THE EAST ANGLIAN EARTHQUAKE OF 1884

THE ESSEX FIELD CLUB.

FOUNDED JANUARY 10TH, 1880.

THIS Association, the only Scientific Society of like aims in Essex, was founded for the study and investigation of the *Natural History, Geology*, and *Pre-historic Archæology* of the County; the publication of the results of such investigations; the formation of a Library of local and scientific works; the formation of a Museum to illustrate the natural productions of Essex; and generally to aid in the dissemination of practical knowledge of Natural Science and Antiquities. A further very important object of the Society is to promote a reverence for the natural features of the County, its Flora and Fauna, and its numerous pre-historic Monuments, and to incite a desire to protect them from wanton spoliation and injury.

The Club holds Ordinary (Scientific) Meetings about once a month, and "Field Meetings" are organized during the summer in various parts of the County and elsewhere, for out-door observation, under the guidance of experienced Naturalists, Geologists, and Archæologists. Other Meetings at the National Museums, Lectures, &c., are arranged from time to time. In organizing the Essex Field Club, the main desire of the founders was to establish an Association which should be *both popular and scientific*, and which should represent, from the point of view of its foundation, the whole County of Essex; to form a central body to which communications and specimens relating to Essex and general Natural History, &c., might be sent for careful consideration and discussion, so that the 'Transactions' should in time comprise a body of fact and inference, useful to the local and scientific student, as well as interesting to the ordinary reader.

The 'Transactions' are issued at intervals, as materials accumulate, and are produced in the best style by Messrs. West, Newman & Co., the well-known printers of natural-history books; and plates and woodcuts are used to elucidate the text whenever possible. *Since the formation of*

the Club nearly 1400 closely-printed pages of 'Transactions,' Reports, &c., have been issued, illustrated with plates and woodcuts. All the publications of the Club are in print, and can be obtained from the Librarian, as detailed below.

In 1881 a careful examination of the ancient camp in Epping Forest, known as Ambresbury Banks, was made, and a report published in the 'Transactions.' In the following year a similar investigation of the camp at Loughton was entered upon, an account of which was published in the same in 1884. By means of these successful researches the Club has been enabled to settle many important points in the history of the old Forest of Essex. The Club is now engaged upon an attempt to elucidate the nature and use of the mysterious "Dene-holes" existing in various parts of Essex and elsewhere. The Club has also actively endeavoured to check the wanton destruction of our native animals and plants, and to retard the effacement of the primitive and natural conditions of the districts comprised within the sphere of its action. It is believed that the energetic action of the Essex Field Club during the years 1880-83 largely contributed to the defeat of the various schemes injuriously affecting Epping Forest put forward during that period, and the work of the Society in this direction has earned the hearty approval and thanks of the scientific and general press, and of the public. An important pamphlet on these subjects has been published by the Club, and copies may be obtained of the Librarian, as stated below. A scheme for the registration and cataloguing of the Pre-historic Monuments of Essex is in contemplation, and will be carried out with as little delay as possible.

Although bearing a county title, the Club offers exceptional advantages to metropolitan residents. Many of the excursions start from London, and both Field and Ordinary Meetings are as accessible as if the Society were purely a Metropolitan Field Club. Many parts of Essex are but little known, although of the greatest interest to the naturalist, geologist, and antiquary. It is anticipated that the organization of the Club in connection with the Field Meetings will enable many to become acquainted with this portion of the Eastern Counties, which so well repays the attention of the intelligent visitor.

Members (Ladies and Gentlemen) are elected by ballot, on the proposal of two members. The Annual Subscription is 10s. 6d. per annum, with an Entrance Fee of 10s. 6d. Application for Membership should be addressed to the Hon. Secretary, WILLIAM COLE, 7, Knighton Villas, Buckhurst Hill, Essex.

PUBLICATIONS OF THE ESSEX FIELD CLUB.

Duplicate volumes and parts are supplied to *Members* at a discount of 25 per cent. from the following prices, post free. All the Publications of the Club are still in print, but Parts 3 and 4 can only be supplied with complete volumes:—*President's Inaugural Address* (6d.); *A Day's Elephant Hunting in Essex* (1s.); *Transactions*, Part 1 (1s.); Part 2 (2s.); Part 5 (5s. 6d.); Part 6 (7s. 6d.); Part 7 (10s. 6d.); Part 8 (5s. 6d.); Vol. I., unbound (6s.); Vol. II., unbound (15s.); Vol. III., unbound (16s.); Vol. IV., Part 1, *Transactions* (5s.); Do., *Proceedings* (3s.); *Report on East Anglian Earthquake* (7s. 6d.); *Reports on the Explorations of the two Ancient Camps in Epping Forest.* A few authors' copies of these Reports are in hand, price 4s., post free.

Papers and Memorials on the Protection of Wild Animals and Plants, and the present condition and future management of Epping Forest (1s.).

ESSEX FIELD CLUB SPECIAL MEMOIRS.

VOL. I.

EDITED BY WILLIAM COLE,

HONORARY SECRETARY.

"Whereas the four elements had agreed to live together in peace, the earthquake came and set them by the ears, to the detriment of property and danger of life." — *Translated from a pamphlet containing some account of a prolonged earthquake in Leghorn in 1741, by Raphael Meldola, of Bayonne; published in Leghorn, 1742.*

"The circumstances which accompany any observed fact are main features of its observation, at least until it is ascertained by sufficient experience what circumstances have nothing to do with it, and might therefore have been left unobserved without sacrificing *the fact.* In observing and recording a fact therefore altogether new, we ought not to omit any circumstance capable of being noted, lest some one of the omitted circumstances should be essentially connected with the fact, and its omission should therefore reduce the implied statement of *a law of Nature*, to the mere record of an *historical event.*"—*Herschel's 'Preliminary Discourse on the Study of Natural Philosophy.'*

ESSEX FIELD CLUB SPECIAL MEMOIRS, Vol. I.

REPORT

ON THE

EAST ANGLIAN EARTHQUAKE

OF

APRIL 22ND, 1884.

BY

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AND

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MEMBER OF THE GEOLOGISTS' ASSOCIATION.

[*Drawn up by R. Meldola, and read in abstract at the Meeting of the Essex Field Club, February 28th, 1885.*]

With Maps and other Illustrations.

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PREFACE.

THE present report upon the most serious natural calamity that has befallen the county of Essex within the historical period has occupied the greater part of our scanty leisure time since its occurrence, and to many of our readers it may appear that the volume which we now offer as the result of our labour is out of all proportion to the magnitude of the event. In detailing the facts of the earthquake at such length we have been actuated by the desire of producing a report which we think we may venture to regard as typical of a "local investigation" in the sense insisted upon by the Corresponding Societies Committee of the British Association for the Advancement of Science. We are of opinion that such investigations should deal as exhaustively as possible with the *facts* relating to any particular subject, and at the same time that the legitimate conclusions should be drawn from these facts with especial reference to the district over which the local society extends its operations. This position we have endeavoured to take up in the following report, although of course a phenomenon affecting such a wide area as the present earthquake passes beyond the province of a purely local subject, and we can only express our regret that we have not been able to secure to a greater extent the co-operation of other societies in neighbouring counties. It may, however, be fairly pleaded that earthquakes of this magnitude are of such rare occurrence in our country that seismology as a subject is hardly pursued, and that very few persons know how or what to observe under such circumstances. It is hoped that our report may for this reason be found of some service to seismologists in general, although we can but sincerely wish that their opportunities for investigation may be few and far between. The whole subject is of such great complexity, and its practical investigation is surrounded by so many difficulties, that it must as yet be regarded as one of the most infantile of the modern branches of Science. It is only by the labours of those who, like

Profs. Milne and Ewing, have had in Japan such frequent opportunities of measuring and recording earthquake-shocks that we can ever hope to arrive at a true knowledge of the laws governing these phenomena. We have lost no opportunity, therefore, in this report of interpreting the observations by the light of the results which have been achieved in Japan by means of specially-constructed instruments in the hands of skilful observers, so that, although nominally concerned with one earthquake only, we are not without hope that the present work may be considered to contain sufficient general matter to establish its position as a guide to those about to take up the study of seismology.

One point in connection with the report which will doubtless strike our readers is the general untrustworthiness of what may be called common-place observations in any attempt to submit an earthquake to exact mathematical treatment. If our labours serve only to emphasize this inadequacy of non-instrumental methods of observation, we feel that our efforts will not have been altogether exerted in vain. We can only add that we have made as much out of the materials at our disposal as we possibly could; whether we have made too much of our materials and have drawn unwarranted inferences we must leave to the judgment of our scientific readers.

In conclusion, we can but express the wish that this task had been taken up by some more qualified specialists than we can lay claim to be considered in the present subject. As a local phenomenon, we felt it our duty, however, to represent to the Essex Field Club the necessity for taking up the subject, the more especially as the occurrence received no official recognition, and we considered that in the interests of British Science such a visitation should not be allowed to pass without being fully recorded. On behalf of the Club we have striven to perform this duty in the midst of other occupations, and whether we have succeeded in adding anything of permanent value to seismological science or not, we cannot but feel satisfaction in knowing that the great Essex earthquake of 1884 is no longer an unwritten chapter in the history of the county.

ANALYTICAL TABLE OF CONTENTS.

Errata et Corrigenda.

Page 4, line 16 from bottom, *for* "Hollinshed," *read* "Holinshed."

,, 7. The 1734 earthquake probably refers to a shock in *Iceland* (Gent. Mag., vol. iv., p. 455).

,, 32, note 16. The formula for the velocity of transmission is Newton's.

,, 60, line 4 from top, *for* "chimneys," *read* "chimney."

,, 60, line 6 from top, *for* "detachment," *read* "attachment."

,, 76, line 3 from top, *for* "pendulums winging," *read* "pendulum swinging."

,, 129, top line. Buntingford should be added to list of Herts. stations where shock was felt. Report by the Rev. C. W. Harvey, Throcking Rectory; communicated by Mr. J. Hopkinson, F.G.S.

,, 144, line 14 from bottom, *after* "lady," *add* "in."

,, 152. In Mr. Whipple's letter (under Kew), *for* "9.17.18 a.m.," *read* "9.17 or 18 a.m."

,, 155, last line of note 50, *for* "p. 2," *read* "p. 20."

,, 173, line 8 from top, *for* "casual," *read* "causal."

,, 181, line 17 from top, *after* "Chalk," *add* "and Drift."

THE EAST ANGLIAN EARTHQUAKE

APRIL 22ND, 1884.

I. Historical Introduction.

Soon after nine on the morning of Tuesday, April 22nd of last year, the eastern parts of this country were shaken by a seismic disturbance, which, although happily unattended by loss of life, for destructiveness and wide distribution has been without a parallel in Britain for at least four centuries. The county of Essex, in which the shock originated, appears in fact, during the historical period, to have been exceptionally free from such visitations. The last serious earthquake in East Anglia takes us back to the year 1480, when buildings were thrown down and much damage caused in Norfolk, the shock having extended widely throughout the country.

A glance through any catalogue of British earthquakes will show that our country has from the earliest periods of history been subject to frequent shocks, for the most part slight, and even in the worst cases fortunately falling far below the average of those terrible disturbances which have wrought such havoc in other European and in tropical countries. In connection with the present report, it appeared to be of interest to prepare a list of all those shocks by which structural damage had been caused in former times in Britain; and in offering this catalogue of nearly 60 records, which may be considered fairly exhaustive as far as it goes, it must be pointed out that the list by no means comprises the whole number of our most

widely felt earthquakes, since numerous records exist showing that shocks of considerable strength, and extending over wide areas, may fail to produce any structural damage, either on account of the great depth of the focus, or, among other reasons, because the epicentrum happens to be far from damageable structures.[1]

It was at first contemplated to have given a complete chronological catalogue of all the earthquakes that had been recorded in Britain, as no such catalogue at present exists. Mr. William White had kindly volunteered to co-operate in this work, and nearly 350 had been entered down to the end of the year 1843, when we discovered that a similar task was being undertaken from another another point of view, by Prof. J. P. O'Reilly, of the Royal College of Science of Ireland (See Trans. Roy. Irish Acad., vol. xxviii., Science, p. 285). This circumstance, together with the fact that such a general catalogue would have been beyond the scope of the present report, led us to abandon the original scheme and to confine ourselves to those earthquakes which had caused structural damage, the result of our joint labours being given in the list below. Mallet's British Association Catalogue, which ends in 1842, has been taken as the basis of our list, and by diligent literary research, we have been enabled to add several well-authenticated shocks which had escaped the notice of this eminent seismologist. For the earlier records I am indebted to Mr. C. L. Prince, F.R.A.S., of Crowborough Observatory, Sussex, who was good enough to copy out and transmit a list of earthquakes from a rare work in his possession, entitled 'A General Chronological Table of Meteors, Weather, Seasons and Diseases,' probably by Dr. Thomas Short, F.R.S., in two vols., London, 1749. It seemed desirable to ascertain, if possible, where the author of this work had taken such very early records from, and Mr. White having failed to find a copy of the book in the British Museum Library, I applied to Mr. Prince, who wrote:—"He

[1] The epicentrum is the point on the earth's surface vertically over the focus or centrum, the line joining the centrum and epicentrum corresponding to the "seismic vertical" of the older seismologists.

does not give his authorities respecting the earthquakes, but says in the preface that the work could not 'possibly have been done whilst these scraps of histories lay scattered in a vast multitude of authors of different designs and professions, as Historians civil, ecclesiastical and political; Physicians, Divines, Naturalists, Monks, Fryars, Journallists, Travellers, &c.' He states further that he was sixteen years in collecting and compiling the Chronology." In a later communication Mr. Prince sent the following additional extract, from the end of Dr. Short's Chronicles:—"Having gone now as far as we have *vouchers* and brought down the Rev. Mr. Say's history of the weather to 1717, where the late ingenious Dr. Wintringham begins to be more particular, &c."

After each record in the following list the authorities are given, Mallet's references having been in most cases verified, and in many instances his accounts enlarged with respect to the details of damage. In addition to Mallet's authorities the following general works have been consulted, together with the special works mentioned in the catalogue below:—

'Appendix to a Chronological and Historical Account of the most Memorable Earthquakes that have happened in the World, from the beginning of the Christian Period to the present year 1750. By a Gentleman of the University of Cambridge.' Cambridge, 1750.

The Catalogue of Earthquakes in the 'London Magazine,' vol. xix., 1750.

Chambers' 'Cyclopædia of Arts and Sciences,' vol. ii., 1758.

Palmer's 'Index to the Times Newspaper,' 1860 to 1883.

Haydn's 'Dictionary of Dates,' 17th ed., 1881.

List of British Earthquakes which have caused Structural Damage.

A.D. 103. In Somersetshire; a city swallowed up. (Dr. Short.)

132. In the west of Scotland; men and cattle swallowed up. (Dr. Short.)

204. A city in Brecknockshire swallowed up. (Dr. Short).

261. A terrible one in Cumberland. (Dr. Short.)
287. One ruined a great part of Worcester. (Dr. Short.)
424. In Cornwall; great losses; many killed. (Dr. Short.)
488. At Canterbury; did great hurt. (Dr. Short.)
534. Somersetshire, with great damage. (Dr. Short.)
677. At Glasgow; destroyed many people and houses. (Dr. Short.)
844. York, very hurtful. (Dr. Short.)
1000. In Cumberland; swallowed up people, cattle and houses. (Dr. Short and contemporary chronicles.) On March 29th of this year a general European earthquake is recorded; no particular place mentioned. Possibly coincident with the Cumberland earthquake.
1014. In Cumberland; much people and cattle lost. (Dr. Short.)
1019. In Scotland; much people and cattle lost. (Dr. Short.)
1107 or 1114. Lincolnshire; walls of Croyland Church in course of building "gave way, and the south wall was cracked in so many places that the carpenters were obliged to shore it up with timbers till the roof was raised." Coincident with violent earthquake in Italy. ('History of the County of Lincoln,' Anon., 1834, vol. i., p. 311.)
1133. Aug. 4th; morning. In England, very violent. Loud subterranean noise heard; houses thrown down. (Matthew of Westminster; Gentleman of the University of Cambridge; Dr. Short, &c.)
1185. April 15th, 16th, or 17th. All England, and especially at Lincoln, where the Cathedral and many other buildings were thrown down. Hollinshed speaks of this as "a sore earthquake, ... such a one as the like had not been heard of in England since the beginning of the world." (Mallet gives following references:—Dom Bouquet, t. xvii., p. 465, t. xviii., pp. 60, 188, 328; Martène et Durand; Rerum Anglic. Script, &c. This earthquake is not recorded by Dr. Short.)
1186. After middle of September. Throughout Europe, and especially in England, Calabria, and Sicily, in all of which places great structural damage was caused. (Matthew of Westminster, &c.; Mallet. An earthquake which overthrew many buildings is recorded by Matthew Paris as having occurred in 1187; possibly identical with foregoing.)
1246. June 1st, 9th hour. Especially in Kent, where several churches are said to have been "overturned." V. Hoff gives the date as May 19th. (Higdens's 'Polychronica';

Fabyan's Chronicle; Camden; Gent. Univ. Camb.; Mallet, &c. Not in Dr. Short's list.)

1247. Feb. 13th. Different parts of England, and especially London and along banks of Thames. Buildings thrown down. (Matthew Paris; 'Collection Académique'; Mallet, &c.)

1248. Dec. 21st. In west of England; Bath and Wells. Part of tower of Cathedral at latter place thrown down. Cathedral of St. David's partially destroyed and many churches in Somersetshire damaged. Said to have been felt in Piedmont, Savoy, and Syria. (Matthew Paris; Mallet, &c.)

1275. Sept. 11th, between 1st and 3rd hour of the day. Many churches thrown down; amongst them St. Michael's, Glastonbury. (Matthew of Westminster; Mallet; &c.) This shock was felt in London. (William Maitland's 'History of London,' 1739, p. 64.)

1380. May 21st; all over England; "shook and shattered some buildings in Canterbury." (Chr. W. Thorn. col. 2157, and Lond. Mag. Catalogue, vol. xix., 1750.)

1382. May 21st and 24th. In England, France, Brabant, Flanders, &c.; most violent in England, where several churches are said to have been thrown down in the south-eastern parts. In Baker's 'Chronicle of the Kings of England,' 1655, the date is given as May 24th, in the 6th year of Richard II.[2] (Mallet gives references to Martène et Durand; Baronius; Coll. Acad. &c.)

1480. Dec. 28th. Norwich, and almost the whole of England. Buildings thrown down and much damage. "A very great earthquake." (Rev. Francis Blomefield's 'Topographical History of the County of Norfolk.' 5 vols. 1739—1775. Quoted by H. B. Woodward in Trans. Norf. and Norwich Nat. Hist. Soc. vol. iii. Not recorded by Dr. Short or Mallet.)

1574. Feb. 26th, between 5 and 6 p.m. York, Worcester, Gloucester, Bristol, Herefordshire and neighbouring counties. Plates and books thrown down at Tewkesbury;

[2] This shock happened during the trial of Wycliff, and caused the meeting at Westminster to disperse in alarm before the termination of the proceedings, thus gaining for the assembly the designation of "the Council of the Earthquake." That structural damage was caused appears from the following lines, written by an eye-witness:—

"Castels, walles, towers and steples fyll,
Houses and trees and cragges fro the hyll."

(*Hardyng's Chron.* pp. 339—340.)

See also some lines in 'Wright's Political Songs, from Edward II. to Henry VII.,' p. 251. These references are from C. Edmund Maurice's 'Lives of English Popular Leaders in the Middle Ages,' pp. 208, 209.

Ruthen Castle partly destroyed; bell in Denbigh market-house sounded twice, and several chimneys thrown down. People kneeling in Norton Chapel (near Gloucester?) were almost all thrown down. (Mallet, on authority of Stow's Chron.; Coll. Acad., &c.)

1580. April 6th, 6 p.m. London, Dover, and the whole of Kent; also in France, Belgium, and Holland. In London said to have lasted about one minute; at 9 and 11 p.m., and 4 a.m. on the 7th, slighter shocks in Kent. Part of Temple Church and some masonry from old St. Paul's, together with many chimneys in London thrown down; two apprentices at Christ Church killed by falling masonry. Stow says:—"Ye great clocke bell in the Palace of Westminster strake of itselfe against ye hammer with shaking, as diuers clockes and bells in the City and elsewhere did ye like." At Dover and Sandwich the sea was much agitated, and a serious landslip was caused at the former place. Saltwood Castle, Kent, Sutton Church and churches at Sandwich damaged; bells sounded in Hythe Church. Said to have been felt at Norwich. In Baker's Chronicle this earthquake is said to have been felt at York, where stones were shaken out of buildings, and bells in churches were made to jingle. He states that the night following, the earth trembled once or twice in Kent. (Camden's Hist. of Eliz.; Phil. Trans., vol. xlvi.; Stow's Chron., &c. Mallet gives several other authorities.) Another strong shock in Kent on May 2nd, about 2 a.m.

1596. Kent; did great damage to buildings and killed several people. (Brit. Chronologist, 1755, vol. i., p. 175. Not recorded by Dr. Short or Mallet.)

1638. End of year. Chichester. Much damage; several shocks. (Mallet gives reference to Dresdner gelehr. Ang. 1756.)

1651. April; about 5 in the afternoon. Cumberland and Westmoreland; some chimneys thrown down. ('Admirable Curiosities, Rarities and Wonders,' by R. Burton, 9th ed., London, 1728, p. 37. Not recorded by Dr. Short or Mallet. Communicated by G. J. Symons, F.R.S.)

1692. Sept. 8th, between 2 and 3. p.m. A violent European earthquake, focus probably in Brabant. Felt in London, Sheerness, Deal, Dover, Norwich, Ipswich, Colchester, Coxhall [Coggeshall], &c, According to Hasted (Hist. of Kent, vol. iv., p. 433) this shock was felt also at Canterbury. Evelyn, in his 'Diary,' gives the date as Sept. 15th, and states that the shock was felt in his house at Wotton, Surrey, by servants in the upper rooms, but not

by those at dinner below. Mallet gives the distribution as Paris, Normandy, England, Flanders, Holland, Mayence, Frankfort and Valais. (Mallet gives, among other references, Bertrand; Coll. Acad.; Phil. Trans. vol. xlvi.; and John Glyde's 'History of Ipswich,' 1850. See also special references to Essex given in this Report, pp. 11 and 12.)

1704. Jan. 8th (N.S.), 5 h. 3 or 4 m., p.m. Lincolnshire and Yorkshire. Felt at Hull, Beverley, South Dalton, and feebly at Selby and Navenby. Most violent in neighbourhood of Lincoln. At Hull, a sound heard like the sighing of the wind, although perfectly calm; doors and furniture moved and chimneys thrown down. At Selby and Navenby, noise heard like the rolling of a vehicle. (Phil. Trans., vol. xlvi.; Dr. Short; Mallet, &c.)

1784. August. Ireland; over 100 houses and 5 churches destroyed. (Brit. Chronologist, vol. ii., 1775; not recorded by Mallet.)

1786. May 1st, 1 a.m. Ochil Hills, Scotland. Another shock at noon of preceding day, accompanied by subterranean noises. "Rent several houses and put the people to flight." (Gent. Mag., vol. vi.)

1750. Feb. 19th (N.S.), about 12 h. 40 m. p.m. Strong shock in London and surrounding districts, and especially along Thames from Greenwich to Richmond. Felt also at Hereford and at Havre, Boulogne, and in Picardy and Brittany. Shock felt by ships in the Thames. A few chimneys thrown down in London and suburbs. (Phil. Trans., vol. xlvi., Appendix; Mallet; see also special references from Gent. Mag., vol. xx., given in this Report, p. 12.)

1750. March 19th (N.S.), 5 h. 40 m. a.m. London, Cheshunt, Hertford, Ware, Copthall (near Epping), Croydon, Beckenham, Tooting, Chelsea, Fulham, Epsom and Turnham. Also at Portsmouth about 6 p.m., and stronger in Isle of Wight; and at Bath (feebly). Several successive shocks; more violent than earthquake of previous month. Loud noise like thunder or passing waggon. Bells rung in church steeples; chimneys thrown down and houses damaged in London; "great stones fell from the new spire of Westminster Abbey." Slight shocks were felt in London and vicinity the following day, at 2 and 4 a.m. (Phil. Trans., vol. xlvi., Appendix; Mallet; see also special references from Gent. Mag., vol. xx., given in this Report, p. 12.)

1750. Oct. 11th, between 12 and 1 p.m. Counties of Northampton, Leicester, Rutland, Nottingham, Lincoln and Suffolk. Extended from Warwick to Bury St. Edmunds and from Lincoln to Northampton; felt as far north as South

Derbyshire. Four successive shocks, rather violent, accompanied by loud noise. Felt at Coventry, Derby, Nottingham, Northampton, Grantham, Lincoln, Peterborough, Ely, &c. Chimneys thrown down in Northampton and slight damage at Leicester. (Phil. Trans., vol. xlvi., Appendix; Lond. Mag., vol. xix.; Mallet, &c.)

1752. Feb. 23rd. Dartmoor and neighbourhood; a smart shock. Felt at Manaton, Moretonhampstead, and Widdicombe, where houses were injured and one of the pinnacles of the church thrown down. (Mrs. Brays' description in 'Borders of the Tamar and Tavy,' vol. i., p. 310. Ed. 1863).

1755. July 31st, between 6 and 7 a.m. Yorkshire, Lincolnshire and Northamptonshire. The walls of a house at Frodingham partly fell. Felt also at Burringham Moors, Luddington, Rushdon and Althorp. (Lond. Mag., vol. xxiv. Mallet, on the authority of v. Hoff, gives the date as Aug. 1st, and only mentions Northamptonshire.)

1755. Nov. 17th, evening. Whitehaven and Irton, Cumberland; and Herefordshire. Houses said to have been thrown down in Herefordshire (Mallet on authority of Coll. Acad., and v. Hoff.)

1756. Jan. 2nd, about 7 h. 30 m. p.m. West of Ireland; a smart shock; damage caused at Ballymore, some miles from Tuam (Mallet, on authority of Journ. Encycl.)

1768. May 15th, 4 h. 15 m. p.m. Newcastle, Manchester, Darlington, Kendal, and places in Yorkshire. At Kendal the river was much agitated and a rumbling noise preceded shock. At Manchester walls were moved and the flagging of a kitchen seen to heave. (Annual Register, vol. xi.; Mallet, &c.)

1769. Middle of November. Inverness; several houses thrown down. (Ann. Reg., vol. xii.)

1786. Aug. 11th, shortly before 2 a.m. Whitehaven, Cockermouth, Workington, Maryport and Keswick (Cumberland), Cartmell (Lancashire), Lancaster, Kendal, Newcastle, Glasgow, Carlisle, Aberdeen, Isle of Man and Dublin. Buildings damaged, chimneys thrown down, people thrown off their feet, and birds from their perches. At Newcastle two shocks; at Whitehaven several. Usual noise heard preceding shock. (Gent. Mag. vol. lvii.; Ann. Reg., vol. xxix.; Phil. Trans.. vol. lxxvii.; Mallet, &c.)

1790. Feb. 27th, 4 a.m. Ormside, Westmoreland. Violent shock and loud explosion; two fissures formed, one 200 feet long and very deep, into which houses and cattle sunk. Probably a landslip. (Gent. Mag., vol. lx.; Mallet, &c.)

1792. March 2nd, about 8 h. 40 m. p.m. Counties of

Bedford, Leicester, Nottingham, Rutland and Lincoln. Felt at Stamford, Doncaster, Kettering, Nottingham, Bottesford (Leicestershire), Newark, Southwell, &c. Some old houses thrown down at Biggleswade (Bedfordshire). Mallet gives date as March 1st, 8.30 p.m. (Gent. Mag., vol. lxii., Part i.; Ann. Reg., vol. xxxv.)

1793. Sept. 28th, 4 p.m. Salisbury and Shaftesbury. Usual noise; chimneys thrown down and bells rung. (Gent. Mag., vol. lxiii.; Mallet.)

1795. Nov. 18th, about 11 p.m. From Leeds to Bristol and from Norwich to Liverpool. Severe at Derby and Nottingham. Felt also at York, Sheffield, Doncaster, Northampton, Coventry, Leicester, Oxford, Birmingham, &c. Accompanied by usual subterranean noise. Chimneys thrown down and bells rung at Nottingham and Derby. (Phil. Trans., 1796; Gent. Mag., vol. lxvii.; Mallet, &c.)

1799. Feb. 6th, night. Guernsey. "Several houses rent from top to bottom." (Gent. Mag., vol. lxix.)

1812. May 1st, 6 h. 20 m. p.m. Wales and Gloucestershire. Felt at Swansea and other places towards Cardiff. Chimneys thrown down at Neath. Accompanied by usual sound. (Gent. Mag., vol. lxxxii., Part 1.)

1816. Aug. 13th, 10 h. 45 m. or 11 p.m. Inverness and country for 100 miles round. Felt distinctly at Edinburgh and Glasgow. Top of the spire of the church at Inverness twisted round; doors swung, bells rung, and a large sluice gate thrown up through a distance of a foot; water of Loch Leven rendered turbid. A slight shock thirty minutes later. (Gent. Mag., vol. lxxxvi., Part 2; 'Annals of Philosophy,' vol. viii.; Mallet, &c.)

1838. March 17th, 1 p.m. Shrewsbury and neighbouring villages; Meole, Hanwood, Dorrington, Longden, Pontesbury, &c. Rumbling noise, houses and furniture violently shaken, bells rung, and bricks thrown from a chimney. Felt strongly in coal pits. (Ann. Reg. 1838; Mallet, &c.)

1839. Oct. 23rd, about 10 h. 30 m. p.m. Over nearly two-thirds of Scotland, extending as far north as the Caledonian Canal. Focus probably Comrie in Perthshire, a place constantly subject to slight shocks. The movement here appeared to be vertical; walls were injured and furniture displaced. Very loud noise heard; water in many places agitated. (D. Milne, in Edin. New Phil. Journ., vol. xxxv.; Mallet, &c.)

1841. April 21st, 1 h. 35 m. a .m. Oban, Argyleshire. Felt strongly at Lismore lighthouse, the upper part of which was made to vibrate; loud noise heard. The ferry-house at

Connal, nine miles east of the lighthouse, rent by the shock. Three slighter shocks felt at Oban on April 19th. (Edinb. New. Phil. Journ., vol. xxxvi.: Mallet.)

1841. July 30th, 8 a.m. Comrie, Perthshire; chimneys broken and walls rent at Garrickrow, Ross, Duneira, &c. Extent of shock given as follows:—E. Newburgh (38 miles), W. Dalmally (about same distance), N. Glenlion (30 miles), S. Alloa and Stirling (20 to 30 miles). Dykes thrown down in many places; loud noise. Many shocks felt the same day and during every month of the year. (Brit. Assoc. Rep., Manchester, 1842.)

1863. Oct. 6th, about 3 h. 22 m. a.m. Midland and southern counties, Wales and Ireland. Extended northwards to Doncaster, Huddersfield and Clitheroe; east to Market Rasen, Peterborough and Bedford; south to London, Dorchester, and Plymouth; west to Dublin and Wexford. Shock felt most strongly at Hereford, Ross, Brecon, Monmouth, Newport and Galway. Felt also at Derby, Lancaster, Ulverston, Harrogate, Malton, Scarborough, Bury St. Edmunds, Brighton, Isle of Wight; also at Birmingham, Wolverhampton, Market Harborough, Burton-on-Trent, Gloucester and the neighbourhood of the Cotteswold Hills, Taunton, Cheltenham, Exeter, Dudley (crockery broken and clocks stopped), Worcester, &c. At this last place some chimney-pots displaced; at Congleton (Cheshire), bricks and chimneys displaced. Felt also at sea, 20 miles from Milford Haven. In some places loud rumbling noise heard, particularly at Hereford and Burton-on-Trent. ('Times,' Oct. 7th, 1863.) Houses injured at Sellack, in Herefordshire. (See present Report, under Ashby Parva.)

1865. Jan. 27th, shortly before 6 h. 10 m. At Hempsted Court, near Gloucester; a wooden shed thrown down. Other shocks on same day felt at Beeston Observatory, near Nottingham, Leicester, Chulford near Stroud, Brighton, Liverpool, Usk (Monmouthshire), and on the previous day in London (Kennington), Newport (Monmouth), and Cardiff. On 29th at Sunbury, and on the 30th at the same place. On Feb. 1st at Beeston again. Several European earthquakes and Hecla active about these dates. ('Times,' Feb. 1st, 4th and 9th, 1865.)

1869. March 15th, a few minutes after 6 p.m. East Lancashire and borders of West Yorkshire. Violent at Accrington, Haslingden, Rosegrove and Waterfoot, lasting 7 or 8 seconds; perceptible at Blackburn, Bury, &c.; a momentary tremor in Manchester. Also felt at Pendleton, Cheetwood and Hull. A chimney said to have been thrown down

at Newchurch, and the wall of Haslingden railway-station reported to have been slightly cracked. Slighter shocks on March 17th in E. Yorkshire, and on the 25th at Manchester, &c. ('Times,' March 16th, 17th, 19th, and 29th, 1869.)

1881. August 26th, about noon. Teversal, Nottinghamshire, and at Tackley. Slight damage to a chimney and ceiling. ('Times,' Aug. 30th, 1881.)

As will be seen from the foregoing catalogue, many shocks of apparently great destructiveness have from time to time been recorded, but the early accounts are most probably exaggerated, and are certainly too vague to admit of any fair estimation of their severity. It is only where specific accounts of the damage to cathedrals, churches, and other buildings have been handed down, that there is some means of approximately judging of the intensity, and estimated by this standard the earthquakes of 1185, 1246, 1248, 1275, 1382, and 1480, appear to be the only ones which admit of comparison with that of April 22nd, 1884; or, in other words, since authentic records were kept, there have been but six earthquakes in Britain which may have equalled or exceeded in intensity that which forms the subject of the present Report.

But although Essex had previous to last April been exempt from destructive shocks, there are some few records of earthquakes originating elsewhere, which in former times made themselves felt in our county. As a contribution to local history, it will be of interest to give these records here in chronological order.

