.		Screen fell; not recognised as earthquake.
69. Hay, John, 130 Stanley Street, Kinning Park,			Loud thud as of a heavy fall.		Upstairs heard nothing.
VIII. EAST OF CITY.					
70. Alexander, Rev. John, Chaplain's Room, H.M. Prison, Duke St.,			Loud rumbling.	W. to E.	East wall swayed Eastward.
71. Smeal, W. G., 117 London Street,			Noise below.		Not heard nor felt near by.
IX. SOUTH-EASTERN DISTRICT.					
72. Hardie, G. D., Clarkston, Busby,			Rock blasting.	N.W. to S.E.	Heavy vibration.
73. Leslie, William, Jessamine, East Kilbride,		8.55.			He noticed it, but Mrs. Leslie did not.
74. Wallace, James, Wistran, Douglas Drive, Cambuslang,			Like explosion or dull thud of fall above; sound same time as shock.	N. to S.	
75. Macpherson, Edward, Ardleven, Stewarton, Cambuslang,				N. to S.	Ornaments inclined.

SOUTH-EASTERN DISTRICT— <i>continued</i> .	TIME.	SOUND.	DIRECTION.		
76. Boyle, R., Fernlea, 8 Parkhill Drive, Rutherglen, <i>Re</i> Burnside, Rutherglen, Giffnock, Technical College,		Like fall. Heard in town. Blow on roof.	E. to W.	West door opened.	
X. EASTERN DISTRICT.					
77. Gray, Mrs. Jane W., Commercial Bank House, Kirkintilloch,	About 9.	Fall of furniture.	To North-Eastward	Not heard close by.	
78. Lawson, L. B., Ashfield, Kirkintilloch,	8.42.	Noise of quivering wall.		Tremor.	
79. Haeger, C., Presbytery, Glenboig,	About 9.			Eastward. W. to E.	2 shocks 2 secs. apart not felt near by at N. Mount Vernon. Vigorous tremor felt by a few. Shiver; plates jingled.
80. Smith, Miss Tina, Glenfarg, Stepps,	Just before 9.				
81. Warrall, George, 6 Buchanan Gardens, Mount Vernon,	Before 9.				
82. Outhill, W., Beechwood, Uddingston,	Before 9.				
83. M'Gowan, Frank, Swinton Tavern, Easterhouse,	9.46.	Bump.			
X. MISCELLANEOUS.					
84. Morton, Dr., Town and County Club, Ayr,	6.45-7.	Times at various Signal Cabins. Do.		Tremor.	
85. Pettigrew, T. W., Caledonian Railway,					
86. Christie, J. C., North British Railway,					

Further evidence as to the distribution was given in the Glasgow papers from 15th to 17th December.