In 1692 (Sept. 8th, between 2 and 3 p.m.), there occurred a severe earthquake in Europe, which was felt in some parts of Kent, Middlesex (London), Essex, Suffolk (Ipswich), Norfolk (Norwich), &c. In Essex there are records from Colchester and Coggeshall, which are given below *in extenso*:—

"On Thursday, Sept. 8, 1692, there happened about two of the clock in the afternoon, for the space of a minute or more, an universal earthquake all over England, France, Holland, and some parts of Germany. And particularly it was attested to me by the masons that were there

a-plastering the Steple of St. Peter's, in this town, and upon the uppermost scaffold, that the Steple parted so wide in the midst that they could have put their hand into the crack or cleft, and immediately shut up close again, without any damage to the workmen (who expected all would have fallen down), or to the Steple itself. Most of the houses here and elsewhere shook, and part of a chimney fell down on North Hill; and very many who were sensible of it were taken at the same time with a giddiness in their head for some short time. In witness of what is here related, I have hereto set my hand. Robert Dickman, Minister of St. Peter, Colchester." —'History and Description of the Ancient Town of Colchester,' by Thomas Cromwell, 1825, vol. i., p. 188. This record is from the parish register.

The record relating to Coggeshall is quoted from 'Bufton's Diary,' by the Rev. Bryan Dale in his 'Annals of Coggeshall," 1863:—

"1692. September 8th being Thursday and ye same day that Jacob Cox dyed about 2 o'clock there was an Earthquake at Coxall and many towns beside hereabouts and at London and several other Countries we heard and ye news-letter said it was at ye same time in Holland and ye rest of ye provinces in ye Netherlands—I was in our garret at that time and heard ye house crack and perceived it shake and was afraid it would fall and therefore ran downstairs."

The next records are in the year 1750:—

Thursday, February 8th (o.s.). "Between 12 and 1 o'clock afternoon an earthquake was felt throughout *London* and *Westminster;* the councellors in the court of king's bench and chancery in *Westminster Hall* were so alarmed that they expected the building to fall; and in the new buildings about *Grosvenor Square* People ran out of their houses, the chairs shaking, and the pewter rattling on the shelves; a slaughterhouse with a hayloft over it was thrown down in *Southwark,* a chimney in *Leadenhall-street* and another in *Billiter Square,* several chimeys and part of a house near *Horslydown.*

"On enquiring we find that the shock was felt at *Deptford* and *Greenwich* to *Gravesend,* at *Dagnams*[3] and *Paynesbridge,* between *Rumford* and *Brentwood,* at *Coopersale* near *Epping,* at *Woodford, Walthamstow, Hertford, Highgate, Finchley,*—

[3] "Another shock was felt here half an hour after the first."

not at *Barnet;* just perceived at *Richmond* in *Surrey, Bromley* in *Kent,* not at *Deal* or *Canterbury;* the news mentions it at *Calais* and in Italy."—'Gentleman's Magazine,' vol. xx., p. 89.

Tuesday, March 8th (o.s.). "This morning, at half an hour after five o'clock, the town [London] was again alarmed with another shock of an earthquake, which is generally allowed to be more violent and of a longer continuance than that felt this day month; great numbers of people were awakened from their sleep merely by its violence, which however has done no other mischief than throwing down several chimneys, and damaging some houses. The shock was so great in some parts, that the people ran from their houses and beds almost naked. In the high grounds by *Grosvenor Square,* &c., it is said to have been felt more than in other parts, the brasses and pewter of several kitchens being thrown down and to some distance from the shelves. In *St. James's Park,* and all the other places, the ground moved very perceptibly, and the noise seemed to break three times. About five o'clock was a continual, though confused lightening, till within a minute or two of the shock being felt. It is reported by many people, that there was a small shock between one and two this morning. A lady in *Piccadilly,* a curious collector of old china, who had piled it on stands, had it flung down and broke; and a great china-shop in *St. James's Street* had the like accident: bells in several steeples were struck by the chime hammers; and great stones fell from the new spire of *Westminster Abbey.* A maid-servant in *Charterhouse Square* was thrown out of bed by the shock and broke her arm. The dogs were sensible of it; and some of them howled in an uncommon manner, and fish jumped half a yard above water.

"The shock was felt at *Cheshunt, Hertford, Ware, Copthall* near (not at) *Epping, Beckenham* in *Kent.*"—'Gentleman's Magazine,' vol. xx., p. 187.

In Noorthouck's 'History of London,' 1753, this shock is said to have been felt also at Loughton, and "in the skirts of Epping next to London but not in Epping Street, likewise at Thegdon-mount [Theydon Mount?] and Nettswell . . . . and very violently at Waltham; also at Bromley, Beckenham and Croydon in Kent, at which two last places it occasioned the hammers of the clocks to strike upon the bells."

The great earthquake of November 1st, 1755, by which Lisbon was destroyed, and which shook an area of the earth's surface four times greater than the whole of Europe, was felt in many parts of this country, and tidal disturbances were produced round our coasts. The inland waters were also thrown into agitation in many parts of England[4] and Scotland. Amongst these records the following communication to the Royal Society relating to the county of Essex will be of local interest:—

"Agitation of Water in Rochford, Essex, Novr. 1, 1755, in a Letter from the Rev. Mr. Thomlinson, to the Rev. Dr. Sykes.

"Christmas-day, 1756.

"It will surprise you to hear that we had some symptoms of an earthquake at this place, on the very same day, and about the same hour, in which the late dreadful convulsion of the earth was in so particular a manner fatal to Portugal. One instance of it was of a pond in a close of Mr. Sly's adjoining the churchyard; where the water was observed by Mr. Sly himself to flow a considerable way up the mouth of the pond, and then returning to flow up the opposite side, repeating this sort of motion for about a quarter of an hour. What is further remarkable in this case is that, at the very time of this fluctuation, Mr. Sly had the curiosity to examine the condition of two other ponds, which are but a small distance from the former, and found them both very still and quiet. It may deserve notice, that the motion of the water in Mr. Sly's pond was only from East to West and from West to East alternately. Whether the fluctuation in those other ponds, which have been mentioned in the newspaper, was the same, it may be worth while, it will at least be a matter of curiosity, to inquire. Mr. Sly's pond is very large and almost round. Its mouth is on the East side. The two neighbouring ponds lie in length from North to South, and are comparatively very narrow in their breadth from East to West, which may in some measure account for the motion of the water in them, if there was any, being less

[4] Amongst many other places where this oscillation of the water was observed was Shirburn Castle, Oxfordshire, where the present earthquake was also felt. I am indebted to the Countess of Macclesfield for sending me the extract relating to this observation, and I only regret that want of space forbids my quoting it *in extenso*. See Phil. Trans., vol. xlix., p. 368. For an explanation of these phenomena see a paper by Prof. J. Milne, 'Nature,' vol. xxvi., p. 629 (Oct. 26th, 1882.

observable; but I have no reason to suppose there was any, as Mr. Sly could discern none.

"Mr. Sly, immediately on his return home, informed his family of this very astonishing and unaccountable accident, and had not the least suspicion at that time of there being any earthquake, either here or in any other part of the world."—Phil. Trans., vol. xlix, pp. 364 and 365.

II. Preparation of the Report.

In striking contrast with those earthquakes by which Britain was visited in early times, and of which the tale travelled but slowly through the land, increasing in exaggeration, and becoming largely mixed with superstitious embellishment as the news spread from town to town, the occurrence of the present shock was made known and many of the details made public throughout the country in the evening papers of the day of the disaster. As soon as the news was confirmed that the disturbance had originated in our county, I communicated with some of our members living in and about the area of destruction, with the object of getting reliable information as to the nature and amount of damage, being strongly impressed with the necesssity of putting upon record, in the interests of science, a complete account of this visitation, and feeling that the duty of undertaking such a task naturally devolved upon the Essex Field Club, as the only organized local scientific society extending its operations over the county. The subject was accordingly brought under the notice of the Club, at the meeting held on April 26th of last year, and I took upon myself the labour of drawing up the report, the more willingly as I found that Mr. William White, one of our most active members, was much interested in the occurrence, and was prepared to give me the benefit of his co-operation. Before commencing work it was evidently essential to make a personal inspection of the districts most severely shaken, and on May 3rd, the earliest opportunity that presented itself, I left for Colchester, accompanied by Mr. T. V. Holmes, F.G.S. (late of the Geological Survey), and our Hon. Secretary, Mr. William Cole. From Colchester we had the advantage of the local

guidance of our members, Mr. Henry Laver, F.L.S., and Mr. J. C. Shenstone, F.R.M.S.; and the arrangements which these gentlemen had kindly made on our behalf, much facilitated our visit of inspection. Two days were devoted to an examination of the damage caused in the town and surrounding villages, many notes and sketches being taken in the field.

Before our departure I received some useful information from one of our members, Mr. W. H. Bird, of Buckhurst Hill, who had been through the damaged villages on April 23rd. I learnt also that my friend, Mr. G. J. Symons, F.R.S., the well-known meteorologist, had likewise been over the ground the day after the earthquake, and an interview with this gentleman fortunately secured his warm sympathy and promise of co-operation for the proposed Report. In the 'Times' of April 23rd, Mr. Symons had appealed for information; and during his visit he had made many notes and had entered all the cases of damage that came under his notice on the 6-inch ordnance map. After making use of these materials for the preparation of the article on the earthquake which appeared in the 'Meteorological Magazine' for May, 1884, Mr. Symons kindly handed over to me the whole of his correspondence, notes and maps, together with many other letters and newspapers that had reached him too late to be made use of for his own notice; and much of the completeness of the present report is due to the valuable assistance which Mr. Symons has from the first so readily afforded.

On May 10th, at the invitation of our Vice-President, Mr. E. A. Fitch, F.L.S., I (in company with Mr. W. Cole) attended a public meeting convened by the Mayor of Maldon, on behalf of the Mansion House Earthquake Relief Fund, and took the opportunity of making a further appeal for information, which resulted in the communication of some additional observations from this neighbourhood; I was also enabled during this visit to interview several of the residents whose houses had been shaken by the disturbance, and to make further notes of the effects observed.

On commencing to arrange the materials thus accumulated, it was found, as might have been anticipated, that most of the observations were devoid of much scientific value, chiefly owing to the absence of recording instruments in the area shaken, partly on account of the want of knowledge as to what to observe, and partly on account of the alarm into which the inhabitants were naturally thrown and which prevented any definite observations being made at the time. In order to lose no observation which might prove of value, it was therefore thought desirable to make further appeals before the damaged buildings had been completely repaired, and before the recollection of the event had, with the lapse of time, become too indistinct to be reliable. Accordingly, at the Club meeting held on May 24th, a preliminary sketch of the progress of the work was given, and it was pointed out what kind of observations were most likely to be of use, and again in 'Nature' of June 12th (vol. xxx., p. 145) I made an appeal for further scientific information. In addition to these efforts to obtain trustworthy observations while the subject was still fresh in memory, by the kindness of our member, Mr. F. H. Meggy, of Chelmsford, the following set of questions, drawn up by Mr. White, was circulated throughout the county, by means of the 'Chelmsford Chronicle' (May 24th), and other local papers :—

1. Whether the disturbance was violent or slight in your neighbourhood.
2. If any sounds premonitory to or accompanying the shock were heard, and their nature.
3. Atmospheric conditions, temperature, barometric readings.
4. In the case of stoppage of clocks, the exact time and direction of swing of pendulum and of pictures or other suspended objects (bearings of the walls, &c.).
5. Whether sufficiently forcible to set bells ringing or to dislodge articles of furniture, open doors, &c.
6. Duration of the oscillation in seconds, if noted (as approximate as possible), and whether more than one shock.
7. Did any shower follow the earthquake, or was any special wind-current noticed ?
8. Full details as to effect upon springs.

9. In the case of dislocation of walls and chimneys, the direction of fall or twist.

10. The superficial geology so far as known.

Through the courtesy of Mr. A. E. Gibbs, an inquiry for particulars respecting the county of Hertfordshire was made public through the columns of the 'Herts Advertiser and St. Alban's Times' of May 10th.

The large accumulation of notes, letters, and newspaper cuttings secured through these various sources having been sorted and read, it was found necessary to at once open correspondence with many of the writers, in order to elicit further particulars, and, thanks to the assistance given by Mr. White, but few observers who appeared to have noticed any fact of importance, or who had failed to express themselves with sufficient distinctness in the first place, escaped this form of application. It may be of interest to give here the numbers of the letters and post-cards which were finally received :—

From Essex	109	Sussex	3
Suffolk	8	Hampshire	2
Norfolk	3	Buckinghamshire ...	3
Lincolnshire	4	Gloucestershire ...	1
Cambridgeshire ...	3	Somersetshire	1
Hertfordshire	4	Ostend	1
Leicestershire	3	Miscellaneous communications not containing specific reports, but having reference to the work	104
Northamptonshire ...	1		
Oxfordshire	4		
Rutland	1		
Warwickshire	1		
Derbyshire	2		
Cheshire	1		
Middlesex	48	Total	321
Surrey	3		
Kent	11		

It is with much pleasure that I take the present opportunity of thanking my numerous correspondents; and although space forbids the mention of each individual to whom I am indebted for information, furnished either directly or through Mr. Symons or Mr. White, I cannot pass over

certain names without special recognition of services rendered.

First and foremost, our member Mr. J. C. Shenstone, of Colchester, has laboured constantly for us during the progress of the work, kindly visiting and reporting upon any case of damage of which the details were recorded insufficiently in the first instance, and has always with the greatest readiness responded to appeals for information, regardless of any personal inconvenience to which my frequent applications must, I am afraid, have often subjected him. The value and extent of Mr. Shenstone's services will be best estimated by the frequency with which his observations are quoted in the body of the Report.

Amongst others to whom I am under an obligation for assistance of various kinds, I may mention the following:—

Mr. James Jackson, of Wivenhoe Hall, has been good enough to furnish the detailed analysis of the whole amount of damage given in a subsequent section of the Report.

Mr. E. A. Fitch, our Vice-President, has supplied many notes from Maldon and neighbourhood.

Mr. E. B. Knobel, F.G.S., Sec. R.A.S., of Bocking, has forwarded a report from his own neighbourhood, and some valuable notes from those parts of the area of structural damage visited by him.

Mr. F. H. Meggy has kindly supplied notes from Chelmsford and vicinity.

Mr. Alfred P. Wire, of Leytonstone, has communicated on my behalf with many of his friends in various parts of Essex.

Mrs. Dennis, of Layer Rows, has been good enough to furnish an excellent report from Layer-de-la-Haye and neighbourhood.

Mr. E. T. Dowson has supplied many notes from Suffolk and Norfolk, in a communication to Mr. Symons.

Mr. C. F. Hayward, F.S.A., has kindly collected several reports from residents in London.

For assistance given in the geological portions of the Report, I have great pleasure in expressing my thanks to our President, Mr. T. V. Holmes, who, as already mentioned,

accompanied me on the tour of inspection and gave me the benefit of his experience in the field. I am also indebted for assistance to Messrs. W. Topley, W. Whitaker, and G. H. Kinahan, all of the Geological Survey. To Prof. J. P. O'Reilly, of the Royal College of Science for Ireland, I am indebted for a number of his memoirs and papers bearing on certain geological aspects of the direction of earthquake movement. For much valuable advice respecting the dynamical principles of seismology I beg to acknowledge my indebtedness to the published writings, as also to several private communications from Prof. J. A. Ewing, of the University of Dundee, formerly President of the Seismological Society of Japan, and one of our first authorities on earthquake measurement. From Prof. John Milne, F.G.S., of Tokio, Secretary of the Seismological Society of Japan, I have also received copies of many of his papers, which have been of the greatest value in the preparation of the present Report.

Free use has been made of the reports in the local and metropolitan newspapers, and I am glad to be able to bear witness to the general accuracy and excellence of the accounts, which were published with an alacrity that certainly does credit to modern journalism.[5] The information supplied by the correspondents of 'Nature,' has also been made use of with due acknowledgment. Of special reports issued by local societies, I have only met with one which in any way attempts to give an account of the general effects experienced throughout the county over which the Society extends its operations—I refer to Mr. C. A. Markham's paper, which appears in No. 19 of the 'Journal of the Northamptonshire Natural History Society and Field Club,' published in August, 1884. This absence of record on the part of the local societies is certainly to be deplored, as accurate observations from those counties contiguous to our

[5] A special edition of the 'Essex Telegraph' was issued on the evening of April 22nd, and all the accounts and letters which appeared in that paper were afterwards reprinted and issued in the form of a small pamphlet by the publisher, Mr. F. Wright, of Head Street, Colchester.

own, such as Suffolk and Cambridge, were especially required. Seismological observations come fairly within the scope of, and could be most appropriately undertaken by, local scientific societies, to whom I may take the present opportunity of pointing out the necessity and importance of systematic work in this field. Scarcely a month passes without some part of Britain being shaken by a seismic disturbance, and there are certain stations in this country where permanent instruments might be set up with considerable advantage to the cause of science.[6]

III. General Characters of the Disturbance.

The present earthquake having been, as already pointed out, the most serious which has shaken our country for over four centuries, it is interesting to make a comparison between the completeness of the records and those earlier accounts of earthquakes which have been handed down from the times when such means of communication as railways, electric telegraphs and daily newspapers were unknown. The shock was doubtless felt in many districts from which no records have been received, but even with these deficiencies the number of notices and the general amount of detail given is most instructive, as furnishing a comparative estimate of the increase both in the number and keenness of the observers, as well as in the means of intercommunication in modern times. The same fact is brought out by considering the reports from the large towns in comparison with those from

[6] Since writing the above, a paper on "Earthquakes and Subsidences in Norfolk," by Horace B. Woodward, F.G.S., has been published in vol. iii. of the 'Transactions of the Norfolk and Norwich Naturalists' Society.' In July, 1884, Mr. Edward Parfitt read a paper on "Earthquakes in Devonshire," which appears in the 'Transactions of the Devonshire Association for the Advancement of Science, Literature and Art,' vol. xvi., pp. 641—661. It gives great satisfaction to know also that instruments are to be established at the Ben Nevis Observatory, under the able superintendence of Prof. J. A. Ewing. [A short paper on the Essex Earthquake by Mr. G. H. Kinahan, read before the Royal Dublin Society on June 16th, 1884, has been published since the foregoing note was written. Proc. Roy. Dub. Soc. 1884, p. 318.]

the smaller villages and hamlets given in the succeeding pages. Regarded merely from a numerical point of view undue prominence would appear to be assigned to the notices from such towns as London and Ipswich, but this must be ascribed to the larger number of observers most likely to notice such an occurrence, as well as to the accumulation in these areas of a greater amount of what may be called "seismic material," in the form of high and shakeable buildings.

Extent of the Shock.—Taking as the centre the village of Abberton, which was certainly very near the epicentrum, the extreme distances to which the disturbance made itself felt were:—

E. Ostend. Long. 2° 58′ E.
W. Street, Somersetshire. Long. 2° 45′ W.
S. Freshwater, Isle of Wight. Lat. 50° 40′ N.
N. Brigg, Lincolnshire. Lat. 53° 33′ N.

The greatest distances measured from the centre are:—

N.N.W. Brigg. 135 miles.
N.W. Altrincham. 180 miles.
W.S.W. Street. 170 miles.
S.W. Freshwater. 135 miles.
S.S.E. Boulogne. 90 miles.
S.E. Ostend. 100 miles.

The mean radius is thus 135 miles, and, assuming the area shaken to be circular, we have for this area of country

$$\pi\, 135^2 = 57{,}256 \text{ square miles.}$$

A parallelogram described through the above-mentioned extreme stations would be about 242 miles from E. to W., and 200 miles from N. to S., giving an area of 48,400 square miles. The mean of the areas thus found is 52,828 square miles.

It appears therefore that the sensible shock extended over fully 50,000 square miles.[7]

[7] A record has since been published, stating that the shock was probably felt as far west as Exeter, long. W. 3° 32′; lat. N. 50° 43′, but this does not materially affect the calculation.

Intensity of the Shock.—The data necessary for calculating the intensity of an earthquake shock with any approach to accuracy[8] can only be obtained from instrumental records, and, as the present disturbance was wholly unrecorded by such means, the intensity as compared with other earthquakes can only be roughly estimated by comparing the respective areas shaken.

Thus, taking the amount of material moved as proportional to the moving force, this quantity of material will vary as the square of the radius of the area shaken, so that the intensity of the shock varies as the square of this radius.[9] This method of comparison is of course based on the supposition that the centrum of the shocks being compared is at the same depth beneath the surface, but as the true depth of the origin is in most cases unknown, an error is introduced which renders such calculations of but little value except as crude approximations.

The great Lisbon earthquake of 1755 had a radius of 600 miles, so that, as compared with the present shock (assuming the two disturbances to have originated at the same depth), the intensity was :—

$$600^2 : 135^2 = 360{,}000 : 18{,}225 = 19.7.$$

The Lisbon earthquake was thus nearly 20 times the intensity of the present shock.

Taking Mallet's classification according to extreme radius, earthquakes are of the 1st, 2nd, or 3rd class, according as the area shaken has a radius of 540, 180, or 60 miles. The shock forming the subject of the present Report was thus intermediate between the 2nd and 3rd classes.

[8] The intensity of a shock is proportional to the maximum kinetic energy of the objects on the earth's surface relatively to that surface, or symbolically :—

$$I \propto \frac{A}{T^2}$$

where I is intensity, A amplitude, and T the period of vibration. See a paper by Messrs. Milne and Gray, 'Phil. Mag.,' Nov. 1884, p. 371; also Prof. Ewing's record on 'Earthquake Measurement,' Tokio, 1883, p. 9, for a more elaborate treatment of this subject.

[9] Milne, on the Japanese earthquake of Feb. 22nd, 1880. Trans. Seism. Soc. Japan, vol. i., part ii., p. 53.

The earthquake occurred during a period of general seismic activity throughout the world. When with the progress of the science of seismology a complete catalogue of the earthquakes of the world is drawn up, in continuation of Mallet's great work, and brought down to the present time, it will be found that the Essex earthquake was one of a group extending over a period of several years, and characterised by exceptional violence in various parts of the world. Without expanding the present Report to an unnecessary length by going too far back in time, it will be of interest to indicate briefly the disturbances which have been felt in this country for three years previous to the shock of April 22nd of last year, together with the more violent of those earthquakes which have been experienced in other European countries during the same period[10]:—

1881. Jan. 12th, about 7 h. a.m. Bridge of Allan, Stirling. Smart shock; no damage. ('Nature,' Jan. 20th.)

1881. Jan. 27th, about 2 h. 20 m. p.m. Over a considerable area of Switzerland; church bells sounded, books thrown from shelves and pictures from walls; over 100 chimneys thrown down in Berne. A slighter shock at 8 p.m. the same day; the 24th, earthquake, and probably the most severe recorded from Switzerland since Nov. 1879. Many slighter shocks in Italy on Jan. 24th and 25th. ('Nature,' Feb. 3rd.) Many shocks during this month also in Hungary, Austria, &c. (*Ibid.*, Feb. 10th, 1881.)

1881. Feb. 23rd. St. Michael's, Azores; 36 successive shocks; church and 200 houses said to have been thrown down and many people killed. Connected with a submarine eruption. Shocks continued into the following month. ('Nature,' March 3rd, on the authority of the 'Daily News.')

1881. March 4th, 1 h. 5 m. 30 s. a.m. The Island of Ischia; Casamenella almost entirely destroyed and many houses in Casamicciola and Lacco thrown down. From 100 to 130 persons killed and 160 seriously wounded. A terrific shock,

[10] The list here given mainly comprises earthquakes of sufficient intensity to produce structural damage; lesser shocks, which were *very numerous* throughout Europe during this period, have been omitted, except as regards Great Britain. The object of the list is simply to give an idea how widespread and active the manifestation of seismic energy has been during the last three or four years. The records have been chiefly confined to Europe for the sake of brevity.

followed by a series of weaker vibrations and accompanied by loud subterranean thunder. Lesser disturbances felt in various parts of Europe from the 2nd to the 5th of March; most severely felt in northern Italy. Seismographs at Naples and Vesuvius not affected. (H. J. Johnston Lavis, in 'Nature' of March 24th, and Brit. Assoc. Rep., Southport, 1883.)

1881. March 16th, 12 h. 10 m. a.m. Another slighter shock at Casamicciola and Lacco; damaged walls and a tile factory thrown down. A slight shock on March 27th at 6 h. 45 m. a.m. ('Nature,' March 24th and 31st.)

1881. April 3rd, 1 h. 50 m. p.m. The Island of Chios; three violent shocks, causing the total destruction of 45 towns and villages and the loss of over 4000 lives; enormous fissures opened and great landslips caused from the hills and mountains. Shocks repeated almost daily to April 19th, 250 being noted since the first destructive disturbance. Many towns on the mainland were also seriously injured by the earthquake. Mount Vesuvius active. ('Nature,' April 14th, on authority of 'Daily News.')

1881. May 20th, night. Chios again; two strong shocks bringing down several houses that had escaped the last earthquake. ('Nature,' May 26th.)

1881. June 9th, 12 h. 35 m. a.m. Switzerland; focus probably valley of Upper Rhone; seven or eight oscillations accompanied by usual noise; bells rung, walls cracked, slates dislodged and chimneys thrown down. On this same date an earthquake was reported at Constantinople as having devastated 34 villages in the district of Van. ('Nature,' June 16th.)

1881. June 11th, 9 h. 30 m. a.m. Chios again; some structural damage. ('Nature,' June 16th.)

1881. July 22nd, 2 h. 48 m. a.m. Switzerland, France and Italy, extending over 8000 square kilometres. Preceded and succeeded by slighter shocks; chimneys thrown down and walls cracked in neighbourhood of Chambéry and Aix-les-Bains. ('Nature,' Aug. 18th, on authority of Swiss Seismological Commission.)

1881. Aug. 26th, night. Chios and Tchesme; said to have been more severe than the shock of April 3rd; great destruction of property. ('Nature,' Sept. 1st.) At noon on this date a shock in Nottinghamshire. (See previous catalogue, p. 11.)

1881. Aug. 27th, 4 h. 45 m. p.m. Gorey, Ireland. Felt at Courtown House. ('Nature,' Sept. 15th.)

1881. Sept. 10th, about 8 h. a.m. Italy, in the Abruzzi; several houses damaged and a few people killed and

wounded; church at Atessa seriously damaged. ('Nature,' Sept. 15th.)

1881. Sept. 30th. Anatolia; buildings damaged and 11 persons killed at Changeri. ('Nature,' Oct. 6th.)

1881. Nov. 5th. Carinthia, several shocks in different parts; at Emünd at 10 h. 5 m. a.m., chimneys thrown down and walls damaged. ('Nature,' Nov. 24th.)

1881. December 29th. Kastamoumi; two strong shocks at Kiangari; considerable damage. ('Nature,' Jan. 5th, 1882.)

1882. Oct. 14th, about 3 h. and 7 h. 30 m. a.m. Comrie, Perthshire; 2nd shock the more violent; subterranean thunder. ('Nature,' Oct. 19.)

1882. Oct. (?). Verona, Cassone and Breschia; houses destroyed. ('Nature,' Oct. 26th.)

1882. Oct. 28th, 6 p.m., with repeated shocks to midnight of the 29th. Italy, Cascia. Several old houses thrown down. Believed to have been connected with an eruption of Etna. ('Nature,' Nov. 23rd.)

1883. Jan. 16th, 5 p.m. Monmouth; slight shock accompanied by light rushing sound. ('Nature,' Jan. 18th.) Another shock felt at Hastings on the same day, at 9 h. 9 m. 30 s. a.m. (*Ibid.*, Jan. 25th.) On this date 22 shocks felt at Centi, province of Murcia, Spain; several houses destroyed. (*Ibid.*, Jan. 25th.)

1883. March 5th, 7 h. 30 m. a.m. Cyprus; the most severe shock experienced for many years; uncemented walls thrown down at Limassol. ('Nature,' March 22nd.)

1883. June 25th, about 1 h. 38 m. p.m. Devonshire and Cornwall; followed by a slighter shock at 2 h. 7 m. p.m., and accompanied by a loud noise. Felt at Horrabridge, Boscastle, Holsworthy, Hartland, Clovelly, Bude, Princetown, Launceston, Tavistock, &c. Houses shaken, windows and crockery rattled; no damage. ('Nature,' June 28th.)

1883. July 28th, about 9 h. 25 m. p.m. The Island of Ischia. A terrific report, followed by a series of minor reports. Casamicciola and the districts of Tresta, Olivieri, Penella, Casamonte, Mezzavia, most of Lacco, Fango, Monterone, and Vajola di Forio reduced to ruins, and much damage elsewhere throughout the island; nearly 2000 lives lost. Preceded by general seismic disturbance throughout southern Europe, and succeeded by shocks in the same district on July 29th and August 1st, 2nd, 3rd, 8th and 12th, and Sept. 9th and 10th. Great landslips caused from Monte Epomes, Mt. Rotaro, and Mt. Nuovo; cliff edges slipped down and numerous fissures formed. Seismographs

at Naples influenced by disturbance. (H. J. Johnston Lavis's 'Notices on the Earthquakes of Ischia of 1881 and 1883,' Naples, 1883; and Brit. Assoc. Rep., Southport, 1883.)

1883. Sept. 23rd. Casamicciola again; two strong shocks; one house wrecked. ('Nature,' Sept. 27th.)

1883. Oct. 10th, morning. Bournemouth; slight shock. ('Nature,' Oct. 25th and Nov. 1st.)

1884. Jan. 3rd. Sadakli, near Brussa (Asia Minor); some destruction caused. According to Prof. Forel, this was an "earthquake period" in Switzerland, Italy and Portugal, as numerous shocks occurred in this and the preceding month. ('Nature,' Jan. 17th.)

1884. Jan. 23rd. Many shocks during previous fortnight in the province of Castambul; minarets of mosques thrown down. ('Nature,' Jan. 31st.)

1884. Feb. 18th, (about) 1 h. 10 m. a.m. Essex; Mersea Island and neighbourhood. A slight shock accompanied by loud noise. (See present Report).

1884. March 25th, 9 p.m. Hungary; many houses damaged at Djakovar. ('Nature,' April 10th.)

1884. March 29th, about sunset. Castambul: some old buildings thrown down. ('Nature,' April 3rd.)

Many other earthquakes of great destructiveness occurred during this period, both in the New and Old Worlds, and without here entering into details it may be pointed out that the year 1883 witnessed one of the most stupendous volcanic outbursts of modern times. I refer to the great eruption at the Island of Krakatoa in the Sunda Straits, which commenced in May, reached its maximum on August 26th, and lasted to October 10th, producing great changes in the physical geography of the island, overwhelming large numbers of villages, and causing the loss of many thousand lives.[11] Since the Essex earthquake, the following shocks have been recorded in England and the Channel Islands:—

1884. June 24th, about 5 a.m. Colchester; a slight shock felt by all the inmates of Mr. Henry Laver's house. (Information given by Mr. Laver.)

1884. Aug. 26th, morning. Jersey; violent shaking; crockery rattled; rumbling sound. No damage.

[11] A Committee of the Royal Society is at present engaged in drawing up a report on this catastrophe.

1884. Nov. 14th, 5 h. 10 m. p.m. Lancashire; a loud report heard at Clitheroe; furniture shaken and horses nearly thrown to the ground; no damage.

1884. Dec. 25th, about 10 h. 20 m. p.m. Wiltshire; a slight shock felt at Ramsbury, about time of the first shock of the great Spanish earthquake. (Alfred Batson, in 'Nature,' Jan. 1st, 1885.)

1885.[12] Jan. 22nd, about 8 h. 42 m. Devonshire and Somersetshire; Taunton, Bradford, Creech, the Crewcombe Valley, Combe Florey, Lydeard St. Lawrence, Handy Cross, Stogumber, Monksilver, Bampton, Shillingford, Combehead, W. Buckland, Nymhead, &c. Sound like the passing of a heavy traction engine, houses violently shaken, crockery rattled; a piece of wall thrown down at Bampton. (Local papers; Mr. Edward Parfitt, in 'Nature,' Feb. 12th; and Mr. W. A. Sandford, *Ibid*, Jan. 29th.)

Since the commencement of April, 1884, the following shocks have occurred on the Continent of Europe:—

1884. April 9th, 8 p.m. Italy; Spoleto; violent; bells rung and clocks stopped. ('Nature,' May 15th.)

1884. April 10th, 9 h. 50 m. Italy; Cosenza and Paola; slight. (*Ibid.*)

1884. July 19th, night. Agram; subterranean rumbling; no damage. ('Nature,' July 24th. This place is subject to frequent shocks.)

1884. July 23rd, 2 h. 40 m. p.m. Ischia; strong shock at Forio; rumbling noise; no damage. ('Nature,' July 31st.)

1884. Aug. 3rd, afternoon. Bosnia; several strong shocks at Foca. ('Nature,' Aug. 7th.)

1884. Aug. 5th and 6th. Iceland; violent earthquakes at Cape Reykjanes, which split masonry of lighthouse. Connected with the new volcanic island which had risen off here at the end of July. (W. G. Spence Paterson, 'Nature,' Nov. 13th.)

1884. Aug. 7th, 2 a.m. Italy, along the whole range of the Alban Hills; two chimneys thrown down at Ariccia. ('Nature,' Aug. 14th.) At 3 h. 30 m. two shocks at Rome and as far as Porto d'Anzio. (*Ibid.*)

1884. Sept. 2nd. Lower Austria; Ban en Voeslau and Gainfarn and as far as Wiener Neustadt; no damage reported. ('Liverpool Evening Express,' Sept. 3rd.)

[12] It was reported in the newspapers that another shock had been felt at Lexden, on Jan. 18th, about midnight, but inquiries in the neighbourhood proved that this statement was erroneous. See 'Nature,' Jan. 29th, p. 289.

1884. Oct. 8th, 12 h. 10 m. p.m. Lower Austria; Schrems, Zwettl, &c.; preceded by subterranean noise. ('Nature,' Nov. 6th.)

1884. Nov. 23rd and 24th. Shocks near Briançon, department of the Hautes Alpes. ('Nature,' Dec. 4th.)

1884. Nov. 27th, about 11 p.m. Severe shock at Grenoble; no damage. About the same time several shocks at Lyons, at Marseilles (where furniture was upset), Antibes (Dep. Alpes Maritimes), Draguignan (Dep. Var.), and at Geneva. ('Standard,' Nov. 29th, and 'Nature,' Dec. 4th.)

1884–1885. South Spain. On Dec. 25th, shortly before 9 p.m., a violent shock, causing immense damage in the southern provinces, especially at Malaga, Torrox, Antequera, Loja, Granada, Alhama, Jaen, Seville, Albuequeros, Albunuelas, &c. Numerous towns and villages wrecked, and over 1000 human lives, together with 10,000 head of cattle, sacrificed. A landslip from a mountain at Periana, in Malaga, overwhelmed from 700 to 800 buildings. The area most severely shaken was about 25,000 square miles in extent, the first shock being felt as far north as Madrid. Focus probably the axis of the Sierras Alhama. Shocks repeated almost daily up to the middle of February, 1885, on some occasions of sufficient intensity to cause further structural damage. On Dec. 25th, at 8 h. 17 m. and 11 p.m. (Berne time), slight shocks at Zernetz, Engadine. On Dec. 28th structural damage caused by a severe shock at Tarvis, Carinthia, and about 7 a.m. on the same day a violent shock at Sundal and Oxendal on the west coast of Norway, a locality very rarely visited by such disturbances.

1885. Jan. 1st, 2 a.m. Lausanne; slight.

1885. Jan. 4th. Southern Styria; numerous shocks and slight damage. At the same time felt near Mont Cenis.

1885. Jan. 5th. Italy; strong shock at Velletri near Rome. On this date also, at 3 a.m. at Chambéry, and at 5 h. 50 m. a.m. at Embrun (Hautes Alpes.)

1885. Jan. 21st, between 0 h. 1 m. a.m. Ennenda, Canton Glarus; slight.

1885. Jan. 27th and 28th. Southern Styria; several shocks.

1885. Feb. 2nd, evening. Bosnia and Herzegovina; severe shocks.

1885. Feb. 15th. Savoy; slight shocks about time of renewed disturbances in South Spain. Felt in Valley of Isère and at Chambéry.

1885. Feb. 25th, 8 h. 30 m. p.m. South Hungary; three severe shocks with usual noise at Temesuar. Slighter shocks on following morning.

1885. Feb. 27th. South Spain; renewed disturbances. Two sharp shocks; many houses in the provinces of Granada and Malaga damaged, and buildings injured by previous earthquakes thrown down. Most severe at Granada, Loja, and Alhama.

The Earthquake in relation to Meteorological Conditions.—Although no intimate connection between the occurrence of earthquakes and barometric fluctuations has as yet been established, there seems reason to believe that in certain cases, and especially in volcanic regions, a sudden diminution of pressure might cause an incipient earthquake to be precipitated to a crisis.[13] This is not surprising when we consider that a fall in the barometer of 1-100th of an inch represents the removal of a weight of atmospheric air equal to 20,000,000 pounds per square mile of surface. During the great earthquake period in Spain at the close of last year, for instance, there appear to have been violent gales, accompanied by extreme oscillations of the barometer,[14] although of course this may simply be a case of coincidence. The tendency to connect such unusual and terrible visitations as earthquakes with extraordinary atmospheric phenomena, such as fiery meteors, storms and tempests, &c., has been manifest from the earliest periods, and is by no means extinct at the present time. Thus, with respect to the recent earthquake, a report from Lowestoft asserts that "a remarkable agitation of the water in the New Dock took place, assuming the appearance of a water-spout rising from off the surface. A volume of sand, too, was noticed in a state of gyration." From Wansford in Northamptonshire, also, an observer states that a whirlwind passed over the field where he was working, and a similar phenomenon will be found recorded in the Report as having been noticed at Tring in Hertfordshire. There can be no

[13] See the "Second Report of the Committee appointed for the Measurement of the Lunar Disturbance of Gravity," by. Prof. G. H. Darwin; Brit. Assoc. Rep., Southampton, 1882, p. 111. In the case of microseismic oscillations there certainly appears to be tolerably distinct evidence of such a connection. *Ibid.*, p. 96 *et seq.* Also Prof. Milne on "Earth Tremors," Trans. Seism. Soc., Japan; a paper read Oct. 25th, 1883.

[14] 'Nature,' Jan. 15th, 1885, p. 238.

reason for doubting the fact that on a calm spring morning vorticose movements may suddenly arise in the atmosphere—such phenomena are in fact too common to excite special attention. Looked at in the "dry light" of Science, however, there is not the slightest reason in the present state of knowledge for connecting these atmospheric movements with the earthquake, except as coincidences. With still greater scepticism must be received the statements of a Tillingham correspondent, that "as soon as the shock had passed, a sulphureous vapour was noticed to arise," and of another observer at Wivenhoe, who asserts that a bright steel corkscrew was found tarnished after the earthquake, as a result of the disturbance!

In point of fact the evidence is conclusive that no special meteorological conditions preceded, accompanied, or succeeded the disturbance of last April in direct relationship to that event. The barometer and thermometer had been rising since the previous day, and on the morning of April 22nd the sky was in most parts clear, with bright sunshine and occasional clouds, the wind N.E. or N.N.E. and very light. Both before and after the shock light showers fell in some parts of the country; and at Ely, Canon Joy reports that a heavy hailstorm fell a few minutes before the disturbance. Mr. A. H. Cocks, M.A., of Thames Bank, Great Marlow, states that a party on the Thames at Temple Lock also experienced "a very hard squall immediately preceding the shock." Readings of the barometer and thermometer, given by various observers, will be found in the body of the Report. From these it will be seen that the barometer at Halstead stood at 29·808 inches and the thermometer at 43°; at Faulkbourne the readings at 8.30 a.m. were, bar. 30.02 in., therm. 52°; at Ipswich bar. 30 in., therm. 40°; and at Norwich an aneroid barometer indicated 29.8 in.

Nature and Duration of the movement; number of shocks and subterranean noise.—To the older seismologists an earthquake was simply a wave of elastic compression passing through the materials of the earth's crust, and causing the particles at the surface to oscillate to and fro in a closed curve, the

amplitude and period depending upon the intensity of the originating impulse. Nearly all the calculations formerly made with respect to the maximum velocity of displacement as deduced from the projection of bodies were based on the supposition that the movement at the surface was of the nature of a sudden jerk, and are thus, as pointed out by Prof. Ewing,[15] devoid of value. The old view of earthquake motion might hold good in the case of an instantaneous impulse originating at a point in a homogeneous solid of uniform elasticity in all directions,[16] but such conditions are

[15] 'Earthquake Movement,' Tokio, 1883, p. 75.

[16] A disturbance originating in such a solid gives rise, as is well known to students of dynamics, to two sets of waves, the first or normal vibrations causing the particles to move to and fro *in the direction* of the line of propagation, and the other or transverse vibrations causing the particles to oscillate *at right angles* to the direction of propagation. The first or normal wave in most cases travels faster than the second or wave of distortion. The general formula for the velocity of transmission of a wave is, according to Ewing,

$$\sqrt{\frac{M}{\rho}}$$

where M is the modulus of elasticity for the particular strain of which the wave consists, and ρ the density of the solid. The further the two sets of waves travel from their origin, the more complete is their separation, so that at stations near the focus the effects produced are generally the confused results of the action of both kinds of waves. On arriving obliquely at the surface, where the particles are also free to move in an outward direction, the course of the normal wave becomes changed, and the direction in which a surface particle moves is in no case a rectilinear continuation of the line of direction of the original impulse. In the case of earthquakes of sufficient intensity to produce structural damage it is generally very difficult, and in the absence of instrumental registers is in fact almost impossible, to distinguish between the effects produced by the two kinds of waves, since one component of the distortional wave may coincide in direction with the normal wave. In all earthquakes, moreover, the effects are vastly complicated by the heterogeneous character of the strata through which the wave passes, and the old method of determining the depth of origin by the so-called "angle of emergence" has but little to commend it scientifically in the light of recent investigations. *Cf.* W. Hopkins, "On the Geological Theories of Elevation and Earthquakes," Brit. Assoc. Rep. Oxford, 1847, pp. 74—88, and Prof. Ewing, *loc. cit.*, pp. 1—13. Also a paper by Messrs. Milne and Gray, Phil. Mag., Nov. 1881, p. 369.

never realized in actual earthquakes. In the first place, the disturbance never originates at a mere point, but always along an axis of greater or less extent, such as a fissure or fault. The vibrations thus set up, in travelling to the surface, undergo so many changes of direction by reflection and refraction in passing through the very heterogeneous materials of which the earth's crust is composed, that the motion of a particle at the surface is, in all cases where the movement has been traced by seismographs, of an extraordinary degree of complexity, as may be seen by reference to any of the curves published by the Japanese observers. Thus Prof. Ewing, who, with Prof. Milne, has had the opportunity of recording large numbers of earthquakes in the Plain of Yedo, Japan, summarises his results as follows:—

"Automatic records given by seismographs confirm what has been said, on theoretical grounds, as to the complexity which earthquake motions may be expected to present. They show that, as observed at a station on the surface of the earth, an earthquake consists of a very large number of successive vibrations—in some cases as many as three hundred have been distinctly registered. These are irregular both in period and amplitude, and the amplitude does not exceed a few millimetres, even when the earthquake is of sufficient severity to throw down chimneys and crack walls; while in many instances the greatest motion is no more than a fraction of a millimetre. The periods of the principal motions are usually from half a second to a second, but, as has been already said, the early part of the disturbance often contains vibrations of much greater frequency. The earthquake generally begins and always ends very gradually, and it is a noteworthy fact that there is in general no one motion standing out from the rest as greatly larger than those which precede and follow it. The direction of motion varies irregularly during the disturbance—so much so that in a protracted shock the horizontal movements at a single station occur in all possible azimuths. The duration, that is to say the time during which the shaking lasts at any one point, is rarely less than one minute, often two or three, and in one case in the writer's experience was as much as twelve minutes."[17]

[17] *Loc. cit.*, p. 13. Almost identical results are stated by Milne and Gray in their paper on "Earthquake Observations and Experiments in Japan," Phil. Mag., Nov., 1881, pp. 356—377.

There is every reason to believe that the earthquake with which we are here dealing was precisely similar in character to those frequent shakings which have been so thoroughly studied in the Plain of Yedo. As in the case of the latter, if our earthquake had been made to trace the story of its own movement on a series of seismographic plates, we should no doubt have seen the gradually commencing tremor increasing in amplitude and complexity till the "shock" and destruction occurred, and then again dying gradually out. Certain observations which have been communicated, although lacking the precision of instrumental records, fully bear out this view respecting the character of the motion:—

(1.) An observer at Heybridge noticed that a T-square hanging on a nail commenced to swing some two or three seconds before the shock itself was felt. This indicates that the office was in a state of gentle oscillation for two or three seconds before the arrival of that phase of the movement of larger amplitude which constituted the actual "shock." (See Report under Heybridge.)

(2.) A lady in bed, at Ipswich, lying still and looking out of window at the clouds, suddenly saw the latter apparently thrown into a state of agitation, and immediately afterwards heard the rumbling sound and experienced the shock. The apparent movement of the clouds, so graphically described by this correspondent, must be attributed to the lesser oscillations of the house which preceded the movements of greater amplitude constituting the "shock." (See Report under Ipswich).

With respect to the duration of the movement the estimates, as might have been anticipated, differ widely, the discrepancies being due to the following circumstances:—

(1.) The estimate depending mainly upon the judgment is liable to "personal equation," or to subjective influence, according to the sensitiveness of the observer; in other words, the duration is apt to be estimated by the intensity of the feelings, especially in the area of damage where actual fear for the moment prevails.

(2.) Different buildings are doubtless made to oscillate for different lengths of time by the same disturbance, the vibration period of some structures causing them more readily to take up the earthquake movement and to oscillate longer than other structures whose vibration period does not harmonize so closely with the earthquake period.

(3.) The time during which a building oscillates would be to some extent determined by its position with respect to the direction of propagation of the seismic wave: thus a rectangular building would probably rock for a longer time if the wave met it "broadside" than if the direction of propagation coincided with its greatest length. Similarly, the duration of oscillation would be governed by the relations of the building to other buildings, *i. e.*, whether detached, semi-detached, or forming one of a row of houses, &c.

(4.) The duration of the oscillation would depend upon the nature of the underlying soil; buildings on loose formations like gravel might be expected to swing for a shorter period than buildings on hard elastic rock.

It would have been quite impossible in the time at our disposal to have examined separately into every record respecting the duration of the disturbance, with the object of giving due weight to the above considerations. The estimates by various observers, although for the reasons stated devoid of much scientific value as indicating the actual duration, are perhaps of sufficient interest to be given here, as fixing some rough limits to the duration of the sensible shock. From what has been previously said concerning the general nature of earthquake motion, it will be understood that the whole duration of the movement was most probably greater than that of the so-called "shock," the preliminary and final tremors being too small to affect the observers. The following estimates have been selected from the whole of the records examined:—

Colchester	...	...	8 to 10 seconds.
,,	...	...	2 to 3 ,,
,,	...	...	Over 5 and under 10 seconds.
Birch ...	...	...	7 to 8 seconds.

Langenhoe	Not less than 20 seconds.
Wivenhoe	6 to 7 seconds.
,, (On river)	About 5 seconds.
Chelmsford	,, ,,
Bocking	Under 8 seconds.
Chigwell Row	About 15 seconds.
Dedham	10 to 12 ,,
Great Wakering ...	5 to 7 ,,
Halstead	About 10 seconds.
,, ...	2 seconds.
Stebbing	15 to 30 seconds.
Thorington	About 3 ,,
West Ham	About 5 ,,
Faulkbourne Rectory...	6 to 8 seconds.
Barham	6 to 8 ,,
Ipswich	8 to 10 ,,
,, ...	About 3 seconds.
Norwich	Not exceeding 10 seconds.
Ashby Parva	5 seconds.
Southall	10 to 15 seconds.

After considering all the records purporting to give the number of shocks felt at various stations, and as the result of conversations on this point with many of the observers, I am forced to conclude that within the area of structural damage but few of the statements made are precise enough to be admitted as strict scientific evidence. Much confusion appears to have arisen owing to the observers attaching quite different meanings to the statement "number of shocks." In many cases where the building in which the observation was made performed several distinct vibrations these were considered as so many "shocks," but it will be readily understood that such movements may have been the result of a series of vibrations which, being communicated to the building, would cause the latter to swing, especially if "top-heavy," with a motion analogous to that of an inverted pendulum, the amplitude finally being sufficient to produce the impression of a shock or series of shocks which might bear no direct relationship to the originating impulse. The same result could in fact be produced by a single initial disturbance, for if we imagine a building suddenly displaced from the vertical through an angle of several degrees, it

might perform several oscillations before coming to rest, and each of these to-and-fro movements, if sufficiently pronounced, would by some observers be considered as a distinct shock.

The evidence appears sufficiently conclusive that more than one "shock" (not in the sense of an oscillation) was felt in the area of damage, and of the various records which appear in the report I am disposed to attach the most weight to the statement of Mr. Larman, the chief officer of the Coastguard Station at West Mersea, who gave us a very distinct account of his having experienced two shocks, each preceded by a report, the first being the stronger and louder. It is possible that the first was the direct shock and the second the shock reflected from the Colne Valley at Wivenhoe, there being a certain amount of evidence, as will be seen later on, that such reflection actually occurred.[18]

Beyond the area of damage, and especially at the remote stations, there are numerous records of two distinct shocks having been felt. This is the case, for instance, among other places, at Walton-on-the-Naze, West Ham, Sudbury, Cheltenham, Leamington, West Haddon, Market Harborough, Dover, and in London. With respect to the latter place I was enabled to question the observer, Mrs. Carvalho, of Inverness Terrace, soon after the occurrence, and I am satisfied that the "two shocks" in this case meant two distinct series of vibrations, separated by a short interval. This lady happened at the time to be lying in bed reading, the volume being held balanced in such a position as to render it extremely sensitive to any movement, and the pause in the vibration of the book was particularly described. As will be seen in the descriptive report, the experience of many of the observers at the above-mentioned places appears to have been of a very similar character.

[18] The fact that a sound preceded each shock favours this interpretation rather than the alternative explanation that the two shocks indicated the successive arrivals of the normal and transverse waves. It is, of course, also possible that there were two distinct initial disturbances, but this does not seem probable.

In the present state of seismological science, and in the absence of instrumental records, it would be rash to attempt any specific explanation of this double series of vibrations at the distant stations. It may be of use, however, to indicate briefly how such effects may in general be produced.

One cause for the separation of an earthquake disturbance into two sets of vibrations has already been given, in the different velocities with which the normal and transverse waves are propagated (See note 16, p. 32). According to experiments by Messrs. Milne and Gray[19] with artificial earthquakes the velocities (in hardened mud) of the normal and transverse vibrations were respectively 438 feet and 357 feet per second, the ratio of propagation thus being 1·23. Of course, in harder materials, the velocities would be much greater. It is possible that the two distinct series of vibrations felt at the distant stations may have been produced by the successive arrival of the two sets of waves.

On considering the geological evidence, which will be presented subsequently in detail, it will be seen that the meso-seismic area consists of beds of clay overlying chalk, the latter in its turn resting on harder rocks, which at the greatest known depth appear to belong to the Palæozoic series. Practically this amounts to the same thing as though great thicknesses of comparatively soft materials (clay and chalk) were resting on a basin-shaped floor of hard rock, which gradually came up to the surface as it spread towards the most distant stations. It is evident on theoretical grounds, and has been proved experimentally, that the velocity of propagation of an earthquake wave is much greater in hard elastic materials like the Palæozoic rocks than in soft formations like clay or chalk. According to Mallet the velocities in feet per second are:—

Sand	824·915
Granite (shattered) ...	1306·425
Granite (solid) ...	1664·574

According to the experiments of Milne and Gray the

[19] Phil. Mag., Nov. 1881, p. 366.

velocities of the normal vibrations in centimetres per second are:—

Granite ...	...	395×10^8
Clay rock	...	348×10^8

The double shock felt at the distant stations may thus have indicated the successive arrival of the vibrations, first through the deep-seated hard rocks and then through the overlying softer strata.

It is not here deemed advisable to attempt to decide between these explanations, or to consider the possibility of two distinct initial shocks having occurred. My own impression is that the theory of relative conductivity perhaps affords the most plausible explanation of the double shock, at any rate at the most distant stations, inasmuch as there is reason for believing that one of the two sets of vibrations would completely die out before reaching these remote places. Whether the normal or the transverse vibrations would be the more persistent depends entirely upon the character of the formation through which the wave is propagated.[20]

With reference to the sounds connected with the present disturbance, the accounts are on the whole concordant that the subterranean rumbling noise preceded the actual shock; in one or two instances only is the noise said to have accompanied the shock. There is no doubt that in some cases, and especially within the area of structural damage, the sound of the earthquake disturbance was inextricably blended with the crash of falling masonry and the rattle and jar of the houses. One noteworthy feature is the statement, repeated by a few of the observers who were indoors at the time, that the noise appeared to break in the first place overhead. This would seem to indicate that the amplitude of vibration of the upper parts of the buildings had become sufficient to cause windows, furniture, &c., to rattle before the vibrations of the lower storeys had become of sufficient amplitude to make

[20] See Milne's remarks on this subject, in Trans. Seism. Soc., Japan, vol. iii. pp. 133 and 134.

themselves felt to the inmates. Such effects are, of course, the result of the exaggeration of the movement at the free upper parts of the buildings.

Preceding and succeeding shocks.—It has been repeatedly observed, that in earthquake districts, a period of great disturbance is often preceded and succeeded by slighter shocks. There are not wanting numerous statements in the present case of such shocks having been experienced, but these are for the most part wanting in confirmation, and are too vague to be admitted in the absence of concurrent testimony. It is, of course, possible that slight shocks may have occurred before the 22nd, and these, owing to the totally strange character of the movement, may have escaped notice, except by one or two of the more observant individuals; but as the circumstances were only put upon record after the great shock of the 22nd, and as no instrumental confirmation was possible, it has been deemed advisable to neglect such statements.

Of premonitory shocks, the only one about which there seems to be no doubt is that of February 18th, which has already been recorded (p. 27), and which was felt, not only at the coastguard station at West Mersea, but also by many other people throughout the island, as well as by Mr. Hugh Green, of Strood Villa, whose house, as will be seen subsequently, was most seriously damaged by the shock of the 22nd. Mr. Green informed the Rev. T. R. Musselwhite, of West Mersea Vicarage, of this circumstance, on the same day that it happened. On the occasion of our visit to West Mersea, the chief officer of the Coastguard Station, Mr. Larman, gave a circumstantial account of this shock, which happened during his watch, at about 1.10 or 1.20 on the morning of February 18th, and was preceded by a loud report, which much puzzled him, as the sky was cloudless, and the idea of a clap of thunder, which first naturally suggested itself, had to be abandoned. It is most probable that the main axis of the disturbance of the 22nd was the seat of this premonitory shock.

With regard to the succeeding shocks which are stated to have occurred, the same remarks respecting the want of confirmation are applicable, and the only account to which credence can be given is that of a slight shock about 5 a.m. on June 24th, which has already been recorded on the authority of Mr. Henry Laver, of Colchester. This gentleman, well known as a skilful observer, informed me that he and all the inmates of his house were simultaneously awakened at the time mentioned, and I had the opportunity of verifying this statement by personal inquiry, during the visit of the Essex Field Club to Colchester, in August, 1884.

Miscellaneous effects.—Among the features which the present disturbance displays, in common with other earthquakes, must be mentioned the sudden shock or blow felt on ships and boats on the Colne and Blackwater at the time, and which has always been a familiar experience to observers who have happened to be afloat near an earthquake centre. This effect appears to be attributable to the fact that liquids are incapable of transmitting transverse waves,[21] so that the latter would as it were be filtered off, and the normal wave alone strike upwards through the water.

Among other miscellaneous effects, attention may be directed to the statements of several observers who experienced sensations of giddiness and nausea, an effect of earthquakes which has frequently been noticed,[22] and which in extreme cases has been known to produce actual vomiting.

It will be seen also that several observers who were out of doors walking at the time felt nothing of the shock, although in houses close by the effects were most marked, in some cases even structural damage having been witnessed by persons who were not themselves sensible of the movement. This experience, which has also been previously recorded,[23]

[21] See Prof. Ewing's Memoir, *loc. cit.* p. 1.

[22] Mallet, Brit. Assoc. Rep., Leeds, 1858, p. 133.

[23] Milne, Trans. Seism. Soc., Japan, vol. i. part 2, p. 89. The author remarks also that "an earthquake which would almost shake a city down might, if we were dwelling in tents or outside brick or wooden dwellings, be on many occasions passed by almost unnoticed."

tends to confirm the view that the actual amplitude of vibration at the surface was small in the case of the present earthquake.

IV. Nature and Amount of the Structural Damage.

The damage to buildings caused by an earthquake does not depend merely upon the amplitude of vibration at the surface, but upon the *rate of change* in the motion of a surface particle or the acceleration. Thus slow earthquakes may have a large amplitude[24] but may cause no damage, while short and quick vibrations may dislodge chimneys, fracture walls, or throw down buildings. It has been estimated, judging from the effects of earthquakes of which the acceleration has been measured, that a rate of change of motion of about two feet per second would have produced the results witnessed after the present disturbance. Unfortunately no data were obtainable in the case of the recent disturbance, which could be considered sufficiently trustworthy to enable the maximum velocity of displacement to be calculated, and it would not have been deemed advisable to have burdened this report with calculations open to such objections as apply to the results obtained from the projection or overthrow of bodies, even if the necessary observations had been made at the time.

The actual destruction witnessed throughout the area of damage was, except along the main axis of disturbance, clearly the secondary effect of the shock, and was chiefly the result of the overthrow of heavy chimney-stacks, which in falling crashed through roofs or caused damage in other ways. Along the main axis the direct effects of the disturbance were traceable in fractured walls and rents in the solid brickwork of buildings, the latter often of most substantial construction. It was, in most cases, impossible to discri-

[24] An earthquake in Japan, on Oct. 15th, 1884, gave record of a maximum displacement of the ground (E. and W.) to the extent of 3·7 centimetres (roughly about 1½ in.). The vibration was too slow to cause damage, but Prof. Ewing regards this amplitude as excessive.—'Nature,' April 23rd, 1885, p. 581.

minate precisely between the direct and the secondary effects of the shock, and the damage recorded in the subsequent pages bears reference rather to what was actually witnessed, or to the destruction described by correspondents. Again, it was not found possible to inquire into every case of damage, in order to find out whether any particular chimney was really thrown down by the shock, or simply fractured and taken down afterwards for safety. There is no doubt that many of the chimney-stacks which during our visit were observed to have been removed, were thus taken down, and from reports which subsequently came to hand, it further appears that much damage escaped detection at the time, and was only discovered afterwards by the skilled observation of the surveyor. It has not been considered necessary to call attention here to any of the details of damage, as these, together with any general considerations which their observation may have suggested, will be found in the following section of the report.

In order to relieve the distress caused by the injury of buildings occupied for the most part by a class of inhabitants quite unable to bear the cost of the repairs, a Relief Fund was started at the Mansion House, and the money thus raised was distributed by a sub-committee, to which our member, Mr. F. Chancellor, of Chelmsford, acted as honorary surveyor. The detailed survey thus undertaken has enabled a very fair estimate of the total amount of damage to be made, and through the kindness of Mr. James Jackson, a most active member of this sub-committee, I am enabled to give here a classified table showing the whole amount and distribution of the damage :—

Place or Parish.	Population last Census.	No. of Buildings repaired.	No. of Owners receiving contributions.	Churches.	Chapels.
Abberton	244	26	10	1	1
Aldham.....	433	1	1		
Alresford	259	4	1		
Bergholt, East.....	1,191	1	1		
Bergholt, West	1,067	1	1		
Bradwell-by-Sea	987	28	7	1	
Coggeshall	2,998	2	2	1	
Colchester	28,395	414	123	4	6
Donyland, East	1,264	207	55	1	
Fordham	699	1	1		
Fingringhoe.....	659	49	22	1	1
Langenhoe	234	19	6	1	
Layer Breton	293	3	1	1	
Layer-de-la-Haye	687	27	7	1	
Messing	641	Church only		1	
Mersea, East	280	7	4	1	
Mersea, West	1,082	58	15	1	2
Peldon	458	72	21	1	
Salcot	233	1	1		
Tollesbury	1,434	1	1		
Tolleshunt D'Arcy	828	Church only		1	
Wigboro', Great	421	20	4	1	
Wigboro', Little	91	12	4	1	
Wivenhoe & Elmstead	3,147	259	93	1	1
24 Parishes besides Colchester		1,213	381	20	11

Although some few houses belonging to the wealthier classes were repaired at the cost of the owners, the above list does not fall far short of the actual number of buildings damaged. It may be remarked that the total amount of money distributed by the sub-committee for the purposes of repairs was nearly £9000. In concluding this general statement concerning the damage, it must be pointed out that the amount of the latter was to some considerable extent due to the age and shaky condition of the majority of cottages, &c., on and around the main seismic axis.

V. Descriptive Report.

Essex.

The Area of Structural Damage.

Colchester.—The damage sustained at Colchester, although

testifying to a shock of considerable severity, was due chiefly to the overthrow of chimney-stacks, the injuries being on the whole confined to old or faulty structures. The greatest amount of destruction appears to have fallen upon the north-eastern quarter and the lower parts of the town towards the Hythe, especially along East Hill, Brook Street, Magdalen Street, Barrack Street, &c.; but as this is the oldest portion and therefore crowded with the most shaky tenements, caution must be exercised before drawing any conclusions as to local variations in the severity of the shock. To the west of Colchester, towards Lexden and Stanway, the cases of permanent injury to buildings were comparatively few.

At the time of our visit to the town (May 3rd), considerable advance had been made in the repair of chimney-stacks, but it has been estimated that about five to ten per cent. of the whole number were thrown down. In order to avoid the undue extension of the present report, I do not propose to give all the recorded cases of damage, nor all the details that were noted during our visit, but shall confine my observations to some of the more prominent instances of destruction, and especially to those cases which appear to throw any light upon the nature or direction of the seismic disturbance.

North Station.—The shock was felt just as the 9.20 up-express was on the point of starting. The direction of the railway at the station is about W. 15° N.—E. 15° S. The station-master (Mr. W. Blatch) has communicated the following statement:—

"Just as I was going to start the train there was a rumbling noise resembling distant thunder, and directly the platform seemed to give a gentle heave, like the motion of a wave. For an instant I thought I had a slight dizziness in the head, but then I was convinced that something unusual had happened, and that we were receiving either the shock of an explosion or an earthquake. The passengers in the train all rushed alarmed to the windows of the carriages, and a number of men at work on the new asylum, a large building close to the station, hastened down from the scaffold."

Eastern Counties Asylum for Idiots, Essex Hall.—No special damage was sustained here beyond the cracking of some ceilings. Mr. W. Millard, the superintendent, reports that five clocks were stopped, two with their pendulums swinging E. and W., and three swinging N. and S.

Middleborough and North Hill.—Many chimney-stacks, new and old, thrown down. The "Marquis of Granby" Inn, and the premises of Mr. S. Bond much injured by stacks breaking through roof.

High Street.—Not much damage visible from the front, but many chimney-stacks thrown down at the backs of the houses. The following cases have been noted:—Mr. R. J. Hall's (corner of North Hill), stack thrown into the yard to the rear. At the back of Mr. Bewer's (No. 23), a stack fell on to the roof of the 'Essex Standard' office. Messrs. George Ager and Sons, (No. 27), stack fell through skylight.

Mr. J. B. Harvey, deputy mayor, states that in his premises adjoining the Public Hall all the bells were simultaneously rung and the gaseliers set swinging. Mr. Harvey informs me that his impression was that the gaseliers swung from S.E. to N.W. Of two clocks, one swinging N. and S. and the other E. and W., neither was stopped. Respecting the sound accompanying the shock, he adds that the noise increased in intensity and resembled that of "a locomotive passing through the premises and shaking the house and offices and also the Public Hall adjoining to their foundations." The duration of the disturbance was estimated at from 8 to 10 seconds.

At the Bank (Messrs. Mills, Bawtree, Dawnay, Curzon & Co.) a clock was stopped; pendulum swinging N. and S. At Mr. Hopwood's (No. 47) a French clock was stopped; swing of pendulum S. 6° E.—N. 6° W. On the other hand, two regulators, swinging in the directions S. 25° E.—N. 25° W. and W. 16° S.—E. 16° N., did not stop. At Mr. Hill's six clocks were stopped, all swinging E. and W., among them a large regulator which, as Mr. Hill informed me, was stopped exactly at 9.18. At Mr. Hildyard's (No. 11) a clock (American) was stopped; plane of oscillation N. and S.

The effects of the disturbance upon three stacks of chimneys at Mr. J. C. Shenstone's (No. 18) and neighbour's are sufficiently important to describe in some detail. The positions of the stacks are shown in the accompanying sketch (plan) kindly furnished by Mr. Shenstone:—

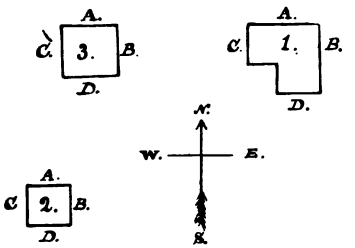

FIG. 1.—Plan showing position of Chimney-stacks at Mr. Shenstone's.

The stacks numbered 1 and 3 were cracked at the base round the N., E., and W. sides, A, B, and C, whilst the S. sides D remained firmly attached, so that the stacks could be tilted towards the S. by a slight push, being hinged by their remaining attachment along the line D. Stack No. 2 was cracked all round the base and displaced about a quarter of an inch towards the S., leaving a quarter of an inch of clean mortar exposed on the northern side A. These facts appear to indicate that the houses were here moved approximately in a N. and S. direction, the disturbance probably travelling from the S.[25]

The premises of Messrs. H. and J. Joslin, Nos. 108 and 109, High Street, were made to oscillate in a direction which Mr. Joslin at the time estimated to be N. and S., the movement lasting "two or three seconds." An assistant was engaged on a drawing placed upon a long glass-topped counter in the show-room, this counter extending in the

[25] Milne states ('Nature,' Oct. 26th, 1882, p. 629), that the motion of the ground *inwards*, towards the origin, is in some instances greater than the motion outwards, away from the origin. This may explain the peculiar fracturing of the chimneys, referred to above.

direction of its length N.N.E. and S.S.W.,[26] and having suspended over it by long hooks descending from two parallel bars about fifty chandeliers and other lamps. Startled by the shock and the jangling of the suspended articles, the assistant looked up and saw the chandeliers, &c., swinging, the plane of their movement being, as far as he could judge, parallel with the direction of the counter and the parallel bars above. The oscillation of these movable articles continued for some time. The sides of some iron bedsteads in the warehouse, resting against a wall facing N., were thrown down towards the S. Of three clocks in this house two swung E. and W. and one N. and S.; only one of the former was stopped.

The Town Hall escaped with but slight injury; only some of the coping shaken down.

Culver Street.—Wesleyan School slightly cracked in N. wall near roof. School was being held at the time, and a panic ensued, but no injury was sustained by the scholars. Chimneys at the Conservative Club thrown down. A warehouse at the back of No. 12, High Street, had a chimney thrown down and the roof considerably damaged.

Stockwell Street.—In the neighbourhood of the 'Essex Telegraph' Printing Works, East Stockwell Street, chimneys were overthrown and ceilings cracked. In West Stockwell Street damage was done at St. Martin's Club, and in another house the chimney-stack broke through from roof to basement. Mr. W. H. Harwood (No. 8) reports that he was standing in a room on the first floor, facing E., and the movement produced a giddiness analogous to that caused by the motion of a ship. The disturbance, he adds, "did not reach me from behind [W.] or from the left side [N.]." A clock was stopped in this house at about 9.17 (seconds not noted); oscillation of pendulum E. and W. Other clocks swinging N. and S. were not affected.

[26] This direction was ascertained by means of a compass at the time of our visit, but as the shop was crowded with iron articles of all kinds but little importance attaches to the compass reading. The direction of the counter (and therefore of the swing of the chandeliers) was approximately N. and S.

Maidenburgh Street.—Many chimneys thrown down and an old cottage partially wrecked. It is of interest to note that this cottage was seen to topple over by a young lady who was walking in Sheep's Head Meadow, at the back of the Castle, and who is stated to have felt nothing of the shock.

Eld Lane, Long and Short Wire Streets.—At the Commercial Café (Short Wire Street), Mr. W. C. Aberdein compared the sound accompanying the shock to "the discharge of a 68 pound gun on the upper deck as felt in the lower deck of a ship," the direction of the disturbance being apparently from the S.W. Bells were rung, and four feet of the centre stack of four flues broke through the roof, the brickwork being thrown towards the S.W. Three clocks swinging N.E. and S.W. were stopped at 9.20, and one swinging N.W. and S.E. was not stopped. The plaster of the ceilings in the bedrooms, built with their rears towards the S.W., showed various cracks. Mr. Aberdein adds that "the chimney-pot and part of the brickwork of a tall chimney on Mr. J. Garland's premises facing the south and west fell, leaving a chimney-pot and brickwork built towards the north and east entire." In Long Wire Street heavy chimney-stacks were thrown down at Mr. George's boot shop (No. 2), and at the Ipswich Shoe Warehouse (No. 33). At Mr. McQueen's (No. 32), glass in the shop window was broken. At Mr. Marriott's (No. 29), a sheet of plate-glass in the shop window was cracked from top to bottom. Along Eld Lane numerous chimneys were overthrown, and at the time of our visit the heaped-up wreckage was piled against the sides of the houses so as to clear the street.

St. John's Street.—The Rookery (Miss White's) damaged by falling brickwork of chimney-stacks. A clock stopped; plane of oscillation of pendulum E. and W.

Osborne, St. Botolph, and Queen Streets.—House of Young Womens' Help Society damaged by the fall of two chimney-stacks. Mr. Stone's premises at the corner of the two first-named streets slightly cracked.[27] A high chimney (new) on

[27] Mr. J. C. Shenstone reports:—"In the centre of the parapet there are two cracks, each about two feet long, one going straight down by the

the house of Messrs. Hart and Fromant, consisting of an oblong block, with its greatest length E. and W., and standing eight or ten feet above the building, was cracked obliquely at the base, and the upper part cracked longitudinally from the top. The upper part of the stack was displaced, and projected over the lower part about two inches towards the E. The eastern side of the basal crack was lower than the western. Mr. Hart reports that in this house two or three clocks, with pendulums swinging E. and W., were stopped, and one clock swinging N. and S. was not stopped. The premises stand upon ground having a considerable slope from W. to E., a circumstance tending to complicate the effects of the wave, as appears from the facts that while the clock stoppages seem to indicate a N. and S. movement, the chimney was displaced towards the E., and in the house plates were thrown down from a dresser facing E., and other articles were also thrown towards the same direction.

At Messrs. W. and R. Cheshire's establishment the shock was severely felt, glass and china goods being thrown off helves and much damage caused by breakage. The house of Mrs. George Bawtree, in Queen Street, was greatly damaged by the fall of chimney-stacks.

Castle and Museum.—In the museum many of the objects were shifted, the direction and amount of twist depending upon the shape of the object and its mode of attachment, so that little information was derived from this source with respect to the prevailing direction of the disturbance.

A Roman amphora under a glass shade, standing on a table-case in the middle of the museum, and an Anglo-Saxon urn, also under a shade, were both twisted round with their stands and shades towards the W., so that the labels which faced S. before the earthquake faced S.W. afterwards. The shells in the collection in the entrance-hall were, as might have been expected from their shapes, much rolled about. One specimen card, with shells attached, was shifted

side of some thick brickwork, the other slanting. One brick is broken through in the oblique crack. With this exception the crack is in the mortar. This house has the appearance of being substantial."

in a northerly direction. The dimensions of this card, as described by Mr. Shenstone, are about 8½ inches long by about 2½ inches wide, and its position in the case was with its greatest length E. and W., but after the passage of the disturbance it was found that its eastern end had moved into a north-easterly position, while its other (western) end had remained nearly in its former position. A somewhat interesting case, as relating to an object pivoted in a manner leaving it tolerably free to turn round on a fixed axis of support in any direction, is that of a Roman hemispherical bronze helmet, in form very much like a peaked jockey's cap, supported peak downwards on a brass upright fixed into a heavy stand, the whole being covered by a glass shade. The helmet was standing on a glass table-case in the south-eastern recess of the Museum, this recess being cut through a solid brick wall 12 feet thick. Before the disturbance the helmet was standing W. and E., but was afterwards found facing the S.W., the shock having twisted it round in a southerly direction. The Curator of the Museum, Mr. Gunner, states that the oscillation was severely felt in the building.

In *Museum Street* a house (Mr. Grimwade's) was reported to be "much cracked."

Priory Street.—Four corner pinnacles of Roman Catholic Chapel loosened. The inmates of the Rev. H. Scane's house were thrown to the floor by the oscillation of the building. At the British School a portion of the ceiling was shaken down.

St. Botolph's Priory.—An archway extending between the two end columns of a row standing E. and W. was loosened by the shock, and fell down the following day.

Along East Hill, Magdalen and Barrack Streets, Hythe Hill, &c., no special notes were taken, nor have many detailed reports been forwarded. It was estimated that in this part of the town 20 or 30 per cent. of the chimneys had been demolished. At Golden Noble Hill many houses were more or less damaged by the fall of stacks and brickwork. In Barrack Street several chimneys were thrown down at

Mr. Moore's (corner of Brook Street) and neighbouring cottages, the stacks in the former case breaking through the roof and causing much damage. Chimneys were also thrown down at the "Duke of York" Inn. Writing from No. 12, East Hill, Mr. Wilson Marriage reports that three clocks in his house were stopped, one swinging E. and W. and the other two N. and S., the time being given as nearly 9.20. Mr. Marriage is of opinion that the general direction of the seismic movement was S.E. to N.W. At East Mill flour sacks were thrown down, and the shock was felt by some men in a barge on the river between the mill and the Hythe. These men stated that "they distinctly saw the wave pass across the meadows lying between East Bridge and the Tendring Hundred Railway." Unfortunately the direction of the movement was not given at the time.

Hythe Hill.—At Messrs. Davey, Paxman and Co.'s Engine Works, on the top of the hill, a wooden girder, about 16 feet long fell over towards the south. This girder was supported in an upright position by beams near the roof, in a long building having an E. and W. direction. Mr. Shenstone reports with respect to this building as follows:—"A plate fixed into its east wall supporting a beam (which beam helps to support the roof) was pulled two inches out of the wall and has remained so. As the wall is quite uninjured I should attribute it to the roof having been bowed in, and not to the wall being bent."

St. Leonard's Rectory, Hythe.—The Rev. Dr. Manning reports that at the Rectory two distinct shocks were felt, closely following one another, a booming subterranean noise accompanying the first. Out of five clocks, all with pendulums swinging E. and W., only one was stopped (9.20). All the bells were set ringing. "Two heavy books thrown nearly three feet from a book-shelf standing against south wall (inner) of dining-room. Ewer overturned in basin standing against outer south wall in bedroom. Two cracks in inner wall of house running N. and S. Two large panes of plate-glass broken in windows (with stone mullions) looking N.W. and S.W. respectively. Two stacks of chimneys shaken down, falling N. and W."

At the Hythe Railway Station chimneys were thrown down, and at the Gas Works the large gas-holders were seen to oscillate, but no important damage has been reported.

To the west of Colchester, as already stated, the damage was but slight. The Water-tower, a massive structure about 140 feet high, supporting a tank capable of holding a quarter of a million gallons, and standing on Balkerne Hill, the highest part of the town, at the junction of North Hill, Head Street, and High Street, was seen to oscillate but sustained no damage.[28]

Head Street.—At the Post-office the ceilings in some of the rooms were cracked, and a clock swinging W. 10° S.—E. 10° N. was stopped. At Head Gate the "Elephant and Castle" was much cracked in front, the cracks running irregularly and in opposite directions along lines of weakness in the mortar. A gap about an inch wide appeared between the inn and Mr. Fuller's auction-rooms adjoining. The latter, an almost new house, was but little injured. At the house of Mrs. Johnson (No. 40) a clock (Austrian regulator) was stopped; plane of vibration of pendulum W. 8° S.—E. 8° N.

St. Mary's Rectory.—Two clocks stopped, one swinging E. and W. and the other N. and S.; also a clock which had not been going for months, and of which the plane of vibration was N. and S. was started into action. A mantelpiece (loose before) against a wall standing E. and W. was thrown down, and a china ornament on a mantelpiece against a wall having a similar direction was thrown forwards (towards the N.) and broken. A candlestick standing back on another mantelpiece (also E. and W.) was moved forwards towards the S., so as to project over the edge of the mantelpiece. The house rocked considerably and all the bells rang, the sound accompanying the disturbance appearing to approach from the S.W. The Rev. J. W. Irvine, who kindly supplied the above information to Dr. Alexander Wallace, further stated that the mistress of St. Mary's School informed him "that the floor at the south

[28] Mr. H. Laver informs me it has since been discovered that there is a slight vertical crack in the central upper part of each arch.

end seemed to move more than at the north end, and some little children were tipped from their benches."

Workhouse.—Three chimney-stacks thrown down through roof. The building is new and substantial.

Churches.—The Rev. Dr. Manning reports, with reference to St. Leonard's (Hythe):—"Upper storey of church tower entirely dislocated (tower at W. end of church), and buttresses at N.W. and S.W. corners severely shaken and injured. Tower said to have been seen to sway from N. to S. Heavy piece of masonry dislodged from N. side of western gable of church. Slight crack in chancel arch on N. and S. sides." Trinity Church much shaken and several cracks in tower. In St. Peter's Church a clock swinging N. and S. was stopped. Lion Walk Congregational Church much damaged by the overthrow of about twenty feet of the spire, the masonry falling partly through the roof and partly to N. 85° E., the portion demolished being that rebuilt to replace the corresponding portion blown down about fifteen years previously, during a strong gale. This incident of the earthquake was witnessed by some members of the family of Dr. Alexander Wallace, of Trinity House, who states that his house was shaken, the windows made to rattle, and bells rung. The following account has been already published by this observer:—

"Those adults of my family who were standing in my garden, occupying and having a view over an acre of ground or more, testified that the first thing noticeable was a low rumbling, proceeding from the earth, not from above; a rolling sound indescribable, unlike anything else; coming to them from a distance in the south-west, passing under them, and proceeding in the north-east direction; next a vibratory rocking, felt chiefly at the knees, causing unsteadiness, and attempts to lay hold on surrounding objects, which only made them feel more unsteady. At the same time surrounding objects, buildings, &c., seemed to be rocking and swaying —oscillating. This is probably an illusory sensation communicated from below, and to be compared with the instability experienced by those who have just landed from a sea voyage. The next they observed were the falling chimneys around, and the crumbling and fall of the spire of the Congregational

Chapel close by. It was clearly noticed that the fall of chimneys to the south-west of them preceded the fall of the spire, which is to the east of us; in fact, they fell one after the other; those furthest to the south-west fell first."

As the result of his general experience, which may be conveniently mentioned here, Dr. Wallace adds that the duration of the disturbance appeared to have been over five and under ten seconds, and that there were more than one, but not more than three, distinct "waves of shock."

The Church of St. Nicholas had a slight crack in the tower running down from one of the belfry windows. St. Paul's Church: small quantities of mortar and plaster shaken down into chancel. St. Martin's: slight damage to masonry of tower.

Summerhill, about 1½ mile N.W. of Colchester.—The Rev. Thomas Cato states:—"We were sitting at breakfast at twenty minutes past nine, when suddenly a jingling sound was heard, which rapidly developed into a deep underground rolling noise. Our house, which is a large, substantially-built one, seemed as if it were falling to pieces. All the bells began to ring." The house stands on a hill about 140 feet above Ordnance datum, and Mr. Cato expresses the opinion that the oscillation was E. and W., all clocks (number not given) with their pendulums swinging in this direction having remained unaffected, whilst others swinging N. and S. were stopped. No structural damage reported.

Lexden.—Post-office and one other house damaged by chimney-stacks falling through roof, and a few chimneys displaced in other parts of the village. A large vase at the entrance to Lexden Park overturned. Mr. Charles D. Keigwin, walking in the park at the time, experienced nothing of the shock.

To the west of Colchester no structural damage of importance has been reported beyond Lexden. Reed Hall (Mr. Harvey), about a mile and a quarter S.W. of Colchester, suffered by the fall of a chimney-stack, which considerably damaged the roof. At Mile End, about three quarters of a mile north of Colchester, on the opposite side of the River

Colne, situated on a London Clay hill, about 160 feet above Ordnance datum, no destruction appears to have been caused. At Greenstead, about 1½ miles to the east of the town, on the other side of the river opposite the Hythe, a considerable percentage of the chimneys were thrown down, and one house reported much damaged. The western side of the church tower was cracked from top to bottom, and part of the plaster coating stripped off; the tower is solid brickwork.

Southward from Colchester, along the Mersea Road, but little damage was observed. The shock is reported to have been severely felt at Broom Hill (Lt.-Col. Walker), a clock being thrown into the middle of the room and a pier-glass broken, but the house escaped permanent injury.[29]

St. Giles's Rectory, about one mile S.S.E. of Colchester, on the edge of glacial gravel, near its junction with a long narrow slip of London Clay, was much cracked and all the chimneys thrown down. The cracks from the base of the chimney-stacks extended down through the house to its basement, and a crack extended from top to bottom of the wall at the S.E. corner, besides numerous cracks in the other walls. A recess built out from the dining-room was quite torn away from the house, leaving a crack about an inch in width. Glasses were thrown off shelves in a store-room and bottles thrown down in the cellar. Mr. J. C. Shenstone reports that this house does not appear to have been very substantially built.

Bourne Pond Mill, a very old building near the rectory, was considerably damaged; ornamental stone-work was thrown down, the gable-end of the mill shifted about two inches, and the mill much shattered.

[29] From later information supplied by Col. Walker and Mr. Shenstone, it appears that this house is very solidly built and only one storey high, being well adapted to withstand an earthquake shock. The only damage was the cracking of some ceilings and the loosening of the keystone of the row of bricks over a glass door facing S.S.E. The clock in question (a heavy one) was standing on a cabinet surrounded by a rail three inches high, over which it was thrown on to the floor, falling towards the W.S.W. In the next room the looking-glass, facing W.S.W., also fell in this direction. In another room a small piece of furniture, standing against a wall facing S.S.E., was moved out into the room.

Cemetery.—A coping-stone was dislodged from one of the chapels, and a chimney thrown down at the gate lodge. Mr. T. B. Harrington, of Marlborough Villa, who witnessed the fall of this last chimney, has furnished me with some interesting details. He was walking along the Mersea Road, in a direction nearly N. 30° W., and when nearing the Cemetery heard a sound which he at first considered to be distant artillery or thunder, but which at the time struck him as being too loud for the usual sound of distant artillery. Mr. Harrington continues:—"While I was wondering what it was (I still kept on walking) I observed the little house quiver and the top part of the chimney and pot fall to the ground. I stood still in amazement, and the instant I saw this the ground very perceptibly heaved under me, in fact it caused me to reel; immediately following that I heard the sound of falling chimneys, tiles, &c." This observer adds, in further explanation, that he first heard the sound, which appeared to approach from his left side (approximately from a south or south-westerly direction) and then moved on for a distance of eight or ten paces before he saw the chimney fall and simultaneously felt the heave of the ground. After this the sound of falling objects was heard for four or five seconds. The morning was quite calm ("scarcely a breath of air"), partly cloudy, with occasional sunshine. Mr. Harrington informs me that at Marlborough Villa, about 400 to 500 yards from the Cemetery gate, no damage was incurred, although bells were rung and objects thrown off mantelpieces. Two clocks were stopped, both swinging N.W. and S.E. (approximately), and other clocks swinging at right angles to these were not affected.

The Mersea Road runs almost due south from the Cemetery for a distance of a mile and then winds towards the S.E. Practically, no damage was observed along here, nor at Blackheath and Berechurch to the west. Some men working on the land at the last place are reported to have witnessed the passage of the earth-wave from S. to N.

Kingsford.—Mr. Horace Green's house seen to totter by the gardener, and the chimneys afterwards found cracked and insecure; a cottage on the estate reported to be wrecked.

Birch, about two miles W.S.W. of Kingsford, appears to be the western limit of structural damage in this direction. Writing from Birch School, Mr. Joseph Wilkins gives the following experience:—

"I was standing in an erect position in the midst of a room 65 feet in length, having a general direction north and south, but which inclines slightly westward. The time was precisely 9.20, and the first intimation of the shock was a loud, but peculiar rumbling sound—a something between the report of an explosion and thunder, or rather a combination of the two. This preceded the wave by about one and a half seconds, and continued about three seconds, during the latter part of which time I felt the floor heave beneath my feet, and a distinct waving or swaying motion from south to north, very similar to the deck of a vessel heaving with a swell of the sea. There was certainly a repetition of the wave; but whether a third followed I cannot be positive, though I am inclined to believe there was. If so, however, the third wave was slight compared with the first. The duration of the waving was about three seconds, so that the whole duration was seven or seven and a half seconds. I was inclined at first to guess the time at 15 seconds, but comparing, as I did soon afterwards, the duration of the shock by the hand of a watch marking seconds, I feel certain that about half that time was as nearly correct as possible. I distinctly experienced the effect of slight 'nausea,' of which I see others have spoken."

A clock with pendulum swinging E. and W., which had been stopped the previous night, was set going by the shock. Mr. Wilkins has been good enough to supply, at my request, the following additional particulars:—

"The clock mentioned in my letter was a large brass skeleton time-piece, standing on a chiffonier in my drawing-room, against a wall running E. and W. It is of English make and escapement, having a rather heavy flat brass pendulum, measuring 8½ inches from the hanging stud and swinging from E. to W. I had stopped it the previous night at 10.20.

"The ceiling of the room adjoining seemed to be 'ricked' with cracks running in a rather zig-zag direction towards the N.E. corner. This room also occupies the N.E. corner of my house. I was myself in the school-room at the moment of the shock. This room is 65 feet long, standing almost due N. and S. (slightly inclining N.E. and S.W.). It is furnished with seven sets of desks in parallel groups of three each, five

sets or fifteen desks in a line with the W. wall and two sets or six desks in a line with the E. wall on the other side of the room. Beneath these desks, resting on ledges or shelves, were about 130 slates, the whole of which clattered and rattled violently during the latter part of the shock, *but not one was thrown out to the floor.* This would seem to imply that the direction of the wave or shock was in a direction S. to N., which was certainly my feeling and experience as I stood in the middle of the floor looking W.—a sudden upheaving of the floor and then a steady gentle swaying towards the N. and back again. On the other hand, there is the mute testimony of the clock, proving a measure of oscillation more or less E. and W."

The structural damage done at Birch was very slight, only a few tiles being shaken down. The church, with a spire 110 feet high, was uninjured.

Returning to the Mersea Road, chimneys are reported to have been thrown down at Cockwort Farm, to the east of the road, a little below the Cemetery, and also at Middlewick, about three quarters of a mile S.E. of this last farm. At Roman Hill a large chimney-stack was thrown down at the house occupied by Mrs. Hughes. Turning off towards Abberton the destruction became more general.

Abberton, about 3½ miles due S. of Colchester.—Hardly a chimney left standing in the village, every roof more or less damaged, and walls cracked in many of the cottages. Here and elsewhere throughout the area of structural damage, it was observed that old brick-built houses had generally suffered more severely than wooden structures.

At the Abberton "Lion Inn" the chimney-stacks fell through the roof, a chest of drawers was overturned, and glass in the bar was broken. At a cottage on the east side of the road, standing approximately N. and S., the chimney-stack at the N. end had a very conspicuous crack at the base slanting towards the S. (as seen on the western side of the stack), at an angle of about 60° with the horizon. Oblique cracks of this kind at the base of chimney-stacks, and forming various angles with the horizon, were very frequently observed during our visit of inspection, and generally (in this district) in cases where the houses stood approximately S. and N., *i.e.*,

facing E. or W. Such cracks appeared to me to furnish no certain indication of the direction of the movement, but to be simply the effects of a series of oscillations, tending to overthrow the chimneys which, when sufficiently strong to resist complete dislocation, would crack along its line of junction with

FIG. 2.—Cottage at Abberton.

the sloping roof, the mode and angle of detachment determining the angle of fracture. In other cases, tall, rectangular, outside chimneys, standing at the end of a cottage high above the building, were prevented from being thrown down by the iron "stays" attaching them to the roof, although the chimney would sometimes be seen to be cracked completely across below the "stay." In other instances, again, the "stay" seems to have actually saved chimneys from any damage whatever, although the brickwork showed signs of being old and rotten.

At a cottage near the last, and standing in the same direction (N. and S.), a long bifurcating crack appeared on the western face, running from roof to basement, and inclining towards the north at an angle of from 30° to 40° with

the horizon. A new and well-built cottage to the S. of the village (standing nearly N. and S.) had suffered severely at its southern end, about 20 feet of brickwork having been thrown from the gable. Mr. G. J. Symons reports that "the occupier saw stacks fall, first to E. or E.N.E. of him, and afterwards others in S.W." Two long eight-day clocks in this house were stopped, the plane of oscillation being respectively W. 18° S.—E. 18° N., and S. 5° E. —N. 5° W. Three old cottages near had lost nearly all their tiles, and the "chimney-stacks were thrown over, the débris falling in the direction S.S.E. to N.N.W. (owner, working in garden, had to steady himself on his spade)." At the school-house the chimney-stack broke through the roof.

Abberton Hall and Abberton House, two substantial buildings, a little to the N.W. of the village, were much shaken, especially the latter, occupied by Mr. Edward W. Bawtree, in which the chimney-stacks were all more or less twisted. Mr. Bawtree has furnished the accompanying sketch of one of these chimneys, which is here introduced with the object of illustrating the extremely complicated effects produced by the seismic movement.

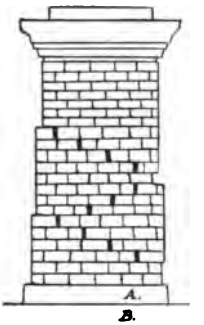

FIG. 3.—Chimney at Abberton House. Northern aspect; seen from below. Very little displacement visible on southern face. A, cement. B, roof.

In this house an eight-day clock, with seconds pendulum, was stopped; pendulum swinging S. 17° W.—N. 17° E.

The Rectory, a new building in course of construction, between the village and the church, had two out of three chimney-stacks dislocated and twisted, and every room more or less damaged. Mr. F. Chancellor, of Chelmsford, under whose superintendence this house was erected, states that it is built on a heavy clay soil and is most substantial, special pains having been taken with the foundations. The two rectangular chimney-stacks (on a sloping roof), were cracked

at the base (level with the ridge of the roof), and twisted about 1½ inches towards the E. The upper (displaced) part of each stack was estimated to weigh about 8 tons. Some of the cracks in the walls were more than a quarter of an inch wide, and a stone window-opening was wrenched so as to displace the mullions an inch out of position. The joists of the floors seem also to have received a violent twist; plaster of ceilings was cracked, pieces of cornice were thrown down, and altogether the house appeared to have received a most severe wrench. At the church (St. Andrew's) the chancel roof lost most of its tiles, and the mullions of one of the windows had been displaced.

About two miles due west of Abberton, with only a few sheds between, is

Layer-de-la-Haye. — The turrets of the church tower thrown down, together with a quantity of the rubble coating, part of the apex of the south aisle, and the stone cross at the end of the nave. Most of the houses were more or less damaged by the fall of chimneys, amongst them being the Malting House (Mr. A. Sanders), Mr. E. Walford's, and all the houses at Layer Cross. Mrs. Dennis, residing at Layer Rows, about a mile S.W. of the church, has kindly furnished some important details. At this house, standing on a London Clay drift-capped hill, about 120 feet above Ordnance datum, one chimney-stack was much cracked, and twisted about half a brick from E. to S.E.; another stack was thrown over to the W., and three others were rendered so unsafe that they had to be taken down. The roof on the S. side was untiled. At the moment of the shock Mrs. Dennis had just opened a door leading into the garden, when she heard a rumbling noise, and bricks fell on both sides of her. The house was seen to oscillate twice

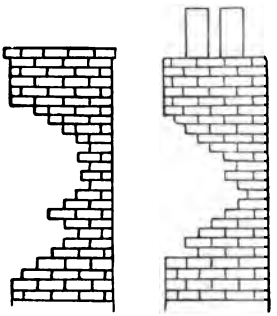

Fig. 4.—Chimneys at Layer Rows, Layer-de-la-Haye. Northern aspect, seen from below. Brickwork thrown out from eastern sides. The portion above the gap in bothcases new brickwork.

from E. to W., and the ground felt to heave. Inside the house walls and ceilings were cracked and bells rung; glasses and ornaments were thrown down and water-jugs turned over, two being spilt to W. Two heavy chests of drawers with backs to E. were moved three inches from the wall and the drawers thrown open. A chiffonier full of books, standing against a W. wall, had all the books shifted forward an inch or two towards the E. and the doors thrown open. A heavy leaden cistern, also against a W. wall, was thrown in the same direction, towards the E. Clocks with pendulums swinging E. and W. were stopped, and the hall lamp swung for some time from E. to W. Milk in six or seven pans was splashed up the eastern sides of the pans 2½ to 8 inches higher than on the western sides.

At a farm-house, about a quarter of a mile from the Rows, a large chimney was partially thrown down at its eastern side, in the same manner as shown in the preceding sketch, and left in a very tottering condition. At this house an old-fashioned cabinet clock, with pendulum swinging N. and S., was not stopped, but the doors (facing W.) were thrown open, showing an impulse from the E.

The whole of the foregoing evidence, as furnished most lucidly by Mrs. Dennis, points (with the exception of the clock stoppages), to a distinct movement E. and W. at this place.

Layer Breton, a little over half a mile S.W. of Layer Rows. —One side and the roof of the church reported to be much damaged; the rectory roof broken through by chimney-stacks, and the chimneys at the Hall and one or two other houses overthrown. I have been informed by Mrs. Dennis that the worst case of damage was an unoccupied farm-house on Layer Breton Heath. Some clocks in the village were stopped, and several eye-witnesses out of doors at the time stated that the houses were moved towards the W. On the whole, the damage sustained here was much less than at Layer-de-la-Haye.

Layer Marney, a little over a mile W. of Layer Breton, appears to be the western limit of structural damage in that

direction. The tower is reported to have been slightly cracked, and Duke's farm-house was cracked in several places and the chimneys thrown down.

Turning eastward again towards Abberton, the adjoining parish of Langenhoe suffered severely. But few specific acccounts have been received from this district, and the following details are derived mainly from my own note-book, Mr. Symons' report and field-book, and the local newspapers.

Langenhoe.—In this straggling village hardly a house escaped damage, the most destruction having occurred towards the W., where it approaches Abberton and Peldon.

The church of St. Andrew, a small and ancient building with a stone tower, said by some archæologists to be of Norman date, was most seriously damaged, the eastern battlements crashing through the roof of the nave into the gallery below, leaving a large gap in the roof. The western battlements fell into the churchyard, and in the western face of the tower an almost perpendicular crack ran from top to bottom (an old crack partially reopened). The walls of the nave were much cracked and warped, the chancel roof untiled, the wreckage falling through on to the pulpit and pews, and the upper part of the gable shaken down. The brickwork of a small porch on the north side of the church was also cracked on each side of and above the doorway. The extreme age of the tower, which appeared to have been much patched, must have contributed to the destruction at this church. The tower was somewhat bulged and out of the perpendicular by subsidence before the shock; the pictures given in some of the local papers, showing a strong inclination of the tower towards the south, were much exaggerated.

At the Rectory the walls and ceilings were much cracked and the chimney-stacks damaged to such an extent that they had all to be taken down. The Rev. W. Parkinson, to whom I am indebted for many of the following details, informs me that the twist of the chimneys appeared to be from N. to S.[80]

[80] Mr. J. E. Taylor, F.G.S., of the Ipswich Museum, who visited this district on April 23rd, states that "the twist had come from the south, for the face of the chimneys which had previously looked in that direc-

Mr. Symons reports that the building, although not old, appeared to be considerably strained, and it was stated that scarcely any of the doors would open or shut. Glass was thrown off shelves and two clocks stopped, the planes of vibration being (hall) S. 8° E.—N. 8° W., and (kitchen) E. and W. Another small clock on a mantelpiece was turned half round, but did not stop; and small pictures suspended by a single cord were turned completely round. A chest of drawers standing against a wall running E. and W. was moved some inches towards the N.N.E., the western end being at least three inches further away from the wall than the eastern end. The time of the shock was given at about 9.20, and its duration at first stated to be 30 seconds, but in a subsequent communication Mr. Parkinson states that "it could not be less than 20." The cracks which were reported to have opened in the Rectory garden, were nothing more than the cracks which usually appear in paths after long-continued dry weather, and they were present before the shock.

Respecting the prevailing direction of the seismic movement at this locality, the evidence is most contradictory. Mr. G. H. Kinahan, F.G.S., who visited the area of damage about a week after the earthquake, states[31] that the shocks seem to "have had a rotary motion," the main direction appearing to have been from the S.E., but the evidence which led this observer to form an opinion as to the direction is not given.[32] On the other hand, an observation communi-

tion, were now turned almost south-easterly." It will be shown, however, in the subsequent portion of this Report, that the direction of twist of chimney-stacks gives no clue whatever to the direction from which the disturbance comes, and quite independently of dynamical principles the same conclusion was arrived at during our visit, since we occasionally observed that stacks on the same or neighbouring houses were twisted in quite opposite directions.

[31] 'Nature,' June 5th, 1884, p. 124.

[32] In a later communication with which I have been favoured by Mr. Kinahan, he informs me that his evidence was derived from the personal experiences of individuals present during the shock, and the directions towards which structures fell. "In the neighbourhood of Langenhoe the waves seemed to be going in different directions, if the

cated by the Rector might be considered to indicate that the disturbance travelled from N.E. to S.W. Mr. Parkinson informs me that a man ploughing in a field on Fingringhoe Hill, with his face towards the N.E., saw the ground move some distance in front of him, then the horses stumbled and floundered about and the plough was thrown out of the furrow; then the man felt the shock, and turning round towards the S.W., saw the turrets of Langenhoe Church thrown down. Another man working in a field to the north of the Rectory gave similar evidence, the ground in front of him to the N.E. appearing to move before he felt the shock. Postponing for the present the discussion of observations of this class, I will only add that, although they may appear, *primâ facie*, to possess a certain value in determining the general direction of the movement, too much weight must not be given to them, as the subjective impression of the observer may have unconsciously led to an erroneous interpretation of the facts, in a manner that will be considered more fully subsequently.

Langenhoe Hall was reported to be partly unroofed, and Wick Farm and Crouch House much damaged. Mr. Pertwee reports that at Langenhoe Lodge the chimneys were thrown down, the walls much cracked, ceilings uplifted, and bottles thrown down and broken.

Returning westwards again towards Abberton, and proceeding in a south-westerly direction along the road to Peldon, all the houses and cottages were noticed to have lost their chimneys. These buildings, which skirt Peet Tye Common, are Peet Tye Place, Pantiles, Peet Tye Farm, Rolls Farm, and others. Some of the chimneys were new and of good workmanship.

Peldon.—The damage here was considerable, this village

chimneys and cracks are taken as evidence, as in some of the structures they have different bearings to those in others . . . . . The twists in the chimneys being in different directions seemed to me to suggest that there must have been some sort of a rotary motion in the neighbourhood of Langenhoe, ... &c." It is possible that the conflicting accounts may here have arisen from the action of direct and reflected waves.

having suffered more than any of the places hitherto mentioned. Every house and cottage sustained more or less injury, some of the buildings having been rendered temporarily uninhabitable.

FIG. 5.—Shattered Cottage at Peldon.

At Peldon Church the substantial square stone tower (at the west end of the church) had lost portions of the battlements, the masonry falling partly into the churchyard, and partly crashing through the roof into the interior. The tower (said to be Norman) was rent on its western face almost vertically from top to bottom, the crack being in some places about half an inch wide. The nave and chancel walls were also much cracked, the latter part of the building only about 40 years old; the wall on different sides of a crack was in some cases "sheared" as much as half an inch to one inch. The vestry chimney was thrown down, falling towards the N. Mr. Symons states that "the glass from a standard lamp was thrown in a line E.S.E. to W.N.W." This observer remarks, with respect to the Rectory, that "large, well-built stacks,

new, but with very heavy cornices, were thrown down, and a similar one was twisted two or three inches; a bronze statuette, weighing about 10 lbs., on a base five or six inches in diameter, and of which the centre of gravity was well within its base, was thrown off the mantelpiece. There were cracks in various places, and not one upstairs room was habitable, owing to the roof being broken in by falling chimney-stacks. In a row of three cottages, facing S.W., out of six chimney-stacks, only one was standing, *viz.*, at the S.E. end, the N.W. stacks having in all cases suffered most; the N.W. end of each cottage had three or four large cracks twenty or thirty feet long, nearly or quite across it in a slanting direction, the top apparently having been thrust forward two or three inches; the S.E. ends appeared to be in their original positions; from the inside of the cottages daylight could be seen through the walls in many places."

Amongst other instances of destruction here may be mentioned a large, modern, strongly-built house, occupied by Mr. G. Holland, which was shattered and rent in all directions. In this house two gallon cans filled with milk nearly to the brim, which were being warmed in an oven, lost about half a gallon of their contents, by the movement to which the building was subjected. The "Rose" Inn was also much wrecked, the roof at both ends being stripped of its tiles, the walls cracked and bulged, and a large, substantially-built stack broke through the centre of the roof, and through the rooms below to the basement, leaving a large gap. Two other stacks were twisted about three inches from E. by N. to W., these chimneys being supported by iron stays below the plane of fracture. It has been reported by a witness that "the whole house appeared to upheave, and the middle of the roof to open, when the mass of falling bricks and chimney-pots tumbled into the interior." The village school-house was much damaged in the roof and the walls cracked.

Peet Tye Hall (Langenhoe) and Moor Farm, both to the east of the village, were damaged, the latter considerably. In this last place Mr. Symons reports that "a piano standing on the S.E. side of a wall running S.S.W. to N.N.E. remained

FIG. 6.—The "Rose" Inn, Peldon.

steady at its N.N.E. end, but was moved seven inches from the wall at the S.S.W. end. A table-lamp fell towards E.S.E., and a small clock was thrown from the mantelpiece a distance of about 5 feet."

Peldon Mill, south-east of the village, on the Mersea Road, opposite the "Rose" Inn, and the adjoining buildings, were considerably damaged, the upper part of Mrs. Went's house having been choked up with brickwork and *débris* on the morning of the disturbance. Mr. Wilson Marriage, in a letter dated April 25th, states that the house was "cracked in all directions, and it will probably have to be entirely rebuilt. The inmates described the sensation as being thrown against the walls, and inducing a clinging to anything for support." Glass and crockery was thrown down and broken, bedsteads, piano and furniture moved about 9 inches

from their positions. A square, slightly tapering engine chimney-shaft, about 80 feet high and 4 feet square at the

FIG. 7.—Twisted Chimney at the "Rose" Inn, Peldon.

middle, well and strongly built of brick, and standing detached from the other buildings, was fractured transversely at about 10 feet from the top, and the upper part left standing, but twisted round about an inch or more in a direction from W. to E. The woodwork of the mill itself did not appear much injured, but the circular brick foundation was cracked in several places. A cottage near the mill was rent all over, one crack at the N. end running transversely through the brickwork, with an inclination towards the E. of about 30°—40° with the horizon.

A little over a quarter of a mile S.E. from Peldon Mill is Strood Villa, the residence of Mr. Hugh Green, surgeon, which certainly presented one of the worst cases of destruction that came under our notice. The building, although modern (1860) and substantially built of brick, was, without exaggeration, wrecked.[33] The chimneys were demolished, every wall cracked and twisted, the door-frames displaced, many window-panes broken, and about 80 feet of the garden wall thrown down. The house, which faces S.S.W., presented the appearance of having been violently twisted round on its foundations; part of the stonework of the entrance-porch was dislodged, the front wall cracked diagonally in opposite directions, and on the south-eastern side another crack, nearly an inch wide in parts, ran obliquely from the top to the bottom corner at an angle of about 40°, passing right through brick and mortar and crossing a window-opening. The consulting-room, which Mr. Green had fortunately left only a few seconds before the shock, was destroyed by the fall of one of the chimney-stacks. In the surgery the bottles were thrown off the shelves; a pier-glass in the drawing-room was wrenched from the wall and thrown to the ground, and generally throughout the house all the furniture and fittings were shifted and more or less damaged, only one room, the kitchen, being left habitable after the earthquake.

The school and schoolmaster's house near Strood Villa likewise sustained much damage.

No very definite facts have come to hand respecting the general direction of the disturbance about this neighbourhood. Mr. Kinahan has expressed the opinion,[34] that the shock was here travelling southwards, and appeared to have had a "rotary motion." In Mr. Symons's field-book occurs the following note:—"Langenhoe Church, dust seen 5 seconds

[33] The suddenness of the shock was well exemplified by the fact that a bird (probably a starling) had been caught in a crack under the eaves of the roof and there died, the remains being still visible on the occasion of the visit of the Essex Field Club to this district, on August 4th, 1884.

[34] 'Nature,' June 5th, 1884, p. 124.

before Strood Mill affected." The church is about N. 20° E. of the mill.

Great Wigborough, nearly 8 miles W.N.W. of Strood Villa.—Two of the corner pinnacles thrown down from the church tower, one falling on to the nave and damaging the roof; the other two pinnacles were loosened and had to be taken down. The tower is also said to have been cracked on its south and west sides, and to have received an inclination over towards the nave. The Rectory was severely shaken, but received no serious injury. The Rev. F. Watson states that he heard a rumbling noise, and his clock was stopped at 9.17; some medicine bottles were seen to jump about, and were then thrown down and broken; a large picture was swung to and fro, and plaster was brought down from a ceiling. The sensation was described "as being in a boat and going up and down, backwards and forwards." Chimneys were thrown down and the roofs damaged at the surrounding farm-houses, Moulsham's, Seaborough, and Brick House. The latter, a substantial two-storeyed brick building, occupied by Mr. Charles Harvey, was much injured about the roof, the chimneys having fallen, and the upper part of the brickwork of the front of the house just beneath the roof, having been thrown down for a distance extending about half the length of the building, leaving the ends of the rafters exposed. Among the houses reported to have been much damaged were Mr. Blythe's, Mrs. Cause's, the "King's Head" Inn (several chimneys levelled), and the Parochial Schools (chimney fell through roof). As evidence of the violence of the movement, the Rev. F. Watson states that "a horse at work was taken off his legs and thrown to the ground."

Little Wigborough, one mile S.E. of Great Wigborough. The Rev. F. Watson reports that the church was "perfectly riddled." In his statement at the Mansion House the Rector added that "the body of the church has separated from the tower, and I cannot think of ever having any more service in it."

To the west and south-west of the Wigboroughs the effects

of the earthquake gradually diminished, and the area of structural damage in this direction ended in the neighbour-

FIG. 8.—Brick House, Great Wigborough.

hood of the Tolleshunts. At Virley and Salcott, situated respectively north and south of Salcott Creek, a few chimneys were thrown down and the village school-house damaged. Salcott Church was reported to have been injured.[85] At

[85] The Rector, the Rev. Edward Musselwhite, wrote to me as follows:—"Virley Church has been for a long time in a very ruinous state (unused); the shock has aided time in its demolition. Salcott Church (less than a quarter of a mile from Virley Church) has a good tower, which a few years since was very carefully restored; to this part I have not perceived that any damage was done, but the old walls of the church, which have for many years shown signs of falling outward, appear to be still more out of the perpendicular; the tiling of the roof was also much shaken. About four old chimneys in the two parishes were shaken down. My own house is a new one. It was considerably lifted but no injury done to it. As an instance of the force and direction of the earth-

Tolleshunt D'Arcy the shock was severely felt, bells were rung, furniture moved, and one or two chimneys thrown down. At Tollesbury chimneys were dislodged, and the movement of the ground felt by men at work in the fields. At these last villages the movement is said to have come from the N.N.E., and to have lasted for six or eight seconds. The tower of Guisnes Court, between Tollesbury and Tolleshunt D'Arcy, is reported to have been permanently displaced.

Turning eastwards again towards Mr. Green's villa on the Mersea Road, we pass over the raised causeway known as the Strood, into Mersea Island.

West Mersea.—The damage here was by no means so great as at Abberton and Peldon, and the first published reports from this neighbourhood were somewhat exaggerated.[36] On the occasion of our visit, when Mr. Larman, the chief officer of the coastguard station, kindly acted as our guide, it was observed that wooden houses, of which there are many in the village, had generally stood the earthquake well, as also had the newer brick houses, the injury being chiefly confined to the older buildings. At the church Mr. Symons reports that "part of a mullion had been thrown W.S.W. from the belfry window, ... and two iron chimney-pots fell away to the S.W. of the church, but that appeared to be all the injury there." I noted, in addition, a vertical crack on the western side of the tower. The Vicarage is reported to have been damaged about the roof. The Rev. T. R. Musselwhite states that the "wave" appeared to travel from N.E. to S.W., and was accompanied by a loud rumbling sound, which lasted a few seconds. With respect to the direction Mr. Symons also remarks that "Two seafaring men here stated that the shock appeared to travel from N.E., one

quake at the Rectory, in the larder, on a slate slab, a basin of milk about three parts full was raised on the north and south sides till the milk flowed over; the greater amount was spilt on the south side. The clocks were all stopped, pendulums swinging N. & S."

[36] As a specimen of what may be called "sensational seismology," there appeared in some of the local papers the ominous heading, in large type, "Mersea Island wrecked!"

describing how he saw women run screaming from houses to N. or N.E. of him, at the instant that he first felt the shock."

At Orleans Cottage and many other houses the chimneys were either thrown down or dislocated at the base and twisted. The Hall and Brick House were reported to have been considerably damaged. At the "White Hart" Inn chimneys were thrown down and part of the brickwork from the gable; one stack was left in such a shaky condition that it was considered unsafe for us to remain in the upper room of the inn during the strong gale which was blowing at the time of our visit. A clock in the bar was stopped at 9.18; pendulum swinging N.W.—S.E. Glasses standing on a table in the bar were tilted off. Mr. Larman informed me, that at the time of the shock he was looking south-eastward, towards the "White Hart," when he saw this house apparently lifted bodily up, and the chimneys thrown over. At the row of coastguard cottages, facing S.S.W., the shock was severely felt, but no damage was done, and not a clock was stopped. Mr. Larman stated that it appeared to him as if there were two reports, the first being the more violent, then the shock was felt, and was followed by a second weaker report and shock. The water of the yard well (80 feet in depth) at the coastguard. station was rendered turbid by the disturbance, and did not become clear for some days afterwards. Mr. Larman and some of the sailors about the neighbourhood were closely questioned as to the occurrence of any tidal phenomena attending the earthquake, but no unusual wave movement was observed, although the shock was felt strongly by boats in the estuary, the boatmen affirming that the direction was from the N.N.E. A man hoeing in a field near the "White Hart" felt the twisting motion of the earth and had the hoe jerked up in his hand. The National School and the schoolmaster's house were much damaged. School was being carried on at the time, and about 140 children were in the room, when one of the chimneys broke through the roof, the brickwork fortunately falling to the side of the room away from the benches occupied by the scholars. A panic was caused, but the schoolmaster (Mr. Thorpe) had the presence

of mind to check the rush outwards, and none of the pupils were injured. The clock in the schoolroom was stopped at 9.15; pendulums winging N.W. and S.E.; clock about three minutes slow. The chimneys at the schoolmaster's house were thrown towards the N.N.E., and a low brick outbuilding was cracked on its eastern face, the fracture running obliquely across the north corner, at an angle of about 40°, and bifurcating for about half its length; the general direction of the slant of the crack was towards the S., the S. forked ends being higher than the northern extremity. The Wesleyan School chimney was also thrown down and the roof damaged; but here, also, although some 60 children were in the room, no injury was sustained by them. To the extreme west of the island very little damage appears to have been done.

From the main village the road runs westward, skirting the shore along the top of a low, clay, drift-covered hill, about 34 feet above the sea level, and sloping somewhat steeply towards the alluvial foreshore. On the southern edge of this road a crack ran along the slope for a distance of about 200 to 300 yards, starting from St. Peter's Well, the square wooden cistern at the mouth of this well being situated on the shore above high water, a little to the south-west of West Mersea Church. The crack in question was almost obliterated and in parts difficult to trace at all at the time of our visit, but we were informed that on the day of the earthquake it was more than two yards in depth and wide enough to insert the fist. There can be no doubt that this crack was opened by the earthquake movement, but the term "fissure" applied to it in some of the early reports led to an exaggerated estimate of its magnitude on the part of those who had not visited the place. I was rather disposed to regard it as a small incipient landslip, which, had the shock been stronger, might have resulted in the sliding of some portion of the southern slope of the hill downwards towards the sea, and this opinion was also shared by Mr. T. V. Holmes. The water of the well, which usually runs out of the cistern in a clear and gentle stream, was jerked forcibly out by the shock

and afterwards ran turbid with suspended matter for about two hours, after which it resumed its original clearness.

At Cross Farm, a little over a mile E.N.E. of W. Mersea, the disturbance opened another small E. and W. crack, from which two little fresh-water streamlets spouted forth and trickled down towards the house for 8 or 9 hours, and then ceased to flow. The farm stands on London Clay, about 54 feet above the sea, and the streamlets, which were about 10 yards apart and one inch wide, were charged with a reddish-coloured sand. A specimen of this sand which had been collected was kindly forwarded to me by Dr. Alexander Wallace, of Colchester, with the following remarks:—"Plenty of water just beneath soil. Sand like this not found about these parts when digging foundations." Some of the sand was kindly submitted to microscopical examination for me by Prof. T. G. Bonney, F.R.S., who has been good enough to supply the following observations:—

"The bulk of it consists of quartz grains, varying from rather angular to moderately rolled, commonly about ·008″ diameter, *i. e.*, a little less than ·01″. I do not notice evidence in them of a composite structure, but this, under the circumstances, might readily be overlooked. There are a few dull green rather rounded grains, probably a glauconite mineral, and some minute opaque nodules, perhaps iron peroxide, or possibly phosphatic. The sand, as is often the case, is stained of a warm buff colour, being coated by a pellicle of hydrous iron peroxide. I do not profess to have made a special study of sand, but I doubt whether any conclusion could be founded on this. It has clearly been derived at the first from a granitoid rock, but that may be said of numbers of other sands. It is no doubt post-cretaceous in its date of transport to these regions; the materials may have for a while rested in Thanet or in Bagshot beds. I should say they had been for a time in deposits belonging to the Crags, from which, or from one of the sands derived from them, they have no doubt immediately come. A strong spring of water might easily bring up sand of this fineness from a depth of several yards."

At a well near these streamlets the water was made to rise about two feet, and was rendered turbid.

Proceeding along the road towards East Mersea, several cottages near Barrow Farm were observed to have lost their chimneys. In one case, two outside flues running up the opposite ends of a cottage were both completely detached from the end walls and thrown down.

East Mersea.—The damage done here was on the whole much less than at W. Mersea. The church tower was considerably shaken and portion of the battlements at the north-west corner thrown down. Mrs. George Round reports that a farm in the parish was considerably damaged. Respecting the direction of the disturbance at this place Mr. H. C. Sorby, F.R.S.[87], describing the damage to the church, states that "the manner in which two portions of the tower have been thrown down seem to indicate a shock from north-west," but he adds that it is "quite as probable that the damage was done by the recoil which, over the greater part of the district, was from that same north-west direction." To the extreme end of the island but very little damage appears to have been done.

Before treating of the eastern portions of the area of greatest destruction to the north of Mersea Island, the effects of the disturbance on the promontory to the south of the Blackwater River may be here described, as much damage was done about Bradwell, and this district, although passed over with slight notice in the early reports, must certainly be comprised within the area of structural damage.

Bradwell.—About 40 chimney-stacks were reported to have been thrown down, the greatest damage having occurred in the neighbourhood of the church and of Weymarks Farm (Mr. J. T. Gale) situated at the extreme north-east corner of the promontory, where it was stated that only one chimney was left standing among three houses, the farm-house itself having been much wrecked. The church tower was shaken, the roof partly untiled, and the rectory much damaged by the fall of a chimney-stack. East Hall (Mr. G. Small) between Weymarks and the village, was also damaged; several windows were broken, and I was informed by Mr. E. A. Fitch, of Maldon, that at this and a neighbouring house very heavy

[87] 'Nature,' May 29th 1884, p. 101.

chimney-stacks were fractured across, and left in such a threatening condition that they had to be taken down. At the school the walls of the building were violently rocked, and the children (about 180) rushed panic-stricken into the road.

In a southerly direction from Bradwell the destructive effects gradually died out towards St. Lawrence and Tillingham.

St. Lawrence.—A chimney thrown down at Motts Farm.

Tillingham.—About half a dozen chimneys thrown down. Buildings seen to oscillate and the motion of the ground felt; clocks stopped and goods thrown off shelves. Shock accompanied by a low rumbling noise.

Turning northwards again and commencing with the eastern shore of the Blackwater:—

Brightlingsea.—Damage not very serious. A few chimneys dislodged and part of the top of the church tower fell through the roof the of nave. In the ship-yards yachts were seen to rock.

Alresford, about 1½ miles N.N.W. of Brightlingsea Church. Chancel roof of church partly untiled on N. side; walls not damaged. Rectory roof injured by fall of portion of the chimneys. School-house roof slightly damaged by fall of coping-stones from chimneys. Damage reported to chimneys and roofs at Alresford Hall, Heath Farm, Lodge Farm, the "Pointer" Inn, and some other cottages in the village. Along the road approaching Alresford from Greenstead, two small brick cottages were observed to have been considerably cracked.

Fingringhoe, on the western side of the Blackwater, about two miles west of Alresford.—Brook Hall and many cottages at South Green, towards Frenchman's Lane, sustained extensive damage. In the village a large percentage of the buildings were more or less injured. Many chimneys were thrown down (30—40 per cent.) and the twists so commonly observed elsewhere were frequently noted, the rotation being in a few instances opposite indirection on the same or neighbouring houses. The following special cases of damage have been reported:—

Fingringhoe Church: the roof of the nave damaged and

the building considerably shaken and cracked inside, but much less injured than Peldon and Langenhoe Churches. The Hall, according to Mr. J. E. Taylor, had "lost the upper part of the western side of the front elevation." Quay Farm-house: walls cracked in numerous places. West House: two chimney-stacks thrown down, the house partly unroofed and the front shaken to such an extent as to require shoring up. Mill House: chimneys thrown down and partially unroofed. Post-office: chimneys levelled and roof damaged. Some fifteen other houses are mentioned as having been more or less injured.

East Donyland and Rowhedge.—A considerable amount of damage was caused here, although the destruction was much less than at Abberton and Peldon.

At the church the gable top of the chancel was broken off, and chimneys at the rectory and old parsonage thrown down. The Post-office, "Ship" Inn, and many buildings along the Quay had chimneys demolished or fractured, roofs untiled and walls in some cases badly cracked. The whole side of one house (Mr. Jennings) was thrown down. At Donyland Brewery the large boiler was shifted but not otherwise damaged; the building itself, which is substantial, was but slightly injured. East Donyland Hall (Mr. Havens) had all its chimneys but one thrown down, the roof much damaged, and the walls cracked both inside and out; the front of the house was left insecure and had to be shored up. Time of shock given as about 9.20. At Donyland Lodge (Major Holroyd) the chimneys were thrown down or dislocated, necessitating removal; the house was rendered temporarily uninhabitable, the kitchen being the only room left in which a fire could be lighted.

At Rowhedge a large percentage of the chimneys were observed to have been dislodged and many twisted towards the N.E. Mr. Symons states that "probably half the chimney-stacks were thrown down, and along the river front, perhaps 75 per cent., and one or two gables had been thrown down; there was a considerable variety of structure, but the new and good brickwork had suffered nearly as much as the old."

At Old Heath, a straggling hamlet between East Donyland and Colchester, about 40 or 50 chimneys were reported to have been thrown down and most of the houses to some extent damaged. Among the special cases noted during our visit was a square brick chimney standing on one side of a sloping roof, which, instead of being cracked at the base, as was so generally observed, had an oblique crack running from one corner. As this form of damage was rare, the following outline sketch is here introduced:—

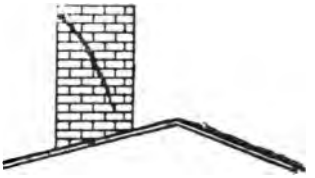

FIG. 9.—Cottage Chimney at Old Heath. South-eastern aspect. Oblique crack running from S.W. corner.

At a neighbouring cottage, an outside flue running up the western end was completely stripped off and thrown down.

WIVENHOE, on the eastern shore of the River Colne, opposite Rowhedge, suffered to a very considerable extent, the damage being especially severe along the river front, where fully 70 per cent. of the chimneys were thrown down, and 50 or 60 houses in the village were unroofed. Many houses along the Quay, some of them most substantially built, were practically wrecked. The general appearance of the village has been aptly compared to that of a place which had been shelled, or had suffered from the effects of a violent explosion. With respect to the amount of injury sustained, this place was considered to rank next to Abberton and Peldon. The time, as given by clock stoppages, was between 9.18 and 9.20.

Wivenhoe Church: the stone and rubble turrets on the N. and W. sides of the tower were thrown down into the churchyard, and the turrets on the other sides were loosened and subsequently had to be taken down. A small wooden cage-like belfry on the top of the tower did not appear to be damaged. The tower was cracked in several places, one large crack running from the top half-way down the northern face. Inside the church some of the stone columns (one in particular) were cracked at the base and twisted; the stone floor of a small vestry-room also showed cracks. Opposite the church a house was observed to have had its chimneys cracked

obliquely across about the middle, and the upper portions displaced nearly two inches towards the N. In West Street the Independent Chapel was much damaged, both inside and out; a chimney over the vestry-room was shattered but left standing; the solid ornamental parapet round the building was partly thrown down on the N. side; the inside walls were cracked, and plaster and cornices, together with the gaselier, thrown down from the ceiling. In this street nearly every chimney was levelled. At Mr. G. Stebbing's a pane of glass in a shop door was broken; the occupier states:—

"When the earthquake came I did not know what it was, but I heard the house rattling, the tins of lobster and salmon rolled about the shop by scores, things were tumbling down in all directions; I felt myself reeling and I caught hold of one of the iron pillars, thinking I was going to be buried alive where I stood."

At the National School a part of the chimney fell and the children assembled were much alarmed, but no other accident occurred.

The following special cases of destruction have been reported and were in great part confirmed during our visit:—

High Street: the Gothic (Mr. George Harvey) rendered temporarily uninhabitable; Mr. E. Harvey's, two stacks dislodged and other damage; Mr. Smith's (parish clerk), the old Post-office (Mr. J. Pratt), Mr. J. F. Turpin's, Capt. Harvey's, Mrs. Kidby's, Mrs. Rayner's, Mr. H. Brown's, and other premises much shattered. The same remark applies to the following inns:—"Black Boy" (end of East Street, Mr. J. Blyth); "Ship at Launch" (near Quay) and yacht stores adjoining; "Anchor" (Mr. D. Ham) damaged in rear; "Live and Let Live" (Mr. Chiswick); "Falcon" (Mr. N. Ham); "Sailor's Return," all the chimneys down; the "Grosvenor" (Mr. J. Goodwin), two stacks hurled into street; the "Greyhound" and adjoining premises (High Street). In East Street Capt. Bartlett's and neighbouring houses lost their chimneys; Mr. Schofield's premises were half unroofed. In New Road a row of eight houses belonging

to Mr. J. G. Chamberlain had all the chimneys but one dislodged, and one of the end houses had lost its gable, leaving the interior exposed. At the gas works the greater part of the circular brick shaft was thrown down.

In the neighbourhood of the Quay the following cases of damage were noted:—Trinity House and adjoining premises (occupied by Messrs. George Harvey and Son and Mr. Bartlett), chimneys thrown through roof into interior, house unroofed, gable thrown down, walls cracked and much of the brickwork thrown down from the upper portions of the walls beneath the roof. At the rear of these premises Mr. D. Ham's yard was filled with wreckage; the owner was in the yard at the time and compared the sound to "the rush of a train underground." Quay House; all chimneys down. Mr. H. T. Cuthbert, yacht decorator; chimneys fallen through roof, walls cracked, two panes of glass in a window broken; the house temporarily abandoned.

Near Anchor Corner much damage was sustained by Mr. Juby and Mr. Moore, three chimneys at the latter premises breaking through the roof, and some of the masonry knocking down and severely bruising Mr. Moore's son, who was in the garden at the time. Two or three other cases of slight personal injury are reported to have occurred in the village. In Bath Street a house occupied by Mr. J. Barr was stripped of its chimney and the whole gable thrown down. Many houses in Brook Street were unroofed and otherwise damaged. Mr. W. H. Bird, of Buckhurst Hill, who visited the earthquake district the day after the shock, informed me that at Wivenhoe he observed a terrace of eight or ten houses, running E. and W., in which not a single chimney was left standing; all had been broken off level with the roof and had fallen towards the N. At the back of the Quay we noticed a row of four small cottages, which had lost their chimneys in a somewhat remarkable manner. The cottages were in a line N.E. and S.W., a low, slate-roofed outhouse projecting from the end of each cottage in a north-westerly direction. The chimney at the end of the roof, just over the outhouse, had in each cottage been thrown down, falling nearly on to

the middle of the slate roof, and presenting the spectacle of a row of four outhouses with a hole at the same position through the roof of each. The chimneys had in this case all fallen over towards the N.W.

Mr. J. Edwin Wilkins, yacht builder, was standing in his yard at the time of the disturbance, near the stern of the "Medora," a new 150-ton yacht, which was well shored up on the stocks in a line nearly N.E. and S.W. The oscillation of the vessel was distinctly seen, one of the after shores dropped and the yacht was lifted off its block and the bow shifted an inch and a quarter. The chimney and part of the gable at the end of the joiner's shop was thrown down towards the S.W. and broke through the roof of a shed, much damaging a small 8-ton yacht beneath. Mr. Wilkins informs me that he was looking at this row of buildings, in a direction nearly S.E. and at a distance of 30 feet, when he saw the chimney "break off and describe a slight curve in the air, the upper part coming down crown undermost" and making a hole through the roof of the shed.[88] In this same ship-yard a

[88] It was reported in some of the papers (J. E. Taylor, in 'Hardwicke's Science Gossip, No. 234, June, 1884, p. 124; J. Edmund Clarke, 'Nat. Hist. Journ., vol. viii., June 15th, 1884, p. 86) that Mr. Wilkins's observations had enabled him to calculate the vertical displacement of the earth at Wivenhoe, and as this seemed a matter of considerable importance, Mr. J. C. Shenstone, at my request, kindly went over to Mr. Wilkins's yard to inspect the place and obtain this gentleman's evidence. I finally received a carefully prepared drawing to scale, accompanied by very full explanations. The data thus furnished are, however, by no means satisfactory, and the amount of displacement found certainly cannot be admitted, the more especially as the drawing indicates a surface wave in the solid earth having the enormous and impossible amplitude of *six feet*. The following is the observation in question:—

As already mentioned above, Mr. Wilkins was standing 30 feet from, and looking at, a row of buildings towards the S.E., the buildings running in a direction N.E. and S.W. Along the upper part of the buildings, which are 30 to 40 feet high, there is a row of windows belonging to the workshops facing N.W., and a corresponding row runs along the opposite (S.E.) face of the buildings overlooking Bath Street, which bounds the yard on this side. Under ordinary circumstances, an observer standing in the yard at the point occupied by Mr. Wilkins, could not see through the upper windows and across the buildings into

square brick shaft, with its corners directed to the cardinal points, was twisted slightly round from the N. towards the

Bath Street, as the line of vision falls on to the roof about 3 feet above the highest part of the window on the Bath Street side of the workshops. Now at the moment of the shock Mr. Wilkins asserts that he was enabled to *see through both windows*, and observed the fall of the chimney and brickwork from a house in Bath Street opposite to the workshops. Taking as data his own height and distance from the buildings, and the height of the opposite windows above the ground, Mr. Wilkins's diagram shows him as lifted vertically to the extent of 3 feet, and the building depressed to the same extent, and tilted over towards him at an angle of 5°. This construction carries the line of sight just across the two windows. I have not thought it necessary to reproduce the drawing here, but I may add that its accuracy is unquestionable, and the fact observed can hardly be denied, coming as it does from an observer whose daily professional avocation leads him to deal with exact measurements. Without venturing to offer any explanation of my own, I will only add, by way of comment, that both the wave length and the angle of tilt of the building are arbitrarily assumed, and could not be found by the method given. It is moreover assumed that the building swayed *as a whole*, whereas the opposite faces may have been displaced with respect to each other in opposite directions. A certain amount of elasticity must be allowed to exist in a building, into the construction of which a large amount of wood enters, as in the present case; this elasticity, together with the unknown wave-length and angle of tilt, entirely vitiates any calculation based on the supposition that the structure simply rocked to and fro as a whole, without undergoing any deformation. I at first thought it possible that Mr. Wilkins had been mistaken in identifying his position, but he satisfactorily removed every doubt on this point, and whilst expressing my thanks to this gentleman for the courtesy with which he supplied me with all the information required, I feel bound, in placing his observation upon record, to express dissent from his interpretation.

(Since writing the above note I have received a letter from Prof. J. A. Ewing to whom I submitted the diagram referred to. This well-known authority in seismology confirms the objections raised by me, and points out "the general truth that a building may assume a slope, by shearing, during an earthquake, although the ground at its base is not sensibly sloped. A series of small horizontal movements of the base will often produce a large accumulated vibration on the part of the superstructure, especially if the roof is heavy, and the construction such as to admit of distortion. In a frame house, without cross-bracing, and with a heavy roof, there is nothing to prevent the swing of the roof being a foot or two in amplitude or even more, though the movements of the base may be fractional parts of an inch. To explain the case in question, however,

E., and at the N. corner of another shaft a single brick about half-way up was displaced and left projecting. Mr. Wilkins has been good enough to furnish me with the following additional notes respecting the effects of the earthquake at Wivenhoe:—At the house of Mr. Blois, five pictures hanging on a wall facing S., which before the shock were parallel with the floor, were afterwards found to form an angle of 5° with the floor: the chimneys of this house were thrown down. At the house of Mr. Barrett seven pictures were affected in a similar manner, and the chimneys also dislodged. Mr. Cuthbert (already alluded to) had one picture displaced 10° and the house practically wrecked. Mr. Wilkins himself had nine pictures shifted 8½°; his chimneys were not thrown down. Mr. Wilkins was inclined to believe that the displacement of the pictures was not produced by a lateral swinging movement, but that the nails, with the walls into which they were driven, were lowered suddenly, and the pictures and cords followed, so that when the wall resumed its normal position the pictures were lifted into a fresh position. Underlying this explanation there is, of course, the assumption that the point of suspension of the picture is lowered *obliquely* with respect to the frame. The Post-office clock, kept true to Greenwich time, was stopped at 9.18.

One circumstance with reference to the damage at Wivenhoe is sufficiently interesting to be recorded here, although the bearing of the fact in question belongs more to the geological portion of this report. My attention was first called to the absence of damage to the houses on each side of the railway cutting south of the station by Mr. E. B. Knobel, F.G.S., of Bocking, who visited the earthquake district four days after the disturbance. This observer wrote:—"The whole of the town seems to have suffered from the shock, with the exception of two rows of houses, one on each side of the railway cutting just south of the

by supposing that the house or shed at Wivenhoe was *sheared* through so large an angle as to bring a line of sight through its windows to the eye of an observer situated at the place sketched is, I must admit, to put a severe strain on the theory as well as on the house.")

station. The row of houses on each side of the cutting is a lot of new red brick dwellings. On the west side the houses are older. As far as I could see and learn, these houses entirely escaped damage." Mr. Symons reports that "at a small but substantial building belonging to Wivenhoe Hall, and just outside the village, an entire gable had fallen to N. (about 100 feet of brickwork.")

Wivenhoe Hall, the residence of Mr. James Jackson, a strongly-built mansion standing on a low drift-covered hill overlooking the river towards Rowhedge, was considerably damaged. Four out of five heavy chimney-stacks were thrown down, the débris falling partly towards the N.E. and partly to S.W.; one stack crashed through the roof into one of the upper bedrooms, nearly two tons of the brickwork falling into a bath which had just been used by Mr. Jackson's nephew. Another chimney was torn away from the side of the house, leaving a wide crack; and at the north-east end of the hall the gable was partly thrown down. On ascending to the roof, it was pointed out to us that the north parapet was cracked and in a loosened condition, while the southern parapet was not injured. Over one of the windows of the southern frontage a considerable portion of the upper row of bricks had fallen out from about the middle towards the E.

This form of damage was occasionally observed elsewhere during our inspection, in some cases the arched row of bricks over a window or doorway having been momentarily loosened, and some of the bricks either allowed to fall out altogether, or else they were retained in their downward course by their conical form. This mode of retention is also well shown in the accompanying figure:—

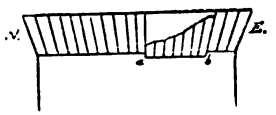

FIG. 10.—Wivenhoe Hall. Row of bricks over window, facing south. The bricks between *a* and *b* partly broken across and slipped downwards.

FIG. 11.—Doorway at Peldon, showing loosened bricks.

Inside the house (Wivenhoe Hall) the upper rooms were much injured by wreckage, and the walls distinctly cracked in many places. On one of the landings an oblique crack in the E. wall had an inclination towards the N. of 40° with the horizon; another crack in the N. wall of one of the upper bedrooms had an eastward inclination of about 60°. The tower and chimneys of the stable were cracked, and the entrance-lodge suffered by the loss of its chimneys and a portion of the ornamental gable. Mr. Jackson informed me that in the kitchen a clock with pendulum swinging N. and S. was stopped, but the dining-room clock, swinging E. and W., was not stopped. With respect to his own experience, Mr. Jackson has published the following statement:—

"As the shock lasted at most six to seven seconds, it was impossible for any observations to extend beyond the immediate surroundings of the individual, and it is only by judicious dealing with a collection of these personal experiences, and a careful inspection of the damage done, that any reliable estimate of the intensity of the earthquake can be formed. My experience was briefly as follows:—I was standing alone in a ground-floor room reading my letters, about 20 minutes past 9 a.m.; suddenly, without being previously aware of any rocking or rumbling sensation, there was a noise as of falling brickwork. I at once came to the conclusion that a semi-detached chimney at the back of the room had fallen; the din increased and became deafening, and the accompanying rolling motion of an earthquake was easily recognisable. No warning symptoms of earthquake occurred; there was bright sunshine at the time, with a clear sky overhead, and there was no abnormal behaviour of the barometer. The shock was not preceded by any smaller premonitory shake, nor was there any subsequent movement after the single shock. Further, no subsidence of water in the ponds could be detected after the event. From the fact that the pendulums of clocks swinging north and south were stopped, while those east and west continued going, it would seem that the wave of earthquake moved somewhat in the latter line, though this theory is scarcely borne out by the action of the shock on buildings, and it is probable that the true line of motion was west-south-west and east-north-east. I may mention that three weeks ago, about the same hour, I noticed what I believed to be a slight earthquake; it was not sufficiently pronounced for me to be certain, though I stated the fact to others at the time."

The "Nook" in the Cemetery Road (Col. Bowen), was much damaged in the roof and upper storey by the descent of the chimney-stacks, and the house had to be abandoned.

At Wivenhoe Cross, about a mile due north of the main village, the damage began to decline. The "Flag" Inn and neighbouring building suffered from falling stacks. At the Rope Walk (Messrs. Browne and Son) about 30 feet of a tall brick shaft had to be taken down, and a large steam boiler in the building beneath was much damaged. Between this hamlet and Greenstead the house at Wivenhoe Park (Mr. H. J. Gurdon-Rebow), modern and strongly built, had the chimneys thrown down, the roof damaged, and the walls and

ceilings inside cracked. The steward, in a plantation at the time, was thrown down by the shock.

On the River Colne at Wivenhoe the disturbance was severely felt, and has been described by many witnesses. Thus Mr. William Ham states :—

"I was on a brig in the river, with my face to the village, and the first indication I had of anything amiss was that the vessel rose a foot. I knew at once that the shock was an earthquake, having experienced similar visitations many times in the Atlantic and in the western islands of the Azores. Recognising immediately the sensation under my feet, I glanced at the shore and saw Husk's and Dick Ham's chimneys at the eastern extremity come down. As the wave rolled on I saw every chimney topple over, until the work of destruction reached the line of the church tower, and then the crashing masonry raised such clouds of dust that I could see no more, and I thought the whole place had collapsed. It was quite five minutes before the atmosphere cleared, and then, of course, the extent of the damage stood revealed. To the best of my belief the shock lasted about five seconds, and it seemed to travel from north to south. At my own house a chimney mirror, of thick plate glass, was pitched off into the middle of the room, upon its back, and shattered into fragments."

Lord Alfred Paget was just getting on board his yacht, the "Santa Cecilia," when the shock came, and he states that he and the officers and crew heard the rumbling sound and felt the oscillation of the vessel, and at the same moment witnessed the destruction in the village. Many reports from those on board the various craft in the river agree that the sensation was comparable with that which would be felt if the vessel had struck suddenly upon a rock. In some cases the masts were seen to oscillate sharply from side to side, and boats under sail for the moment refused to answer their helms. A sailor who was on the river informed Mr. W. H. Harwood, of Colchester, that he distinctly felt a strong movement under the water, the surface of which remained perfectly calm, before any disturbance was observed in the village, which was immediately afterwards apparently lifted bodily up, and the buildings were seen to rock about and

then settle down again. The statements as to the *order of succession* of the phenomena are, however, contradictory, and but little weight attaches to them. From inquiries made during our visit, the absence of any distinct movement of the water in the river was generally confirmed.

The evidence respecting the general direction of the disturbance in this neighbourhood is more conflicting than that received from any other locality, and there can be no doubt that the movement here was of an extremely complex character. Dr. H. C. Sorby, F.R.S., whose yacht, the "Glimpse," lay on the river at East Donyland, about half a mile above Wivenhoe, states[89] that the mate, who was on deck at the time, informed him "that the yacht was first, as it were, moved violently forwards to the west and then even more violently backwards to the east." Mr. G. H. Kinahan informs me, that in his opinion the shock came from N.N.E., and was reflected with a "concussive blow against the fault line of the Colne Valley." Several witnesses have reported that they saw the destruction commence at the eastern extremity of the village, but, for reasons which will be entered into more fully hereafter, I do not think that much importance can be given to observations professing to discriminate between the successive intervals of the passage of the wave of destruction, when the observers are naturally thrown into a state of alarm and at the same time the duration of the destruction is extremely short. Looking at the fact that the main axis of disturbance, as evidenced by the actual amount of destruction, lies to the south-west of Wivenhoe, while practically no damage was caused to the north-east of this village, it seems probable that the disturbance spread rather from the S.W. or S.S.W., the wave being reflected backwards and laterally from the Colne Valley, and thus giving rise to the impression that at Wivenhoe and places to the S.W. (Langenhoe) the disturbance travelled from the N.E. or E.N.E. The abruptness with which the large amount of destruction at Wivenhoe is shielded off as it were from the

[89] 'Nature,' May 29th, 1884, p. 101.

districts to the north-east of this village is certainly suggestive of the Colne Valley having acted as a barrier against which the wave was broken and reflected, giving rise to the complicated effects observed, and confusing the original direction of the disturbance. The tract of country to the north-east of Wivenhoe appears in fact to have been in "seismic shadow."

Summary of Observations in the Area of Structural Damage.

The area now described, comprising some 50 to 60 square miles of country in north-east Essex, may be considered to include the whole region over which the disturbance was of sufficient intensity to cause structural damage to buildings. In the outlying districts a few isolated cases of damage have been reported, but these are exceptional, and refer only to old and shaky structures (generally chimneys) which might have been toppled over by a very moderate amount of oscillation.

Within the area of destruction there occur certain maxima, which when plotted on a map in the order of intensity, give the impression of being somewhat irregularly distributed, but the main axis of disturbance extends on each side of a line about five miles in length, having a direction N.E. and S.W. from Wivenhoe to Peldon. Along this axis the greatest intensity was manifested, as shown by the large percentage of dislodged chimneys, dismantled roofs, &c., and more especially by the fracturing of solid masonry.

In estimating the severity of the shock in the various parts of the chief seismic area, the local conditions must be taken into consideration. Thus the amount of damage at Colchester, when laid down on the map, appears excessive, but this is no doubt due to the larger amount of material which the earthquake had to operate upon. On the other hand, the absence of a large amount of damage cannot be taken as conclusive evidence that the disturbance was not severe at any particular place; it may simply indicate the absence of damageable buildings.

After giving due weight to these various modifying influences, we have come to the conclusion that the towns and villages within the area of destruction may be broadly classed as follows, in the order of the intensity of the shock:—

I. (The main action of disturbance).
   a. Peldon, Abberton, Wivenhoe and Rowhedge. (Maximum destruction).
   b. Langenhoe, Fingringhoe, E. Donyland. (In the main axis of disturbance, but damage not so great).
II. Colchester and Greenstead, W. Mersea.
III. The Wigboroughs, Layer-de-la-Haye.
IV. E. Mersea, Bradwell.
V. Alresford, Brightlingsea.
VI. Layer Breton, Layer Marney, Tillingham, Lexden.
VII. Birch, St. Lawrence, Tolleshunt D'Arcy, Tollesbury, Salcot-Virley. (Damage slight).

In the foregoing list, showing the distribution of damage, the only special feature calling for observation is the diminution of intensity about Langenhoe, Fingringhoe and E. Donyland, this area of lesser destruction dividing the axis of maximum disturbance in a very marked manner, and giving the impression of there being two foci of disturbance in the main N.E. and S.W. axis, one under Wivenhoe and Rowhedge, and the other under the Peldon-Abberton district. This effect, as already suggested, may possibly be due to reflection from Wivenhoe. (See Map; Plate II.).

In giving the evidence for the remainder of Essex, and for the other counties in which the shock was felt, the towns and villages will be classified alphabetically, in order to facilitate reference.

List of places in Essex where the shock was felt.

Aldham, 5 miles W. of Colchester.—Shock rather severe; slight structural damage. One or two chimneys thrown down, tiles shaken off roofs, school-house shaken; house-bells rung.

Althorne, between Maldon and Burnham.—At Stokes Hall (Mr. John T. Rogers) a clock stopped; pendulum swinging N.E. and S.W. Another clock swinging in same plane unaffected.

Ardleigh, 4 miles N.E. of Colchester.—Shock severely felt and rumbling noise heard; bells in church tower caused to ring. Mr. D. E. Cardinall states that "the walls of the room in which we were seemed to undulate just as a large sheet of canvas stretched upon two vertical poles would when struck with a staff. All of us were shaken rapidly to and fro and from side to side in our chairs, as one would be in a poor railway carriage or a badly-laid line. The servants and children upstairs rushed about the rooms in great fright, thinking the house was falling. My head gardener, who was stooping down by a border, sowing seeds, was alarmed by suddenly hearing a great rattling noise from the greenhouses, and the thunder-like rumble underground, when suddenly the earth seemed to rise under him, and his shadow (for the sun was shining brightly) appeared to sway about and he was nearly thrown off his feet. He quickly recovered himself and ran. An under-gardener, some 200 yards from him on the other side of the house, declares he felt nothing and heard nothing. The shock occurred, as nearly as we could tell, at 9.17." Chimneys were reported to have been thrown down at Crockleford Mills, near here.

Writing from the Phœnix Flour Mills, Mr. Thomas Robinson states that in his house a clock was stopped (pendulum swinging N. and S.) and bells were rung; sacks of wheat on the upper floor of the mill fell from E. to W. Oscillation of building strongly felt, both in house and at the mill.

Asheldham, near Dengey.—Shock felt.

Ashingdon, near Rochford.—Shock felt.

Barking.—Slight shock felt by one or two persons.

Basildon, 4 miles S.E. of Billericay.—Slight shock felt.

Bergholt (*East* and *West*).—Shock distinct; slight damage.

Billericay.—Shock slight.

Black Notley.—Shock felt rather strongly in some houses.

Bocking.—Mr. E. B. Knobel, Sec. R.A.S., who resides at this place, has been good enough to forward me the following report, which, as coming from a well-known scientific observer, I here give *in extenso*;—

"I was standing on the first-floor of a building when the shock came—immediately watched the wall at the side of the window, and saw by reference to the clouds that it swayed considerably out of the perpendicular. Felt certain at once it was an earthquake shock, and took time by my watch, which had a known error, and which was confirmed by an observation of the sun the following day as 9 h. 18 m. G.M.T.

Duration of the shock estimated as under three seconds.

I collected the following facts within an hour of the occurrence:—

1. The shock caused a burst of steam to escape out of the safety-valve of a large steam boiler in the factory in which I was at the time. There was about 20 lbs. pressure of steam in the boiler at the time, and the safety-valve was weighted to 30 lbs. The boiler was evidently jerked up and fell quicker than the valve could follow, and consequently steam blew off for an instant.

2. A dye bark, 12 feet long and 2 feet 4 inches wide, filled with water, occupied the following position. Bearings being *true*, not magnetic:—

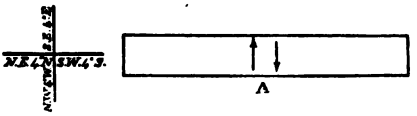

FIG. 12.—A, position of observer. The arrows show the direction of the waves.

At the moment of the shock, a man was standing at A, with his hands on the side of the bark. At the commencement of the shock he was tilted forward towards the S.E., and he felt the bark go with him, then he swayed back. A wave was produced in the water which started from the N.W. side of the bark, and this moved back and forth from

side to side. *No ripple or wave whatever was noticed to move lengthwise of the bark.* When the waves started across the bark it splashed up about ¾ to 1 inch against the S.E. side, but when it returned it was stronger and deeper; that is to say, that the bark was first slightly tilted towards the S.E., then much more strongly tilted towards the N.W.

This evidence is reliable and I collected it soon after the event. It is important as affording an excellent indication of the direction in which the earth-wave travelled.

8. Iron plates suspended from nails in a brick unplastered wall running N.W. and S.E., oscillated to and fro in the plane of the wall. Had the force producing this oscillation been at all inclined to the direction of the wall the plates could not have swung, as they hung with their faces in direct contact with the bricks.

4. Pendent gas lights in the factory, 6 or 8 feet long, swayed in a direction N.W. and S.E. Some gas-pipes were stated to move in a plane at right angles to this, but the most reliable evidence I could obtain at the moment did not confirm it.[40]

5. A wall 60 feet long and about 16 feet high, running due N.W. and S.E., in which there was an old settlement about midway, had a new crack formed by the shock from top to bottom.

6. Two clocks stopped in different houses, the perpendicular to the planes of oscillation of the pendulums in both cases being approximately N.W. and S.E.

I send no personal experiences from this neighbourhood gathered from others, as the accounts were exaggerated."

Boreham.—House-bells rung. Shock felt at Old Hall and also at Boreham Hall, by Major J. L. Tufnell-Tyrell.

Braintree.—Shock distinctly felt; house-bells rung; a rumbling sound heard; no damage.

Braxted Park, near Witham.—Shock felt and rumbling noise heard by Sir Charles Du Cane, who states that the sound passed, as far as he could judge, from E. to W. Oscillation of house seen and movement of earth felt; one clock stopped; marble columns with busts caused to rock and one displaced nearly an inch; slight fall of plaster from ceiling. Time, 9.20.

[40] There was no inducement for the gas-pipes to swing in one direction more than another, they all being fixed and not having any form of joint or movable part.—E. B. K.

Brentwood.—Shock felt by people in the houses; rumbling noise; a lady having breakfast in bed had a cup of coffee spilt.

Broomfield, two miles north of Chelmsford.—Shock felt; no damage. House-bells, telegraph bell at post-office, and a large bell in a clock-tower made to ring. Movable objects in many houses caused to oscillate whilst neighbouring houses were unaffected. An old man thrown from a chair.

Buckhurst Hill.—Dr. Cory, The Elms, felt a "staggering sensation," and two of his patients in bed at the time felt the oscillation; both resided on the east side of Buckhurst Hill. Mr. E. H. Bailey, East Lodge, reports that a clock, facing nearly due S., was stopped at 9 h. 18 m. 15 s. (clock 45 to 75 s. slow). Four other clocks in the house facing E. and W. and one facing N. were unaffected. At Melrose Villa a clock was stopped; plane of oscillation N.W.—S.E. At Laurel Cottage Miss Jane Cole, who was lying in bed unwell, distinctly felt the vibration and saw the oscillation of the wall. Bedroom in upper part of house; bed with its length approximately N. and S. Shock not felt elsewhere in neighbourhood.

Bulmer, near Sudbury (Suffolk).—Shock distinctly felt at Smeetham Hall; furniture displaced; no damage.

Burnham, near Maldon.—Rumbling noise; pictures swung, bells rung and clock stopped. In a builder's shop tools were made to oscillate; a sash-frame leaning against a wall and tables thrown down; vibration felt. Mr. E. A. Fitch informs me that at Hill House (Mr. John Rogers) the shock was felt very severely, ornaments and pictures being much shaken, and one large picture facing N.W. especially seemed as though about to fall over. A sharp concussion was felt also by men in boats on the River Crouch, and several of the fishermen were so alarmed that they were afraid to venture upon the river for days afterwards.

Castle Hedingham.—House-bells rung, rumbling sound heard, oscillation of houses felt, pictures swung, and a man said to have been upset from a chair in which he was seated. No damage.

Chelmsford.—The shock was sharply felt in many buildings, especially at the foot of Springfield Hill, about half a mile from the town. In many of the houses furniture and other movable objects were overturned. Mr. F. H. Meggy, to whom I am indebted for much information from this place, informs me that near the top of the hill, which is covered with from 12 to 20 feet of gravel, the shock was not felt; 1000 feet nearer the town, in a S.W. direction, the movement was felt but no bells were rung, whilst 900 feet further on in the same direction, as well as in the town itself, the disturbance was severe and bells were rung, although no damage was done. At the top of Springfield Hill a horse was thrown down, and the signalman in the box at the Chelmsford railway-station was thrown against the handles of the levers, the structure, which stands on an elevated framework, at the same time swaying to and fro. In a house near Moulsham a breakfast-table was thrown against a partition wall. At the timber-yard, Springfield Wharf, a pile of planks was thrown down. Mr. R. J. Lawrence, writing from the 'Chelmsford Chronicle' office, has furnished me with some interesting details respecting his own experience. He was in the reading-room in a standing position, pressing against a table, reading the paper, when the table suddenly receded about an inch, his body following. The movement was repeated a second and third time, his body being jerked against the table with considerable force. "There was an apparent depression in the floor of the room towards the north, and the sensation was that the whole apartment was being gently swung or thrown into the area beneath." The wall was heard at the same time to give a sharp crack, and on turning towards the door this was found to be shaking. The three waves felt were estimated to last about 5 seconds, and the tremor of the door from 10 to 15 seconds longer. The room in which this occurred is on the second floor and faces N.N.W. The time, "as indicated by unreliable clocks," was 9.18. The foreman on the third floor reported that the walls of his room moved from S.S.E. to N.N.W., and he was himself thrown forwards towards the

E.N.E. Mr. Lawrence adds that at his private house, about half a mile S. of the office, "a parcel of linen about a foot in height, folded for the mangle, was rocked violently from S.S.W. to N.N.E., but was not overturned." The office clock on the ground-floor, plane of vibration E.N.E.—W.S.W., was not stopped. The testimony is tolerably concordant that at Chelmsford the earthquake movement travelled approximately from E.N.E. to W.S.W.

At Crix, 6 miles from Chelmsford, on the Witham Road, Mr. Samuel Hall, F.C.S., informs me the shock was felt at 9.20; pictures were swung to and fro on the wall, the floor of the room heaved distinctly, and on the second floor the oscillation caused a servant to have a feeling of nausea. The shock was not felt in the basement; in the garden the rise and fall of the ground was seen and a subterranean noise heard.

Chignal St. James.—Mr. R. M. Christy informs me that the shock was distinctly felt and bells rung in their house here.

Chigwell Row.—Shock not generally felt. Capt. P. M. Hayward, of Hainault Hall, who was in bed indisposed at the time, informs me that the house oscillated perceptibly, and the windows rattled in their frames for about 15 seconds. Movement apparently E. and W.; time about 9.20.

Clacton.—Shock very slightly felt in some parts of the parish.

Coggeshall. — Shock severe, but very little structural damage. A panic was caused among the girls in the National School, but no serious injury was incurred. In one house a looking-glass was thrown off a table and broken. Mr. George F. Beaumont, of Sunnybank, has been good enough to furnish the following report:—

"I was sitting in my dining-room with my wife and two other ladies, on the morning of the 22nd April, 1884, when we all suddenly experienced an oscillation similar to that which would result from the passing of an express train through a railway-station, or heavy traction-engine along the road. Immediately the shock was over I looked at my clock and observed '20 minutes past nine.' Neither of my clocks stopped, the pendulum of one of which swings from

north to south and of the other from east to west. None of my bells rang; they are hung in a line running E. to W. The glass back of my sideboard which faces E., oscillated, and was the object which most attracted our attention. None of us noticed any noise except that caused by the motion of the sideboard, &c. My house is built of brick, and is situated on a loamy stratum, about 8 feet in thickness, overlying the London Clay, and stands 110 feet above the sea-level, on a bank sloping southward. Chalk is reached at a depth of about 240 feet.

From enquiries I have made of the leading inhabitants of this town, I find that in most of the houses the bells rang more or less, but in some instances violently. In many cases also clocks stopped, but so far as I can gather, the ringing of bells and stoppages of clocks was quite independent of the direction of their vibration. I have not heard of any well in this neighbourhood in which the water has been affected.

Two chimneys were thrown down, and this may be said to represent all the damage that was patent.

The exact time of the occurrence is generally stated to be 9.20 a.m."

The chimneys thrown down were at houses in Bridge Street and Church Street respectively. The tall chimney at the gas-works was also seen to oscillate considerably, and a 5-inch gas main was reported to have been broken across. Mr. R. M. Kirkham reports that he was sitting on a stool in his office in Bridge Street, and was much alarmed by the oscillation of the building, which produced a sensation of dizziness; he states that the stool appeared to rock from W. to E.

Copford, 4 miles W.S.W. of Colchester.—Mr. Henry Laver reports that at a farmhouse near here milk in pans in the dairy was first sent over towards the N.E. and then back towards the S.W.

Danbury, 4 miles E. of Chelmsford. Shock felt throughout the village; doors, windows, &c. rattled; bells rung in many of the houses; no structural damage. Planks in the timber-yard were seen to oscillate. The shock was felt and the crockery made to rattle on the shelves in a cottage on Danbury Heath.

Dedham, 6 miles N.E. of Colchester.—The shock was rather severe here and some structural damage was done. Chimneys at the Hall, the Marlborough Hotel and the "Gun" Inn thrown down. The dining-room ceiling at Dedham Park was reported to have fallen in. Writing from the Lodge, Mr. Rowland T. Cobbold reports that the time was 9.18, as verified by watches, the church clock, and the stoppage of his drawing-room clock (pendulum swinging N.E. and S.W.) Four other clocks facing same direction were not affected. The glass door of a book-case facing S.W. was thrown open; bells on walls facing S.W. were rung, and five or six others on wall facing N.W. did not sound; duration of shock estimated by Mr. Cobbold and his son to be 10—12 seconds.

Dengey, near Tillingham.—Shock felt, especially in the highest parts of the houses; clocks stopped, pictures moved; no structural damage.

Dovercourt.—Shock said to have been slightly felt in some houses.

Dunmow.—Distinctly felt and rumbling sound heard; bells rung in some houses, pictures and glasses thrown down; a man feeding some cattle felt the movement of the ground and the animals ran about in alarm. No structural damage. The Rev. A. B. Bingham Wright, of Stebbing, writes:—

"The shock was felt capriciously; not at all in some houses close to others where it was distinctly experienced. A watchmaker at work at his board before a window N.W. by N.—S.E. by S., was swayed backwards on his seat in this line. The watches hanging in the window in his front swayed to and fro in the plane of their greater diameter; those at right angles to the aforesaid, each side of the window, in the plane of their lesser diameter. He could not say whether the first impulse was from N.W. or S.E. Shock at 9.20, Greenwich time."

Earls Colne.—Shock felt, accompanied by rumbling noise. Doors and windows shaken, bells rung, and suspended objects made to oscillate; a looking-glass thrown off a dressing-table. Many people experienced giddiness and nausea. No structural damage.

Faulkbourne.—See *Witham.*

Feering, near Coggeshall. — Shock somewhat severe and slight damage done. A panic was caused at the school and one boy fainted; rumbling sound heard and mortar thrown down from ceiling. Bells rung and chimneys displaced at Bury Farm. At Church Farm the sound was heard, the movement of the floor felt, pictures moved to and fro against walls, and chimney ornaments were overturned. Mr. F. C. J. Spurrell visited this village in August, 1884, and reports that no damage was done to the church and rectory (both in good repair), but at the Grange, an old Georgian house, tiles had been displaced, the walls slightly cracked, and the chimney-stacks displaced perceptibly as seen from below. The inspection of the Grange was kindly permitted by Major Bannister.

Felstead, 5 miles W.S.W. of Braintree.—Shock distinctly felt between 9.15 and 9.20. Mr. J. French, writing from this place, informs me that he was reading at the time, and experienced a gentle undulation of his chair, which lasted for two or three seconds. No second wave was felt. All pendulous articles oscillated E. and W. Mr. French compared the sound to that of a heap of rubbish being shot down. A clock swinging E. and W. was stopped.

Fordham Heath, a little over 4 miles N.W. of Colchester. —Shock felt; slight damage.

Frating, 2½ miles E.N.E. of Wivenhoe.—The Rev. O. Fisher states ('Nature,' June 5th, 1884, p. 125) that some men hoeing in a field "did not perceive the shock, but felt as if they could not get their hoes to the ground." At Frating Abbey, a new and well-built house, about 40 years old, one chimney was much damaged and the others so much loosened as to require supporting.

Goldhanger, about 3 miles E.N.E. of Maldon. — Shock distinct; no structural damage.

Grays Thurrock.—From inquiries made by Mr. Herbert E. Brooks, it appears that the shock was not felt in this neighbourhood.

Great Baddow, near Chelmsford. — Mr. Henry Corder,

of Grove House, reports that the shock was felt distinctly, "commencing with a severe wrench and then an up and down motion." The furniture rocked, especially a tall bookcase, which appeared to sway N. and S. Clock on mantelpiece stopped at 9 h. 18 m. 30 s. (probably a minute of error); pendulum swinging nearly E. and W. Bells hanging in a row N. and S. were swung but did not ring. No damage in immediate neighbourhood. A mile N., at Sandford Mill, the shock was severely felt; bells hanging in a row E. and W. were all rung. About 3 miles N. of Great Baddow a shed roof was displaced. Mr. J. Brittain Pash, of Rainsford End, informs me that a clock in his dining-room was stopped at 9.20; oscillation of pendulum N. and S.

Great Bentley, 3½ miles E. of Wivenhoe.—Sharp shock, with underground rumbling; oscillation of houses felt and bells in some cases rung; windmill severely shaken. Mrs. Kate T. Sizer, of Moorlands, states that she felt "two shocks directly following, the second smarter than the first."

Great Bromley, about 6 miles nearly E.N.E. of Colchester. —Chimneys at Rectory reported to have been dislodged.

Great Horkesley, 5 miles N.N.W. of Colchester.—Severely felt; no structural damage. House-bells violently rung, low rumbling sound heard, wall of room in Rectory seen to oscillate.

Great Wakering, near Shoeburyness.—Mr. S. W. Poynter, in a letter to the 'Daily News,' reports that the shock was felt here, and distinct underground rumblings were heard. The oscillation of the house was felt and pictures on the N. and S. walls moved, whilst those on the E. and W. walls remained at rest. Duration estimated at from 5 to 7 seconds.

Great Waltham, 4 miles N. of Chelmsford.—Oscillation of houses felt, a ceiling cracked, house-bells rung, and church bell "observed to sway as if prepared to strike." No other damage.

Halstead.—Shock distinctly felt, especially in upper storeys of buildings; a slight rumbling heard by some people; house-bells rung, furniture, &c., disturbed. Colonel Arthur S. H.

Lowe, of Gosfield Hall, has furnished the following account:—

"The earthquake was distinctly felt on Tuesday morning the 22nd, with powerful effect at 9.23 a.m. The vibratory motion lasted about ten seconds, during which the absence of wind was remarkable, and all phenomena carefully noted at once proclaimed it an earthquake shock. Our old hall shook on the S. and E. sides with undulatory motion, many of the floors and walls apparently upheaving and subsiding with manifest agitation, the pictures in the different rooms bulging forward and shaking in their frames: the lake was tremulous with an upheaving oscillation; clocks stopped (facing the E.) and glass clattered everywhere. The barometer, a reading of which I had only taken a few minutes previously, stood without change or apparent depression at 29.808, attached therm. 47°. The thermometer in the air was 43°. The vane stood at N.N.E. The time was taken from a clock corrected by Cambridge time, sent by my son in a letter that morning, he having left the previous day and been asked to do so. None of the clocks facing W. stopped.[41] No structural damage was done at Gosfield, and no individual out of doors seemed to feel it like those within."

Gosfield Hall is 16 miles N.W. of Colchester. Confirmatory evidence has been supplied by the Rev. S. Parkinson, of the Manse, who compared the sound to that of a rapidly approaching train. Mr. F. N. Williams gives the time as 9.20 and the duration as two seconds; "the entire house was shaken and bric-a-brac displaced."

Harlow.—Mr. George Hart reports that the shock was only felt very slightly in a few instances in this neighbourhood.

Harwich.—Shock felt with some severity; in one house a person was thrown down; bells rung and crockery and glass broken. No structural damage. Shock felt severely also at Parkeston.

Havering.—Mr. G. T. Hope reports that the shock was not felt here.

Heybridge, near Maldon.—Shock distinct, accompanied by rumbling sound. At the Towers the rings on the cornice

[41] The plane of vibration of the pendulum is the same whether a clock faces E. or W.—R. M.

of a bedstead were seen to slide along about two feet. Doors were opened, and a clock with pendulum swinging N. and S. was stopped at Jacob's Farm. Time given as 9.19. At the Heybridge Ironworks, Messrs. E. H. Bentall and Co., a large T-square hanging against a wall was observed to swing, and Mr. E. A. Fitch, at my request, has been good enough to supply the following particulars, furnished by Mr. H. Hurrell, who was in the drawing-office at the time, and observed the movement, and who states that he was much impressed by the occurrence. Mr. Hurrell reports as follows:—

"The office stands as shown below in a rough sketch, nearly N.N.E. and S.S.W., and the square, which is 48 inches long, hung on the main beam A.

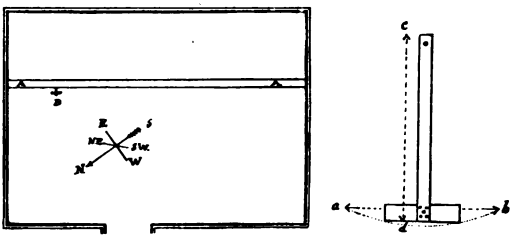

FIG. 13.—Ground-plan of Office; AA, Main beam. B, position of T-square. Length *c*..*d*, 48 inches; arc of oscillation (chord) *a*..*b*, about 10 or 11 inches. The T-square and dotted lines are not drawn to scale.

"It began to swing quite two or three seconds before I felt the shock and before the windows rattled in the casements. I am also nearly certain that the square started from N.N.E. to S.S.W., swinging when at its greatest arc 10 or perhaps 11 inches, and was quite three quarters of a minute before it regained its former steadiness. This latter fact of course shows nothing, as the T-square acted as a pendulum. The position of the office is exact by compass; the square hung on a nail three inches from beam."

The foregoing observation is of considerable importance, as showing that the movement of the wall (and building) was nearly E.N.E. and W.S.W., and that the disturbance probably came from the former direction. It is particularly

noteworthy also, that the building commenced to move a few seconds before the "shock" itself was felt.[42]

Horndon-on-the-Hill.—Mr. S. W. Squier reports that the shock was felt here decidedly but slightly, by one or two families who were in bed or quietly employed. Pictures and bell-pulls shaken.

Ilford.—Shock felt, bells rung, and ornaments thrown down at "Red Lion" Inn. Bells rung and oscillation experienced in one or two other houses.

Kelvedon, near Coggeshall.—Shock felt with considerable force, rumbling noise heard, buildings shaken, and most bells rung; no structural damage. A girl had a pail of water thrown from her hand. At the vicarage a lady was thrown down against the wall of a passage, and in another house a parrot was jerked off its perch. The shock was severely felt by a man down a deep well. Mr. E. G. Varenne informs me that in his house the disturbance was distinctly felt, especially in the higher storeys, where the oscillation was so great that the inmates had to hold on to the furniture to prevent themselves being thrown down. A "great lumbering noise" was heard at the same time. On the E. wall of a room on the ground floor a picture was displaced towards the N., and another on the N. wall was moved towards the W.; one clock out of five was stopped, time 9.20; swing of pendulum E. and W., one bell rang; no damage to building. Shock felt at Inworth Grange.

Langdon Hills.—Oscillation felt.

Latchingdon, 5½ miles S.S.E. of Maldon.—Mr. E. A. Fitch reports that two clocks were stopped here at 9.20; pendulums swinging E. and W.

Leigh, on the shore of the Thames, 3 miles W. of Southend.—Shock distinct; bells rung, chandeliers swung, and agitation among church bells heard by workmen in the church. No damage.

Leyton.—Slightly felt in some houses. No details received.

Little Baddow, near Chelmsford.—A correspondent from this place states that he was reclining out of doors, when he

[42] See p. 34.

felt a wave-like movement of the ground, which almost turned him over; the movement was repeated immediately after. A lady seated writing in the house felt the rocking of the chair and table and saw the swaying of the walls. At the Rectory the walls rocked to an alarming extent. No damage.

Little Waltham, 4 miles N. of Chelmsford,—Mr. Arthur Goodchild reports:—

"At 9.20. a.m. by a clock on my dining-room mantelpiece facing E., I was seated opposite the fire, with the chair swinging on the front legs, when I felt it moved in an extraordinary manner, as though the chair were being violently pushed by somebody or something, and I turned to see what it was; at the same time my wife, who was seated at the breakfast-table behind me, noticed an unusual movement of articles in the room; my youngest daughter, also seated at the table, started up with some alarm at the movements taking place, and called my attention to the pictures which were swinging, and to one in particular. The room stands directly N. and S., and at the N. end, on each side of the window, hang two large prints, one of which, owing to the wall not being perfectly perpendicular, hangs clear, and is suspended from two nails on short wires. I perceived that this picture was swinging violently from E. to W. From these observations I told my family particularly to observe the time, and that these movements denoted an earthquake, the wave having come either from E. to W. or the reverse direction . . . . . The only thing thrown down was a screen supported against the E. wall of a bedroom looking W. I am pretty accurate as to the time, for, having a good compensation-balance watch, I keep all clocks tolerably accurate."

Maldon.—Smart shock felt in some parts of the town, bells rung, doors opened or shut, oscillation of buildings seen; no serious damage. Some people state that there were three distinct waves, the last being the most severe; but the evidence on this point is not conclusive. A man putting in a pane of glass felt the window recede and then come back; and another man who was filing some metal is reported to have missed his stroke and to have been thrown forwards over his work. At the post-office a pane of glass in

the front window was cracked across; window faces nearly N.E. At Mrs. Andrews's, 55, High Street, a kitchen clock on a shelf against a wall facing about S.E. fell forwards off the shelf, and things generally in the house were much shaken. The driver of the Maldon train is reported to have felt the rocking of the engine; direction of railway N.W. and S.E. Mr. E. A. Fitch states that he was on the sea-wall, looking across the Blackwater at the time, and felt or heard nothing, but saw two barges coming down the river move some yards back towards the N.W. without any apparent cause. At Brick House the effects were very slight, the movement of the stable alarming two boys, and things in the house being made to rattle. Mr. Fitch adds that it was nearly high tide, and all the people in boats on the river heard the rumbling, and some thought they had struck suddenly upon a sandbank. The Stansgate coastguards rowed ashore, thinking that a torpedo had exploded somewhere. No trustworthy evidence respecting any movement of the water in the estuary could be obtained.

On May 10th Mr. W. Cole and I visited this town, at the invitation of Mr. Fitch, in order to attend a meeting convened by the Mayor on behalf of the Earthquake Relief Fund, and we were enabled to gather a few additional details. At the "Old Star" Inn (Mr. James Eves) a clock was stopped at about 9.17, plane of vibration N. and S.; three 36-gallon casks in the bar were rocked to and fro, and a cockatoo was thrown off its perch. At cottages in the Mill Road bells were rung and crockery rattled. Mr. S. Stratford, plumber, noticed that the articles appeared to swing from N. to S. Mr. Eves informed us that two clocks swinging N.E. and S.W. stopped, and clocks vibrating E. and W. were unaffected. Mr. Float reported that in a house near the station two clocks vibrating N.W. and S.E. were not stopped, whilst in a neighbouring house two clocks swinging N E. and S.W. were both stopped at 9.20.

Manningtree.—Shock felt with some force; no damage, Clocks stopped at 9.18. The Ipswich train, waiting in the station, was caused to oscillate, and the passengers were

alarmed. The station-master (Mr. Pinner) was tilted from his chair on to his desk. Mr. Pinner reports that the station clock, which stopped at 9.18, was swinging E. and W. The disturbance apparently came from the S.

Marks Tey.—Two shocks felt; no damage. Mark's Hall much shaken.

Mayland, between Althorne and Asheldham.—Shock felt.

Messing, near Coggeshall.—Shock rather severe; slight structural damage. Part of a chimney at a cottage near vicarage thrown down; church slightly damaged. Vicarage oscillated.

Middleton, near Sudbury (Suffolk).—Shock felt.

Mistley Thorn, near Manningtree.—A kitchen copper displaced; one person thrown against the wall of his house and a little girl thrown down.

Mountnessing, near Brentwood. — Oscillation felt by a person in bed.

New England Island, in the River Crouch opposite Burnham.—Mr. E. A. Fitch reports that the shock was distinctly felt by some men occupied in an oyster pit, a shallow excavation on the shore about 20 to 25 feet square and four feet deep. The men were stooping down in four feet of water, turning the oysters, and described the sensation as though they were "about to be swallowed up"; a man outside on the saltings felt nothing,

North Woolwich.—Shock distinctly felt about 9.20; rumbling sound heard.

Purfleet.—Mr. N. Green, writing from the Board School to Mr. A. P. Wire, reports that the shock was not felt here, but a person residing three miles to the east, who was lying ill in bed, felt the oscillation and saw the shaking of the chimney ornaments.

Ramsey, near Harwich.—Shock felt at vicarage, accompanied by a loud rumbling apparently coming from the south. The swaying of the building was felt, and a servant in the upper storey had to lay hold of a bedstead to prevent herself from being thrown down.

Rayleigh.—Shock felt in a few houses.

Rettenden, about 8 miles S.S.E. of Chelmsford.—Shock distinctly felt; house-bells rung. Mr. H. A. Cockey, of Rettenden Hall, reports that he heard a rattling noise and felt the swaying of the house at about 9.20. He was in a bedroom at the time, and states that the pictures on the W. wall swung about three inches, and "looking out of the window (S. aspect) he distinctly saw the frame dip against the sky-line and rise again. The direction of the wave was from N. to S."

Rochford.—Shock felt; clocks stopped; no damage. Mr. Arthur Wallis reports that in Market Square two clocks were stopped, both 8-day time-pieces swinging E. and W. In the Board School an 8-day 12-inch dial, swinging N. and S., was stopped. The articles suspended from the ceiling in an ironmonger's shop were knocked together and made to rattle. A man in a shoemaker's shop rushed out of doors with his shoe off, thinking the shop was about to fall in.

Romford.—Shock felt in a few houses and rumbling heard. Objects on toilet table caused to rattle, and a policeman felt the oscillation of the chair on which he was seated. The following letter has been received from a lady living in the High Street:—

"Yesterday morning, when in my room, which faces south, I heard a cracking noise in the north-east corner of the room, the house seemed to sway forwards towards the south; for a few seconds I felt a trembling, such as would be caused by a traction-engine passing, during which a small picture, hanging on the west wall in the south-west corner, rattled against the wainscot. Expecting I should hear of an explosion, I looked at my watch, which said twenty minutes past nine, and was right by the church clock.

23rd April, 1884. M. Kate Robinson."

Roxwell, 4 miles W.N.W. of Chelmsford.—Slight shock; a few bells rung.

Saffron Walden.—Mr. Joseph Clarke, F.S.A., of the Roos, reports that the shock was only slightly felt here in some parts of the town, mostly by people in bed or in the upper parts of buildings. Mr. G. N. Maynard, Curator of the

Museum, heard the rattling of the windows and felt the shaking of the table in an upper room of the Literary Institution. Time doubtful; about 9.35 (?).

St. Osyth.—No report has been received from here, but on the occasion of the visit of the Essex Field Club to the earthquake district on August 4th, 1884, it was observed that several of the old and shaky chimneys had been repaired, having been to some extent damaged by the shock.

Shoeburyness—Shock felt. No details reported.

Southend.—Oscillation very perceptible: glasses and other articles rattled or thrown off tables and shelves, and bells rung. A lady on the ground floor of a house in Royal Terrace was thrown backwards against the mantelpiece and felt the floor upheave. A clock in this house, oscillating S.S.W. and N.N.E., was stopped at 9.20. Shock and oscillation of buildings distinctly felt at "Royal" and "Hope" Hotels, Cliff Town Parade, Nelson Street, High Street, and on the Pier, this last structure being described as swaying to and fro. Apparent direction of disturbance N. to S. Mr. H. Middleton, writing from the "Hope" Hotel, states that he was in an upper room and saw the oscillation of the walls. His own clock and two more were stopped; pendulums all swinging nearly E. and W.

South Weald, near Brentwood. — Rumbling heard at Gilstead Rectory; lamps upset and furniture moved.

Southminster, about 8 miles N.E. of Burnham.—The Rev. G. C. Berkeley, writing from the Vicarage, states that he was sitting on the sofa, having just finished breakfast, when, about 9.20, he heard an alarming sound, felt the floor move, and, jumping up, observed the swaying of the dining-room wall. On going into the village afterwards, Mr. Berkeley was informed that two bells in the church had rung, clocks were stopped, and glasses and cups on shelves were rocked. Mr. F. Chancellor, of Chelmsford, subsequently surveyed the Vicarage, and discovered that three of the chimney-stacks had been cracked, and had to be partly taken down. Mr. William Page, of Southminster Hall, reports that he was sitting reading in his dining-room, when he was startled by

a great crashing noise, apparently from above, and on looking up saw the wall shaking and the gaselier swinging (direction not recorded). The clock on the mantelpiece was stopped, pendulum swinging E. and W., and this was found to be the case with all the clocks swinging in the same direction, with the exception of a more powerful hall clock; those in which the oscillation of the pendulum was N. and S. were not affected. Bells in this house were rung, and the water in a moat in the grounds was reported to have been agitated, although Mr. Page himself did not witness this occurrence. No structural damage.

Springfield.—See *Chelmsford.* Mr. Henry Corder, of Great Baddow, informs me that slight structural damage was sustained at Belstead Hall, in this parish.

Stanford-le-Hope, near E. Tilbury.—Shock felt by several persons; an invalid felt oscillation of bed; in another house water in a washing-basin was agitated, and the table with its fittings rocked.

Stanway, 1½ miles W.S.W. of Lexden.—Mr. Henry Laver, of Colchester, informs me that in a house near the Union a mangle which was standing nearly N.E. and S.W. was tilted backwards and forwards in its frame three times, and then shook considerably; the first movement was from S.W. to N.E.

Stebbing, 8 miles N.E. of Dunmow.—The Rev. A. B. Bingham Wright, writing from the Vicarage, states:—

"This place stands on unconformable beds of gravel, sand and boulder clay; plastic clay occurs. We felt the shock at 9.18 a.m., Greenwich time. Shock lasted, I should say, 15 to 30 seconds. There was time for expressions of surprise and remarks that it must be either an earthquake or dynamite. The floor of the room was felt to rise and sink as the deck of a ship which meets a wave. There was a rumbling sound. Everything in the room moved; the curtains waved to and fro. A lady sitting in a chair was moved up and down, one leg of the chair rapping the floor as long as the shock lasted. The room stands N.W.—S.E. The pictures swayed on the wall between these points. The whole house, which is crazily built, shook and rattled. The shock was not felt at all by the gardener, who was in the coach-house at the time,

not many yards from the house. I find that, generally speaking, people out of doors did not feel it. No damage was done in this place."

Stisted, between Mark's Hall and Braintree.—Sharp shock; some bricks from a chimney thrown down.

Stratford. — Shock felt by a few people in bedrooms; rumbling noise heard; movement of curtains seen and articles on toilet-table shaken.

Tendring. — Shock felt about this district. See *Great Bentley*, *Great Bromley*, and *Thorpe*.

Thaxted, 6 miles nearly N.N.W. of Dunmow.— Sharp shock, with sound like distant thunder. Church bell and house-bells rung; furniture shaken; shock felt in most houses. No damage.

Thorington, 2 miles N.N.E. of Brightlingsea.—The Rev. Olivier Bourbeau reports that the shock was felt at the parsonage, where bells were rung and a clock stopped. Duration estimated at about three seconds.[43]

Although no serious damage was reported from this neighbourhood, I observed on August 4th, that along the road from Greenstead, approaching Thorington Cross, as well as in the latter place, a few chimneys had been loosened and showed signs of recent repair. The road here crosses a strip of London Clay. In Thorington village but few signs of damage were apparent.

Thorpe-le-Soken, 4½ miles nearly due E. of Great Bentley. —Mr. J. Y. Watson, of Thorpe Grange, reports that at the time of the shock he was standing 200 yards to the west of his house, and neither heard nor felt anything. Entering the garden he was informed that the orchard-house had been violently shaken, the vines suspended on wires having swayed E. and W. In the house a rumbling sound had been

[43] Mr. Bourbeau, in a later communication, kindly supplied the following details:—Thorington Parsonage, Lat. N. 51° 50′ 27″; Long. E. 1° 2′ 30″. The direction of the wall to which the bells were attached was N.N.W. and S.S.E., and Mr. Bourbeau is under the impression that the bells commenced to ring from the N.N.W. end of the row. The clock that stopped was swinging about W. 35° N.—E. 35° S.

heard, windows rattled, tables and chairs rocked, and the oscillation of the house was compared to the motion of a ship sailing against the wind on a roughish sea. No bells rung; no clocks stopped; no structural damage. Mr. Watson adds that the house "stands on high ground; in fact on the summit of the northern slope of the Thorpe Valley. The soil is gravel with, at some distances both north and south, beds of London Clay. Near by, is Rice Bridge, where commences what is called the Tendring Hundred Level—that is, land that would be submerged were the sea allowed to break its present artificial bounds. Along the valley of the level, for about four miles, there is a narrow stream which finds an opening to the sea at Holland Haven. In the parishes bordering on and around this level very little, if any, damage has been done."

Tiptree Heath.—Shock strongly felt at Rectory; bells rung and pictures moved on walls.

Victoria Docks.—Shock felt distinctly by men engaged upon the upper part of some sheds. Felt also at Custom House.

Walthamstow. — Mr. David Howard, F.C.S., of Rectory Manor, reports that the shock was felt only by invalids in bed; three clocks stopped; pendulums swinging E. and W.

Walton-on-the-Naze.—Distinctly felt in some parts of the town, accompanied by rumbling noise. One correspondent states that there were two shocks in rapid succession; oscillation felt at Raglan House, in houses near coastguard station, and at the railway station, where the signal-box rocked to an alarming extent. Mr. Philip Brannon, of Hygeia Lodge, reports that the time of the occurrence was 9.20, and he compares the sound and vibration to that which would be caused by the passing of a heavy traction-engine close to the walls of the house.

Wanstead.—Shock felt by Mr. John Cousens in Grove Road, at 9.20; he was sitting down reading at the time and felt the movement of his chair. Dr. George Weller, of the Mall, reports that he was lying awake in bed and experienced "a most peculiar tremulous and undulating motion of the bed," the things in the room at the same time being shaken.

A lady patient of Dr. Weller's, living in a neighbouring house, also felt the vibration of her bed with sufficient force to cause her to spring up in a state of alarm. Persons in the lower parts of buildings or moving about did not experience the movement.

West Colne, near Halstead.—Mr. C. Page Wood, of Wakes Hall, reports that his house was violently shaken and a great noise heard, apparently proceeding from the upper part of the building; chandeliers and swinging lamps were all thrown into oscillation (direction not recorded), and all the bells in the house were violently rung. The drawing-room clock, plane of vibration of pendulum N. and S., which had been stopped for weeks, was started into action; another clock, swinging E. and W., was not stopped. The pictures in an upper room were all displaced on the walls. Mr. Wood states that the impression produced upon him was "not that the house was swaying to and fro, but that it was breaking up from within." Mr. Wood adds:—

"At the cottages 200 yards eastward a sack of flour is said to have fallen from a chair or stool, clock weights oscillated; at the Rectory near by, the bells rang and a clock stopped.

"I rode out at ten o'clock; at a woman's cottage about a mile west of this place, the flower-pots in the window had been roughly shaken. At Over Hall, two miles westward, a friend had been shaken in his chair, and considered that an explosion or earthquake had taken place. A visitor later on, from Gosfield, knew little about the matter; visitors from Shalford, some 13 miles distant, fancied something had taken place of an unusual character."

West Ham.—Mr. Thomas Royle, F.C.S., of the Cedars, informs me that he was lying in bed and just about to get up, when the bed and house were shaken violently, the agitation lasting about five seconds, "this period being divided into two by a partial cessation of the disturbance. The bedstead shook violently, the fringe of the head-piece swinging to and fro." The lustre-pendants of some ornaments on the mantelpieces in this and another room, were thrown into oscillation and continued to swing for some

minutes; direction of oscillation approximately N.E. and S.W. Time about 9.24; clock error unknown.

Wickham Bishops, 2 miles N.N.W. of Maldon.—Shock felt rather severely; bells rung, furniture shifted; slight structural damage at the Rectory, where, according to a report received from the Rev. M. Clutton, two heavy chimneys were badly shaken, and one of them was so shattered that bricks fell to W. and damaged the roof; one clock stopped, swing of pendulum E. and W.; time not recorded with accuracy. Mr. Dixon's mill reported damaged.

Witham.—The Rev. Frederick Spurrell, Rector of Faulkbourne, near this place, reports that the shock was felt, although no damage was done. In the Rectory a rumbling sound was heard by some of the household, bells were rung, the floor appeared to rise, the house rocked "like a ship at sea," and the iron bars of shutters were rattled. Only one tremor was felt, lasting six or eight seconds. With respect to the meteorological conditions Mr. Spurrell states:—"Since 10 p.m. of the previous night the barometer had risen, as it had all the day. On April 21st, at 8.30 a.m., it stood 29·97 in.; at the same time on the 22nd it was 30·02 in. Thermometer 52° as against 48° the day before; lowest temperature, night of 21st, 30° as against 31° the day before." On the 22nd, at 8.30 a.m., the weather was fair; wind N.E.

At Witham railway-station the signal-boxes and a goods-shed oscillated considerably; workmen in a coal-yard were nearly thrown down. In the town, ornaments and earthenware articles were thrown down, bells rung violently in many houses, and clocks stopped.

Wix (or *Wickes*), about 4 miles nearly S.E. of Manningtree.—Oscillation felt sharply at about 9.20, furniture moved, clocks stopped; no damage.

Woodford.—Shock not distinctly felt, but clocks were stopped; at Anworth House, (Mrs. Dykes), a pendulum clock, swinging nearly N.N.W. and S.S.E. (time not noted), and at Prospect House (Mr. R. Letchford), another clock swinging E. and W. stopped at 9.20.

Writtle, near Chelmsford.—Mr. F. H. Meggy informs me that at this place a man was pumping water at the time of the shock, when the supply suddenly ceased for a few seconds.

Distribution of the Shock over other Counties.

SUFFOLK.

Acton, near Sudbury.—Shock felt.

Akenham.—Oscillation felt, slight rumbling sound heard, furniture slightly moved, walls and floors shaken and bells just rung. Time 9.20.

Aldborough.—Slight shock and rumbling sound heard.

Barham.—The Rev. E. Ledger, F.R.A.S., Rector, writes:—

"The earthquake was felt at 9.18, or it began a few seconds earlier. Watch tested by railway clock set by Greenwich time-signal the same day. It seemed like the passing of one wave S. to N. or. S.S.W. to N.N.E. Rumbling noise preceded. Rattling of windows followed, as though by several shorter undulations. Bells rang in neighbouring houses. Duration about 6 to 8 seconds."

In another communication he adds that:—

"the movement distinctly elevated the chair upon which I sat, and moved it just as a boat upon an otherwise calm sea would be moved by a solitary wave passing underneath it. In the bedrooms the crockery rattled, as did the windows for some seconds after the chief movement of the earth had passed."

Beccles.—Oscillation felt at signal-box of railway-station and by some people indoors; more especially by invalids in bed. Mr. E. T. Dowson reports:—"At the printing-office an unusual motion was noticed at 9.20 a.m., by several persons whom it affected with slight giddiness. One of the readers, while seated at his desk, was swayed from side to side three times from E. to W." Mr. C. Thwaites found that his telescope had been moved slightly on its framework, and he attributed this to the disturbance.

Belstead.—Shock rather severely felt; water in ponds said

to have been agitated and the roof of a carpenter's shop reported to have been cracked in several places.

Bildeston.—Shock distinct, houses shaken, glasses, &c. moved and rattled. Time 9.20.

Boxford.—Shock rather severe; bells rung, clocks stopped, articles shaken from mantelpiece and bricks loosened at the Brewery. A sound "like that of a high wind" was heard. At Groton Rectory two clocks, both swinging E. and W., were stopped at 9.20, and bells in the kitchen attached to a wall having the same direction were all rung. Disturbance felt at Groton House, Boxford Rectory, Peyton Hall, &c.

Brandeston.—Shock felt.

Bungay.—Shock felt slightly; walls and furniture shaken.

Burstall.—Shock rather severe; bells rung or caused to swing; Mr. W. B. Jackaman was seated and felt the oscillation of his chair, and looking up saw the venetian blind shaking.

Bury St. Edmunds.—Shock distinctly felt; bells rung in some houses and buildings shaken in many parts of the town. Writing from Plumpton House, about 6 miles S.W. of the town, Mrs. W. R. Bevan states that she and her daughters and niece were seated at breakfast, when she experienced a sudden and instantaneous oscillation of her chair; time 9.18 (watch correct by railway time). Mrs. Bevan reports that in the village the doors of two neighbouring cottages were thrown open.

Capel St. Mary.—Oscillation distinctly felt.

Cavendish.—Shock distinctly felt about 9.20 in most houses in the village.

Clare.—Oscillation felt about 9.20 in some of the houses; a rumbling noise heard.

Claydon.—"Shock began between 9.17.45 and 9.17.55. Windows rattled and house-bells rang." (Mr. Symons's report).

Clopton.—Shock felt at the Rectory, where the Rev. S. Hooke states that the room in which he was seated oscillated, the windows were shaken, and the things on the table rattled. Time about 9.30 (?).

Cornard, near Sudbury.—Shock felt sharply at Side Hill House.

Elmswell.—Shock felt.

Framlingham.—Shock distinct in many houses; windows shaken and furniture disturbed.

Gorleston.—Shock felt, bells rung, and glasses rattled at Gorleston House. Slight shock felt at the adjoining village of Bradwell. Time about 9.20.

Groton.—See *Boxford.*

Grundisburgh.—Shock felt about 9.20; windows shaken and beds heaved.

Hadleigh.—Shock distinctly felt. A horse frightened at Kate's Hill Farm.

Halesworth.—Slight shock felt by a few people.

Haughley.—Shock felt slightly by many people; bells rung in some houses and furniture disturbed. Felt distinctly at Haughley House, Fishpond House, Plashwood, and the Firs.

Hintlesham.—Shock very distinctly felt and inhabitants much alarmed; a man thrown from a narrow seat on which he was sitting.

Hitcham.—The Rev. A. R. Grant reports that the shock was scarcely felt at all here, only a slight oscillation being experienced by some few persons in the upper parts of houses.

Holbrook.—Shock rather sharp; houses rocked, bells rung, and glasses on a sideboard moved; time about 9.20. Mr. B. Hunter Rodwell is under the impression that there were "three distinct vibrations."

Holton.—Shock distinct.

Hoo.—Bells rung and furniture moved.

Ipswich.—The shock was felt here with more or less distinctness in most parts of the town, and, although no structural damage has been reported, the oscillation appears in some cases to have been very considerable. The particulars here recorded have been selected chiefly from the newspapers[44] and partly from correspondence.

In the western part of the town the earthquake is stated to have been felt with some severity; bells were rung in many

[44] The local information has been mainly derived from the correspondence in the 'Suffolk Times and Mercury' and in the 'East Anglian Daily Times.'

houses, and in one case a door was thrown open. A correspondent from this neighbourhood reports:—

"I was sitting reading in an easy chair in the dining-room, when I heard a sharp rumbling noise, which I took at first for the passing of the Royal Artillery. Instantly, however, I felt an unusual rocking sensation—rather pleasing than otherwise—my chair appearing to rise up and down, and the wall of the room to move outwards and forward, the gaselier in the meanwhile swaying considerably. In eight or ten seconds the motion ceased. I got on my feet, looked at my watch, which indicated the time to be 9.18, and I went to the rear of the house to see whether the walls were not rent, for by this time I felt confident that the noise and motion were caused by an earthquake. My wife and servant, who were standing at the time in another part of the house, were very much alarmed at the rocking of the floor beneath their feet. A hand-painted, terra-cotta plate, standing on the pianoforte in the drawing-room, was thrown down. Curiously enough, the shock was felt by our neighbours on one side but not on the other. A lady in an adjoining house had a distinct feeling of nausea, induced by the unusual sensation."

In the neighbourhood of Prince's Street bells were rung, windows shaken, and the oscillation of the buildings distinctly felt: the same effects were produced in Berners Street, St. Nicholas Street, Friars Street, Bulmer Road, Belstead Road, and Spring Road. The shock appears to have been severely felt in the upper parts of the numerous factories, the workpeople in many cases rushing alarmed into the street. At Stoke Mills the oscillation of the chimney-shaft was seen. At the Custom House and railway-station also the vibration is reported to have been considerable. At some cottages on the south side of the Lock Gates a looking-glass and flower-pots were thrown down and a rumbling noise was heard. From St. Mary Elms Blue Coat School, Mr. J. Hellings reports:—

"About 9.20 a.m. by our school clock, the folding-doors separating the boys' and girls' school-rooms were violently shaken, as if by a tremendous gust of wind. The bell connected with the street door rang, but no one was there when a boy opened the door. At the same time a deep rumbling

noise, as of a heavy waggon, was heard, causing all the children to look up from their work with wondering faces."

In Henley Road Mr. Frederick Turner records that at about 9.17 the disturbance was simultaneously felt by himself and family, the house oscillated with a wave-like motion, the bells were all rung, jugs on pegs and hams suspended from the ceiling were thrown into oscillation. The following letter from this locality has already appeared in Mr. Symons's report:—

"Henley Road, Ipswich.—I presume few persons had the opportunity of observing the clouds on the morning of April 22nd, just previous to the shock of earthquake, that I had, so I venture to send you my observations made at the time.

"I was lying in bed with my face towards a large window, watching the clouds in the north-east part of the sky, and observed them thus for a quarter of an hour, measuring their movements by bars of the window panes, and had decided in my mind that the wind was in the S.E., from the direction the clouds went, hoping we should have it warmer, when all at once the clouds appeared to go and pass in every direction, and mix up together in a remarkable manner. This completely roused my attention, and I looked at a large chestnut tree in the park, saw all the leaves moving, saying to myself, 'Whatever are you shuddering for; there is no wind.' Only the leaves moved, not the tree, which stood on a side hill facing the south.

"Then came the awful rumbling sound under the bed, which heaved up. I started upright, saw the north wall of the room bend in and outward, and the pictures on that wall flapped. Those on the other walls only shook and moved, while everything in the room that could jingle did so. A clock on the north wall did not stop. I saw the small trees in rows from east to west, in the Arboretum, shaking, not as if by wind, but as by a hand quickly shaking their stems. Also a tall plant in a pot in my room shook violently all over. The bells in the kitchen all jingled, and other things clattered, but no damage anywhere. My window looks towards the east, and the north wall is an outside wall. I made the observations, of the clouds, the leaves shaking, then the noise, all distinctly, though in quick succession, one after the other, but in how short a time I can't tell, but the clouds decidedly were the first to show any strange movement.

"Ellen Biddell."

Experiences as to the severity of the movement have been recorded also by correspondents from St. Peter's Street, Tavern Street, the "Golden Lion" Hotel, and in the vicinity of the Ipswich Docks. In Princes Street a boy getting coals was thrown down into the cellar, but escaped without serious hurt; and in the Whitton Road a man was riding a donkey, when the shock precipitated both the animal and its rider to the ground. A correspondent from Granville Street, who was in bed at the time, states that the heavy Arabian bedstead was "violently shaken from side to side like a huge cradle rocked by some giant hand." The whole house oscillated, and the writer's wife, who was in an adjoining room kneeling over a box, was jerked backwards and almost thrown down, but saved herself by holding on to the side of the box. Mr. J. S. Cocksedge, writing from Greyfriars Road, states:—

"I was sitting in the counting-house writing, and felt a most peculiar sensation. The chair seemed to be rocking to and fro, producing a feeling akin to sea-sickness. Thinking my men were moving some heavy pieces of iron, I took no notice; but presently, going into Bridge Street, I saw Mr. F. Mason, who told me the bells in his house had been ringing, and they had also felt it. On inquiry in the foundry of the moulders (who work on the ground), I found they had all felt it, and the iron patterns hanging on the wall had been jingling with the vibration."

Among the numerous clock stoppages in this town, Mr. Edward C. Gibbons, of Avenue Lodge, informs me that their clock, which was stopped, was swinging nearly N. and S. Dr. H. J. Benham gives the exact time of the termination of the shock as 9.18.15, and the duration, according to the estimate of various observers, was from three to ten seconds, although, as might be expected, there is much discrepancy on this point.

At Avenue Lodge, St. John's, the oscillation was considerable, and the inmates were much terrified; bells were rung, glasses moved, and the windows and doors shaken. At

Christchurch Park (Mr. T. N. Fonnereau), also the shock is reported to have been severe; bells were rung and the house swayed perceptibly. Mr. G. A. Biddell, writing from Bishop's Hill, states that the movement of the floor rocked the chair in which he was seated, the walls and ceiling oscillated alarmingly, and the glass pendants, suspended from a glass cone surrounding the gas burner and attached rigidly to the ceiling, were violently shaken and made to jingle. Ten bells on a wall running N. and S. were all rung and moved for some minutes after the shock. Time 9.18; barometer 30 in.; therm. 40°. The gardener in the lower ground felt nothing. No damage to house.

Mr. J. E. Taylor, F.G.S., in a letter to 'Nature' (April 24th, 1884, p. 602), written the day of the occurrence, states:—

"I was sitting down at 9.18 a.m. when the first shock occurred, and it nearly overbalanced me. I felt it must be an earthquake oscillation, although I had never experienced anything like it before, and accordingly waited and watched for the next. The oscillations followed each other for about three seconds, and apparently travelled in a north-north-easterly direction. I underwent quite a new experience, so vivid that I am not likely to forget it. The sensation approached that of nausea."

In surveying the widespread effects of the shock as felt at Ipswich, and comparing the numerous records from this town with the scanty details from the smaller villages to the south, which are in reality nearer the centre of disturbance, it is evident that here, as at Colchester, the large number of reports, and the varied experiences narrated, must be, as already explained, in a great measure ascribed to the larger accumulation of buildings and observers within a given area.

At Kesgrave Hall, 5 miles E.N.E. of Ipswich, a clock stopped about 9.20; pendulum swinging E. and W.

Kettleburgh.—Shock felt.

Kirkley, near Lowestoft.—Shock felt.

Layham, near Hadleigh.—Shock felt strongly throughout parish about 9.20; house-bells rung and clocks stopped.

Leavenheath.—Shock distinctly felt.

Long Melford.—Dr. C. R. Bree reports that the shock was felt and the vibration observed at Hill House, at 9.18 These effects were experienced only in the upper part of the house. Shock felt at Kentwell Hall, Melford Hall, the Rectory, and at other houses in the district; pictures and furniture moved.

Lowestoft.—Shock felt by one or two people.

Marlesford.—Shock felt.

Mettingham, near Beccles.—Mr. E. T. Dowson reports that the shock was felt, and an old-fashioned 8-day clock, in wooden case, with pendulum swinging E. and W., was stopped at 9.20.

Mildenhall.—Sharp shock felt.

Mutford Bridge, near Lowestoft.—Shock felt.

Nayland, 6 miles N. of Colchester.—Shock severe; no serious damage. A small cross thrown down from the gable of the Congregational Church (not the spire, as at first reported in some of the papers).

Needham Market.—Bells rung in some houses, articles on a sideboard rattled. Time reported as 9.19.

Parham, near Framlingham.—Oscillation felt at Parham Hall and other houses in village.

Parkeston.—See Harwich.

Ramsholt.—Shock felt; doors and windows rattled.

Raydon.—Shock severely felt, house shaken, pendent objects thrown into oscillation, and a rumbling noise heard resembling that produced by the passing of a heavy waggon.

Saxmundham.—Slight effects, such as rattling of glasses, &c., produced in some houses.

Shelly Hall, near Raydon.—Vibration severely felt.

Shipmeadow, near Beccles.—A lady felt the oscillation of her chair at 9.20; house bell twice rung.

Shotley.—Rumbling noise heard and vibration of house felt by Mr. Hempson.

Shottisham.—Shock felt.

Sproughton, near Burstall. — Shock severe; inhabitants much alarmed.

Stonham Parva.—The Rev. W. B. Coytes reports that the shock was distinctly felt at the Rectory about 9.20; a piano was rocked and the house much shaken. The effects were experienced also at the Hall.

Stowmarket.—Shock distinctly felt in many houses. At Hill House it is stated that bottles and ornaments were thrown down from the mantelpiece. A man at work upon some repairs connected with the Congregational Church is reported to have been injured by an oak beam which was thrown down by the vibration. Time given about 9.15 (?). Rumbling sound heard in some places.

Stradbrook.—Felt distinctly by a few people.

Sudbury.—Severely felt in most parts of the town; two distinct shocks reported separated by a short interval; rumbling sound heard. Bells rung at one of the banks and in some other houses; pendent objects made to oscillate, furniture and small objects displaced; the goods in a china warehouse caused to clatter violently. Oscillation strongly felt at St. Peter's Church during morning service, and the congregation panic stricken. Strong shock felt at St. Bartholomew's Farm. In some cases the inhabitants rushed alarmed into the streets; oscillation likewise felt by passengers in trains. No damage or injury to individuals reported. Time about 9.30 (?).

Swilland.—Shock severe enough to cause inhabitants to rush into the streets in a state of alarm.

Thurston.—Shock felt.

Trimley.—Shock distinctly felt.

Washbrook.—Shock felt at Amer Hall.

Wetherden, near Haughley.—The Rev. C. J. Goodhart, writing from the Rectory, has supplied the following details:—

"Long. 56′ 43″ E. Lat. 52° 13′ 46″ N. In case it may be worth anything, I send you word that the earthquake happened within a few seconds, one way or the other, of 9·18 Greenwich time *here*. My watch has not been altered for a twelvemonth, and three weeks ago it was just six seconds fast of Greenwich time, allowing 8′ 47″ for difference of

longitude. It is a Waltham watch, and has proved most remarkable in its rate of going. The shock here was from S.E. to N.W., and a picture hanging on a N.W. wall[45] swayed from and to the wall, and in an upper room at the Rectory a looking-glass in the window and the wall were seen to sway backwards and forwards, both being in the same direction as the wall downstairs. The motion upstairs was distinctly greater than that downstairs. No bell was heard to ring here, but one did so in a mansion half a mile off, and others there were seen to shake. All the above was noted before any account of the event had been reported or seen from elsewhere. April 26th, 1884."

Woodbridge.—Slightly felt by several persons. Time about 9.27 (?).

NORFOLK.

Diss.—Shock distinctly felt about 9.25 (?); bells rung, houses felt to oscillate, and considerable alarm caused.

Ditchingham, near Bungay. — At the silk crape factory Mr. E. T. Dowson reports that the upper floors were shaken and the machinery began to "grind." There appeared to be three oscillations. The door of one clock flew open; time about 9.20; clock opened towards S.

Fakenham.—Shock felt slightly by an invalid in bed.

Geldeston.—Mr. E. T. Dowson writes:—"Neither I nor my barograph felt it, but Mrs. P. Clarke states that articles shook at about 9 a.m., and she thought it exceptional at the time."

Harleston.—Shock distinctly felt, especially in the upper rooms of houses.

Lynn.—Oscillation slightly but distinctly felt by several people; in a printing office type was rattled and hanging files of papers observed to swing. Cause unknown at the time.

Northrepps.—Mr. Gurney, of Hill House, informs me that the shock was distinctly felt in the parishes of Cromer, Northrepps, and Southrepps.

[45] This presumably means a wall facing N.W.

North Walsham.—Felt by several people in the upper storeys of houses.

Norwich.—Distinct shock felt in many buildings, and a noise as of a heavy traction engine heard. The following letter has been received from this town :—

"Norfolk and Norwich Hospital, Norwich,
"April 23rd, 1884.

"I was reclining in an easy chair, my head being east and feet west. At 9.18 a.m. I heard a rumbling as if some very heavy engine might be passing, and at the same time the whole hospital oscillated, and of course my chair too, in a direction north and south; the oscillations appeared to me to come from the south; they were five or six apparently, and did not last more than ten seconds. I was able to form a very fair idea of the plane of oscillation from its being perpendicular to my own axis. I looked at my clock immediately, and have allowed for error of time. I can hear of no damage being done anywhere in Norwich. My aneroid was quite steady at 29.8.

"Donald D. Day, F.R.C.S."

Southrepps.—The Rev. R. H. Gwyn informs me that the shock and vibrations were felt in the upper but not in the lower rooms of the Rectory. On the ground floor a large picture in the drawing room moved away from the wall (direction not given), and smaller pictures and furniture were shaken. No bells rung nor clocks stopped.

Swaffham.—Felt slightly in a few houses.

Thetford.—Felt by a person in a bedroom; about 9.30 (?)

Yarmouth.—Shock felt in some houses; bells rung in houses on Marine Drive; furniture shaken, and a rumbling as of a heavy vehicle heard.

Cambridgeshire.

Cambridge.—Shock distinctly felt in various parts of the town and at some of the colleges; rumbling sound heard; doors thrown open and pendent articles swung. Time about 9.15 (?) Mr. J. H. Turner, postmaster, states that he was lying unwell in bed, extended from W. to E. on his side,

when he was rolled "first one way and then back again several times." A town councillor, also in bed, had the same experience.

Mr. Albert H. Waters, of Mill Road, reports that he was looking at a shallow aquarium at about 9.20, and observed the vessel tilted to such an extent that the sand at the shallow end was exposed. This effect would be the result of tilting the table up to the extent of an inch in a direction E. and W. The oscillation of the house was felt, but not violently, "much like being on ship-board." A sensation of giddiness was experienced ('Nature,' May 1st, 1884, p. 19).

Mr. H. Todd, writing from the Cambridge Observatory, states that at the time of the earthquake, observations for the determination of the level of the transit instrument were in progress, and the mercury was so disturbed that the observer had to wait some time, thinking that it arose from some waggon passing along the road.

Ely.—The Rev. F. W. Joy, Minor Canon of Ely, reports that he was sitting reading in his dining-room in a position facing due W., and heard some plates rattle against the cabinet supporting them; at the same time he experienced a gentle oscillation of his chair, and saw the bell-ropes swinging to and fro against the wall. The time (by the Cathedral clock) was 9.18; Mr. Joy is under the impression that the oscillation of his house (the college) was E. and W. A heavy hailstorm fell a few minutes previous to the shock.

Wisbeach.—Slight shock; said to have occurred about 9.15 (?).

Hertfordshire.

Ashwell, near Baldock.—Shock felt at the "Bury" by Mr. E. King Fordham.

Barley, near Royston.—Shock felt slightly but distinctly about 9.20; chiefly on the S. side of the village on the high ground.

Bishops Stortford.—Oscillation distinctly felt in many buildings, house bells rung and furniture disturbed; time about 9.21 (?).

Cheshunt.—Mr. W. C. Boyd, F.L.S. informs me that the shock was felt and a bell rung at "Arlesdene" (Mr. H. C. Wales).

Hertford.—Shock felt slightly in some buildings.

Kings Langley.—Mr. William Jones Loyd, J.P., reports that the shock was distinctly felt at "Langleybury"; in a bed-room, china and movable articles were rattled, the bed curtains shaken, and the oscillation of the chair felt by a person seated; time 9.20.

St. Albans.—Mr. A. E. Gibbs, writing from the office of the 'Herts Advertiser,' informs me that the shock was felt in this town but slightly, and chiefly by persons in bed; no pictures, furniture, or other objects were displaced.

Tring.—The Rev. F. W. Ragg, writing from Masworth Vicarage, Bucks, two miles north of Tring, has published the following valuable letter in 'Nature,' (May 8th, 1884, p. 32):—

"This village lies partly on the lowest beds of the Chalk, and partly on the Gault; it is between N. lat. 51° 49′ and 51° 50′, and W. long. 0° 40′ and 0° 41′. The shock was felt at the church, and at two cottages where invalids were in bed. The church is on rising ground at the edge of the chalk platform which lies between the Chilterns, some two miles away from them. I was on the scaffolding erected for repairs to the church. At a little past nine—it could hardly have been later, I think, than 9.15, if so late—I felt the church give what seemed like a fierce shudder. This seemed to begin on the east, rather to north, and travelled westwards nearly. By shudder, I mean that a sort of vibration began which almost instantly increased in intensity, reached a climax, and then rapidly decreased and died away. It seemed to me to begin slightly north of east, because I remember feeling (for what reason I can hardly say) that the cause was hidden from me behind the east end of the church. I was on the south side, some eighteen feet from the south-east corner. A moment after a whirlwind followed, which began, as I find, near the top of the slope north-east of the church, and followed the churchyard wall which bends round the churchyard to south-west. In a cottage on the junction of the Chalk and Gault (or very near the junction), according to the result of inquiries I have made of an invalid there, the pictures on a wall lying north-west and south-

east moved from and to the wall, but seemed also to move along it somewhat, *i.e.*, north-west and south-east. Flower pots on a table rocked in a direction almost east and west, and a window facing the south-east shook; her bed also, lying north-west and south-east, waved, and seemed as if giving way. This took place, she says, a little after nine. In a cottage on the Gault, where another invalid was lying, a window facing south-west rattled, a picture shook on the wall on which it is fixed, and the bed, lying south-east and north-west, also waved. This was, she thought, at nine, but the time must have been later. She noticed that the wind was still. No noise was heard except the clatter caused by the rattling of the buildings; but at a mill on the Incknield Way, near Tring, lying at nearly lat. 51° 48′ and long 0° 40′, a rumbling was heard."

Ware.—Very slight shock probably felt.

BUCKINGHAMSHIRE.

Great Marlow.—Mr. Alfred H. Cocks, M.A., reports that the oscillation was distinctly felt (about 9.18) in three first floor rooms at Thames Bank; a picture on a wall was seen to swing forwards perceptibly towards the S.W.

Lane End, *Taplow*, and *Princes Risborough.*—Shock felt.

OXFORDSHIRE.

Bicester.—Shock felt.

Chiltern Hills. — Shock felt by Mr. R. T. Hodge at Wyfold Court, on the Chiltern Hills. Mr. Hodge was in bed, and felt the movement of the bed and room; time 9.25 (?).

Oxford.—Oscillation of room felt in one of the colleges at about 9.18.

Watlington.—Writing from Shirburn Castle, near here, the Countess of Macclesfield states:—

"I was sitting at my dressing table at 9.20 when I felt a very slight oscillation of the floor, which lasted about three seconds, and seemed to be from north to south. Two ladies in the upper floor of the Castle felt it also."[46]

[46] The Countess adds "At the time of the great Lisbon earthquake in 1755 the moat that surrounds Shirburn Castle was agitated, and the water rose simultaneously at the north-eastern and south-western corners." (See p. 14).

GLOUCESTERSHIRE.

Bristol.—Shock felt in the southern and lower parts of the town along the Avon; a rumbling sound heard by a resident on the N. side of the river; time about 9.15 (?).

Cheltenham.—Two shocks, separated by a second or two, reported as felt at Northumberland Lodge by Mr. C. Pooley at "about 9 a.m."; the shock felt at the same time[47] in Paragon Parade, and in Hatherley Place; no sound heard. (Information furnished through Mr. G. Heather Williams).

Stroud.—Mr. P. E. B. Porter, of the Uplands, reports that he distinctly felt the vibration while lying in bed; a cardboard almanac hanging on a wall was seen to move (time not given). Felt by an invalid in bed at Dudbridge, one mile S.W. of Stroud on the Middle Lias; and also at Stonehouse, three miles W. of Stroud on the Lower Lias. (Mr. A. Shaw Page, 'Nature,' May 29th, 1881, p. 102).

WORCESTERSHIRE.

Worcester.—Trembling of houses felt in Severn Terrace and other parts of the town. At the Porcelain Works liquids were reported to have been spilt from the vessels containing them.

SHROPSHIRE.

Oscillation felt by a lady in bed at Sidbury, 6 miles S.W. of Bridgnorth.

STAFFORDSHIRE.

Shock felt slightly at Wolverhampton.

WARWICKSHIRE.

Birmingham.—Distinctly felt in many parts of the town;

[47] Mrs. M. C. Hume Rothery, of the Pines, has favoured me with an account of her experiences, but these can hardly refer to the East Anglian earthquake as the time given is "nearly 10.30." She mentions a previous shock felt by a friend before 8 a.m. on April 22nd, and another felt on the other side of the town "one night three or four weeks before the 22nd."

glasses shaken off the shelves at the Central Restaurant; shock felt also at the Court Restaurant.

Leamington.—Mrs. M. Saunders, residing in St. Mary's Road, was in bed at about 9.20, and felt the oscillation of the large iron bedstead, which produced a feeling of nausea. A small and heavy inlaid Chinese table rocked distinctly, and the window curtains were shaken. There seemed to be two shocks with a marked pause between, the direction apparently being N. and S., with a slight inclination E. and W. Another person on the ground floor felt the oscillation of her chair and heard a low rumbling like a gust of wind. No clocks stopped. Shock scarcely noticed in other parts of the town.

Rugby.—Oscillation of house felt by Mr. A. Percy Smith at about 9.20 ('Nature,' April 24th, 1884, p. 602).

Northamptonshire.

Cottesbrooke.—Shock felt by Lord and Lady Erskine; articles in room shaken.

Creaton.—Shock felt in bed by Mr. F. Langham.

Ecton.—Movement felt by Mr. C. W. H. Sotheby, High Sheriff.

Eye.—Shock felt by a lady in bed. Mr. C. A. Markham reports that a lady in this village "was advancing to a table at the time, and when in the act of putting her hand upon it, the table received a sudden jerk, so noticeable as to startle her."

Great Billing.—Loud noise heard, and household articles seen to vibrate.

Guildsborough.—Oscillation of chair felt by Lady Cicely Clifton at the Grange at about 9.20.

Kettering.—Felt in Broadway, Gold Street, and other parts of the town; crockery, &c., rattled.

Nassington.—Shock felt here and at the Vicarage by the Rev. Dr. Barrett; furniture moved and glasses jingled; a rumbling like distant thunder heard; time 9.20.

Northampton.—Shock felt in town and throughout district;

a noise like the rumbling of a waggon heard. Mr. C. A. Markham reports many instances of the earthquake having been felt in the town, chiefly by people in bed or quietly seated. Pictures were shaken, lustres rattled, and the usual effects experienced. An old Roman wall two feet thick, standing in a garden, was shaken, and the planks which propped it up fell into the next garden. The swaying movement of the houses appears to have been distinctly felt. Time given as 9.20 or 9.30.

Peterborough.—Shock felt in Lincoln Road, London Road, and Bridge Street; also at Fletton Spring.

Pitsford.—Shock felt at Pitsford Lodge about 9.20.

Sywell.—Shock felt at Rectory about 9.30; bed and hangings shaken.

Thrapstone.—Oscillation felt by invalids in bed.

Watford Court.—Shock felt by Lady Henley about 9.20.

Weedon.—Shock distinctly felt in Ordnance Buildings.

Wellingborough.—Mr. C. A. Markham reports "The shock was felt in many parts of the town, notably in the warehouses of Messrs. Watkin and Messrs. Brown. At the Club the ceiling cracked and fell, and clocks stopped."

West Haddon.—Oscillations felt by an invalid in bed; two series separated by an interval of two or three seconds; curtains seen to move; time given as about 9.15.

Rutland.

Uppingham.—Writing from West Deyne, Mr. G. H. Mullins reports that the shock was felt all round, but not at that place.

Huntingdon.

No report has been received from this county, and the shock, if felt at all, must have been very slight.

Leicestershire.

Ashby Parva.—The following letter from this place has already appeared in Mr. Symons's report:—

"I was in bed (being an invalid), but writing at the time. My chronometer is temporarily out of gear. At

9.19 G.M.T. by my watch, and several clocks in the house (none of which can be trusted separately to a minute or two), I heard a roaring noise in the E., which made me look to a window facing E. by S. Almost simultaneously, I heard a fall of soot and some pieces of mortar, and then became conscious that my bed was swaying, or being slightly tilted, apparently from S. to N. (or N. to S.). The shock I computed to last five seconds, and the oscillations—to which I paid careful attention, having had experience of earthquakes long ago—seemed about two per second; I lay perfectly still, instead of looking at the watch. Of those members of my household who were on the ground floor none felt anything. Two servants, occupied in separate rooms on the same floor as I was on myself, heard the noise, and complained that they were seized with giddiness. The shock seemed to me to be marked by far less noise—I mean subterranean noise—but by what one would call 'more swing and far less tremor,' that is, by oscillation of greater length, than that of October, 1863, which I felt (much more violently than others in England) at Sellack, in Herefordshire, where some houses were injured on that occasion.—W. Clement Ley."

Husband's Bosworth.—A correspondent reports that the shock was felt in a house six miles from Market Harborough, on the borders of Northamptonshire. A lady sitting at breakfast at 9.20 felt the oscillation of the table and saw the chandelier swing; a low rumbling sound was heard; direction apparently E. and W.

Leicester.—Shock felt distinctly in many parts of the town, especially at Stonygate, the highest part, where furniture and ornaments were moved, and the oscillation of the house was felt. At a room 60 feet from the ground, in a large factory (Messrs. R. Walker and Sons), the workmen felt the oscillation to a considerable extent, stools were rocked, and the machinery made to 'clank'; great consternation was caused. (Report received from Mr. Robert Walker, of 'Woodside').

Market Harborough.—Shock felt in upper storeys; two distinct series of oscillations said to have been experienced. Mr. C. A. Markham reports that at Messrs. Symington's

factory the building rocked so much that people at work in the lantern room thought it was about to fall.

Lincolnshire.

Boston.—Mr. William Bedford reports that he was sitting in his office near the steam mill, and felt the earth tremor most distinctly; time 9.20; direction apparently S. to N.

Brigg.—Shock felt. (Report from Mr. Alfred Atkinson).

Crowland.—Oscillation of bed felt at about 9.20 by the Rev. Mr. Long; no sound heard (Mr. C. A. Markham's report).

Long Sutton.—Oscillation of church steeple rather strongly felt by workmen engaged in some repairs upon it; they thought it was going to fall, and all came down.

Partney, two miles N.E. of Spilsby.—A lady in bed at about 9.20 felt the head of the bed (against an outside wall with S.W. aspect) vibrate violently as though a train were rushing past, and afterwards heard a faint rumbling noise like distant thunder. Vibration felt by other persons on the same floor, but not by anyone downstairs.

Skegness.—Shock felt.

Spilsby.—Shock distinctly felt by a person in bed in an upper room; the bed oscillated, and the doors of a large wardrobe partially opened; china and bottles rattled. No rumbling sound heard. Time about 9.15.

Stamford.—"Two members of the Conservative Association, whilst reading papers in the reading room, felt the earthquake" (Mr. C. A. Markham's report).

Sutton Bridge.—Mr. H. G. Grimley reports that he felt the shock slightly; room shaken and window rattled.

Wainfleet.—Shock felt.

Nottinghamshire.

No report received from this county.

Derbyshire.

Brassington, near Wirksworth.—Shock felt slightly at the Vicarage, where a bedstead was shaken as though a dog were under it. (Report from the Rev. J. Macrae).

Derby.—Mr. Richard Keene reports that he distinctly felt the swaying of the chair in which he was seated, and heard a window rattle in an upper room of his house in Irongate; time 9.20.

Findern, near Derby.—Felt by an invalid in bed, who states that the curtains were shaken, and the doors of a wardrobe facing W. were thrown open. A bedroom door facing W. was shut by the oscillation, which was felt also by other persons on the same floor; windows rattled, and light boxes on a wardrobe appeared about to topple over; time about 9.20; direction apparently E. and W. (Report from the Rev. B. W. Spilsbury).

Cheshire.

Altrincham.—Vibration distinctly felt. (Report received from Mr. A. Wimpory.)

The northern limit to which the earth tremor extended thus appears to be Brigg or Glandford-Brigg, Lincolnshire, lat. N. 53° 33′, long. W. 0° 29′, and the western limits Altrincham, Cheshire, lat. N. 53° 23′, long. W. 2° 21′, and Bristol, lat. N. 51° 26′, long. W. 2° 35′.

It will be convenient next to follow the course of the disturbance southwards:—

Middlesex.

London and Suburbs.—Shock felt slightly but distinctly in many parts, the effects being chiefly perceptible in the upper storeys of buildings. As no earthquake has been experienced in and around the metropolis to such a widespread extent for considerably more than a century, it will be of interest to give the records in some detail:—

Strand.—Oscillation very perceptible; in many houses furniture, &c., was shaken, chandeliers slightly swung; lustres and chimney ornaments rattled. Movements in some houes sufficient to alarm inmates. Shock felt in and about

the Temple; also at the Charing Cross Hotel. Mr. White informs me that a gentleman walking along the Strand at the time felt a sudden sensation of giddiness and nausea, causing him to reel.

Houses of Parliament.—Movement of scaffolding said to have been distinctly felt by workmen engaged upon some repairs to the Victoria Tower. Reported to have been felt also in the library of the House of Commons.

Adelphi.—Writing from 12, York Buildings, Major Mainwaring Jones reports that he felt the shock slightly in his chambers; time by Westminster clock as nearly as possible 9.19.

Victoria Street, S.W.—The shock was felt by a lady at 3, Morpeth Terrace, who was sitting writing at 9.20, when the table and chair were tilted and her pen was lifted. From the direction in which she was seated the movement appeared to be S.S.W. and N.N.E. A second and stronger oscillation followed almost immediately, and this set "two old-fashioned lustres on the chimneypiece ringing sharply;" the vibration of the pendants continued for some minutes (direction not noted). A servant moving about felt nothing, but another servant sitting writing in the kitchen felt her chair tipped towards the N.N.E. The house in question is in flats, and these effects were experienced on the second floor. The disturbance was also felt by the occupants of the top floor. (Report received from Mary A. Ewart.)

Chapel Street, S.W.—The Hon. R. Abercromby states that the shock was felt here (No. 21) by his brother at 9h. 19m. 30s. a.m. (corrected). No record was given by his barograph.

Ebury Street, S.W.—Vibration felt at No. 146 at 9.20.

Claverton Street, S.W.—The Rev. W. Linton Wilson, who was staying here, informs me that Mrs. Wilson, who was in bed at the time (9.20), noticed the swinging of the bed curtains; the direction of the movement was N.N.E. and S.S.W.

Gloucester Street, Warwick Square, S.W.—Miss Florence Howard reports that on the third floor she felt the swaying

of the bed on which she was lying:—"Window rattled, door (open) vibrated (seemingly up and down) on its hinges; china shook. Lasted, I should say, eight or ten seconds. Rocking came first, then trembling followed immediately." Servant kneeling in room also felt the movements; time 9.15 (?); direction apparently E. and W.

Pimlico and Chelsea.—Shock felt in many houses; a rumbling sound heard in neighbourhood of Chelsea Barracks.

Regent Street.—Vibration felt distinctly by many persons at No. 164 at about 9.20; chairs and their occupants trembled considerably. (Report received from Miss Moon).

Hereford Gardens, Marble Arch. — Writing from No. 12, Mr. George Pringle, Secretary to the Ecclesiastical Commission, reports that he distinctly felt the tremor there, and at first attributed it to the passing of heavy traffic, but soon recognised the novel character of the motion. The room is surrounded by small lightly-framed etchings, suspended by hooks on rods, and these were oscillated considerably on the W. and N. walls of the room, especially those on the latter which hung from the longer wires, and which swung perceptibly E. & W. for some minutes: time about 9.19. Dr. Gower, medical inspector of prisons, also felt the shock in this house at about 9.18 by his watch.

Seymour Street, Hyde Park. — Clock stopped at 9.15 (thought to be three or four minutes slow) at No. 81; pendulum swinging N. and S.; no shock felt. (Report by Mr. Charles Shard). Vibration felt at No. 77.

Inverness Terrace, Hyde Park.—My cousin, Mrs. S. N. Carvalho, residing at No. 8, informs me that she was lying in bed reading, and distinctly felt the vibration of the bed and of the book which she held in her hand; there appeared to her to be two distinct shocks, separated by a short interval. Surgeon-Major W. C. B. Eatwell, residing at No. 69, reports ('Nature,' May 1st, 1884, p. 18) that he also felt the vibration, and at first attributed it to a train passing on the Underground Railway near his house, but having experienced an earthquake in India he recognized the peculiarity of the

movement, and took the time, which was 9.32 by his watch, afterwards found to be 15 minutes fast, thus making the time of the shock 9.17.

Queen's Garden's, Bayswater.—At a young ladies' school here, one of the pupils in an upper room had a book shaken from her hand by the shock.

Kildare Terrace, Bayswater.—Major-General Hutchinson, writing from No. 16, reports that he felt the shock distinctly whilst at breakfast. Having experienced earthquakes in India, he recognized the motion and immediately took the time (9.18).

Norfolk Terrace, Bayswater.—Mr. Thomas E. Dallas, of No. 5, reports that he was lying in bed on the second floor, and felt the vibration of the bed. There appeared to be two or three sets of vibrations, the first and second set separated by a very short interval.

Paddington.—Oscillation felt at Accountant's Office, Great Western Railway Station, at 9.18.

Portsdown Road, Maida Vale.—Mr. F. B. Edmonds, writing from No. 72, reports as follows:—"(1) The shock occurred between 9.15 and 9.20; certainly before 9.20. (2) The shock lasted about 5 seconds. (3) The rocking motion was accompanied by a peculiar vibratory motion quite new to me." These effects were experienced on the third floor, and were noted at the time, but were not ascribed to an earthquake till later in the afternoon, when the news was published in the evening papers.

Clifton Gardens, Maida Vale.—Shock felt by a lady in bed at No. 49; bed oscillated and bed-curtains rather violently shaken; windows slightly rattled—not so much as when a heavy van passes: time 9.35; watch about 15 minutes fast. These effects were observed on the second floor; persons moving about on the lower floors felt nothing (Report by Miss C. Waring).

Kensington Park Gardens, Notting Hill.—At No. 19 a lady in bed at 9.20 felt a gentle swinging movement of the room; direction apparently E. and W. (Report from Mary Waddilove). Mr. William Crookes, F.R.S., informs me that the shock was not felt by any person in his house at No. 7.

Holland Park Terrace, W.—Mr. Alfred Crookes, No. 15, writes as follows:—

"As my wife and I were sitting reading after breakfast, I felt a sort of sidelong heaving of the chair and a sinking giddy sensation in my head, and at the same moment the folding doors, which were shut, bumped backwards and forwards three times without opening, and the windows back and front of the house (nearly due N. and S.), rattled sharply. I looked at the clock immediately, and remarked to my wife that it must have been an earthquake."

The house stands about 100 feet above sea-level, and Mr. and Mrs. Crookes were having breakfast in an upper room. Nothing was felt in the next house.

Addison Road, W.—Writing from No. 82, Mr. W. R. Gady reports that he was in his dressing-room and observed the swinging of the curtains of a shower-bath; at the same moment his wife, in bed in an adjoining room, felt the movement of the bed and saw the curtains shaken. Movement apparently E. and W.; time 9.19; watch correct by Greenwich time within 15 seconds.

Kilburn.—The following letter to the 'Kilburn Times' of May 2nd has been forwarded to me by the writer, Dr. Henry T. Wharton, M.A., of 89, St. George's Road:—

"The earthquake which occurred on Tuesday morning, April 22nd, was more widely felt in Kilburn than your brief note would imply. Many of my patients noticed it, although none of them thought of assigning the right cause to the phenomena. A lady in St. George's Road fancied that a traction-engine must have been passing, only she wondered why she could hear no noise; she was always curious to feel an earthquake, but she has no desire to repeat this, her first experience of one. More than one member of a family in Priory Road wondered why the furniture, and especially the ornaments on the mantelpiece, rocked so strangely, and they observed to one another, 'If we had still been in Lisbon, we should have thought it was an earthquake.' An invalid in Goldhurst Road was much mystified by the motion of the bed-hangings. In some instances pictures hanging awry on the wall, with a strange uniformity, such as no housemaid would cause, bore witness that they had felt the seismic disturbance. An old nurse in Sutherland Gardens was so

terrified that she dared not get out of bed until the lady's maid came and assured her that the end of the world had not come."

Hampstead.—Shock felt at 20, Belsize Square by Mr. George P. Wornum; time 9.25 (?); a steady swaying movement, apparently N. and S. Shock felt also in South Hampstead, by persons in bed; three distinct vibrations, of which the first was the strongest; movement apparently N. and S. Mr. A. Vaughan Jennings reports that it was felt as a swaying movement on third floors, but not on basements.

Writing from The Ivy House, Christ Church, Hampstead Heath, the Rev. Newman Hall reports that at 9.17 he was sitting in his study on the second floor, and suddenly felt the house vibrate three times, apparently from N.E. to S.W. He adds:—"The vibration lasted from two to three seconds, and ceased as suddenly as it began. There was no sound, no wind, and no vehicle passing. I felt a slight dizziness." Mr. C. L. Woodd, of 'Roslyn,' who was in bed at the time, felt the bed heave twice, and glasses in the room were jingled; time about 9.23 (?). Shock felt also by several other persons in Hampstead.

Crouch End.—Shock distinctly felt about 9.18 or 9.20, at 'Redwood,' Crescent Road; a clock stopped, pendulum swinging about W. 12° N.—E. 12° S.: two shocks with a slight interval between, the whole lasting 6—7 seconds; slight displacement of some of the picture-frames on walls. (Report by Mr. F. E. Kew).

Hornsey Rise.—Shock reported to have been felt in several houses.

Haverstock Hill.—Mr. Arthur B. Woodd, M.A., of The Woodlands, has sent the following report:—

"I was in my room at the top of the house and at the N.W. end of it. At 9.17 a.m. (railway time by electric clock), I was astonished to see a large Japanese bronze ornament on my centre table swaying to and fro, and to hear a bronze plate supported by it rattle, and also a smaller bronze ornament, from which rings were suspended, greatly

agitated—so much so that a jingling sound was produced by the rings being brought in contact with the body of the vase. This latter vase stood on a table at the south end of the room. Accompanying the vibratory motion was a rumbling sound like the rapid movement of heavy furniture in the room below; the rumbling and the shaking lasted for nearly half a minute. The direction of the wave (for I at once imagined it to be the result of an earthquake), was nearly S. by W.—N. by E. This I judge from the fact that there were on the same table two precisely similar bronze ornaments, one at right angles to the other in position. The one (mentioned previously) had its broadest part, from which the rings are suspended, extending nearly N. and S.; the other had its widest part E. and W. nearly. The first mentioned emitted the jingling sound, the latter, although shaken, did not."

Mr. H. O. Forbes, who has experienced many earthquakes in the Malay Archipelago, states[48] that he felt the shock at 87, Queen's Crescent at 9.22 (?). The direction was apparently N. to S. "in short, rapid undulations." Duration estimated at 33 seconds. Mr. Forbes adds that on January 18th, about 4.5 p.m., he and his wife and brother experienced a previous and decided earthquake shock at this place.

Highgate Road, N.W.—Oscillation felt by a person in bed at Grove Terrace; three distinct movements; curtain shaken. (Report from Mr. John C. Strange).

Camden Square, N.W.—Mr. G. J. Symons informs me that a clock was stopped at No. 6 in the Square; pendulum swinging N.W.—S.E.

Arlington Road, Camden Town.—Vibration of bed felt by Mr. J. T. Lockhart at No. 3.

Returning to the W. and W.C. districts, numerous reports have been received from various quarters:—

Queen Anne Street, Cavendish Square.—The call-bell at a surgeon's (No. 12) was caused to ring; shock not felt. (Information furnished by Mr. S. N. Carvalho, jun.).

Oxford Street.—Writing from No. 276 (corner of Holles Street), Messrs. H. and M. Southwell report that the shock

[48] 'Nature,' April 24th, 1884, p. 602.

was felt there to a sufficient extent to cause four persons, writing on the second floor, to leave their desks and make for the street. Motion also felt on first floor; direction of oscillation apparently E. and W.

Holles Street.—Vibration of room felt by a gentleman reading in bed.

Bedford Square.—Dr. Jabez Hogg writes to say that at No. 1 his daughter, who was just leaving her room, at about 9.20, felt the room violently shaken, and the glass pendants of the candlesticks on the mantelpiece jingled loudly. The disturbance was also felt in the room above, and was at first attributed to the fall of a heavy piece of furniture.

Russell Square.—Shock felt at No. 46 (Mrs. Horne), and by Mr. Gunn in the adjoining house; bedsteads felt to oscillate, gas fittings jingled, and chandelier in drawing-room seen to swing; motion said to have been E. and W. for about 30 seconds. Vibration also felt and clocks stopped in one or two other houses.

Montague Street.—The following information has been kindly collected for me by Mr. C. F. Hayward, F.S.A.:—

At No. 20 Dr. Alfred Elwes, who has had previous experience of many earthquakes in Italy, was seated at breakfast on the first floor reading, and noticed the sound of what appeared to be a sudden gust of wind, and the instant afterwards felt his chair gently rocked; a large picture hanging on a S. wall moved forwards (towards the S.); time about 9.25 (?), motion very gentle. Mr. Hayward himself, who was at breakfast below, felt nothing. At No. 22 the disturbance was plainly felt at about 9.20, by a lady and her daughter at breakfast; pictures on the walls were moved in a direction E. and W.

Guilford Street.—The night-bell at a doctor's house is reported to have been rung at about 9.20: attributed to the earthquake.

Hunter Street.—Mr. A. Cowper Ranyard, F.R.A.S., residing at No. 13, informs me that some counterpoise weights on his reflecting telescope were displaced in his observatory, and as the door is always kept locked during his absence, he

could only attribute their displacement to the earthquake movement. By the kind invitation of Mr. Ranyard, I was enabled to make an examination of the instrument referred to, which is an eighteen-inch reflector, supported on walls rising about 21½ inches above ground, and sunk three feet below ground, the walls resting on a concrete foundation. The two 28 lb. counterpoise weights to the polar axis were resting on a support hanging from the end of a lever-arm standing N. and S., this lever magnifying any motion of the supporting axis about six times. The weights, which were flat and slotted, had been nearly shaken off their support, the lowest weight having been displaced to a sufficient extent to touch the iron frame of the instrument. Unfortunately, the displacement of these weights gives no precise information as to the direction of the vibrations, as the slots permitted them to slide off only in one direction; it can only be affirmed that the movement was more or less in a N. and S. direction; nor can the amount of their displacement be used as a basis for calculating the amount of displacement of the ground during the passage of the disturbance, as the effect produced was doubtless the result, not of a single "shock," but the cumulative action of a series of small vibrations.

Brunswick Square.—Oscillation felt in an upper room at No. 11, by a person seated in a chair. (Information furnished by Dr. Maurice Davis).

Doughty Street.—Vibration felt in upper storey by a lady bed at No. 52; bed standing with its length E. and W. (Information given by Miss L. Lyons).

John Street, Bedford Row.—At No. 21 my mother, Mrs. Meldola, who was in bed on the second floor, distinctly felt the oscillation of the bedstead (standing with its length nearly E. and W.), and at first attributed it to a cat shaking himself under the bed, but the animal was found on searching to be in a different corner of the room. On returning home in the evening and mentioning that an earthquake had been felt in London, my mother related her experience, and on my questioning her as to the time, said "about 9.15."

Theobald's Road.—Shock felt at No. 20 by a gentleman in bed in an upper room.

Warwick Court, Gray's Inn.—Shock felt by Mr. Arthur Viles, who was awakened by the oscillation of his bed; a gentle undulation, apparently from E. to W.; lasted fully five seconds.

Lincoln's Inn Fields—Mr. C. F. Hayward informs me that the vibration was felt by a gentleman at breakfast on the fourth floor at No. 36, at about 9.20. The floor appeared to be moving, and the back of his chair to be giving way.

Hatton Garden. — Messrs. Hazell, Watson and Viney, printers, report that at their office, five storeys high, the vibration of the building was so strongly felt on the upper floors, that a large number of the men began to rush away in alarm. They state that other buildings in the same street were also affected.

Cow Cross Street, E.C.—Mr. Lambert Samuel (Nos. 14, 15 and 16), reports that the oscillation was strongly felt on the three upper floors of his house (six-storeyed); forms, benches, shelves and gas-fittings were shaken, and several of the work-people rushed down to enquire if an explosion had taken place.

St. Bartholomew's Hospital.—A medical student in the museum heard a noise and saw some teeth suspended in a glass jar moving from side to side and striking the walls of the jar; a large number of bones suspended in glass cases were also set swinging.

Queen Street, Cheapside.—Shock felt in upper floors at Messrs. Smith, Son, and Co.'s, a six-floored building; several men stopped work in alarm.

Cornhill.—Mr. J. H. Steward, optician, states that he was surprised to see the suspended instruments in his establishment oscillating with an unsteady motion. One instrument, weighing between 20 and 30 lbs., and hanging on a flat metal hook, had a motion of quite two inches.

Leadenhall Street.—Clock stopped at 9.20 (may have been a minute or 1½ minute fast) at No. 109; pendulum swinging nearly N. and S. (Report from Mr. Edward Gellatly).

Finsbury Square.—Clock stopped at 9.20 at No. 17; pendulum swinging N. and S. (Report from Mr. A. Garrard).

Myddelton Square, Pentonville.—Shock felt at No. 8 by Mr. E. L. Garbett.

Highbury Grove.—Mr. E. Parry Stevenson reports that at No. 21 a clock was stopped, "between 9.15 and 9.20." Another clock was stopped at No. 5 (Mr. H. W. Davis) about 9.25 (?). My friend, Mr. John Spiller, at my request was good enough to ascertain the direction of the swing of the pendulums of these clocks, which proved in both cases to be E. and W.

Dalston.—Shock felt by a person kneeling at the time (9.20); folding doors partly opened by the movement.

Amherst Road, Hackney.—Writing from No. 175, Mr. Graham Grossmith states that he was sitting in his dressing-room, facing N., and was suddenly rocked backwards and forwards from N. to S.; at the same moment Mrs. Grossmith felt the bed in which she was lying oscillate in the same direction; time about 9.15 (clock error unknown).

Hackney Downs.—Mr. John Earl, of 8, Goulton Road, writes as follows:—

"I was sitting reading in an arm-chair, at about 25 minutes past 9 by Hackney Church, when I felt my chair vibrate 5 or 6 times from N. to S., sensibly moving me. Being surprised at this unusual occurrence, I looked round and saw the glass pendants, hanging from two old-fashioned glass lustres standing on the marble mantelpiece of the dining-room where I sat, in active motion, swaying from N. to S., and immediately came to the conclusion that this was caused by a disturbance of the earth . . . . . The room in which I sat is on the ground floor, and is built on the original gravel soil. The house is one storey high. Outside, the road was perfectly quiet, no vehicle of any kind passing at the time."

Clapton Common, Upper Clapton.—Mr. Ogden, of the firm of Ogden, Bowes and Co., states that at his private house, No. 93, a clock stopped at about 9.21; pendulum swinging E.N.E.—W.S.W.

Shadwell.—The following report from this neighbourhood has been published by Mr. E. F. Payne, New Crane Mills:—

"At about twenty minutes past nine this morning a loud

rumbling was heard, and a severe shaking was given to houses in this neighbourhood. The housekeeper at Messrs. Pitt Brothers and Co., 10, Wapping Wall, and one of the partners, were considerably affected by it. Mr. G. Pitt was shaken in his chair while at breakfast, and Mrs. Mulley, of 9, Wapping Wall, next door, was obliged to hold on to her seat in consequence of the vibration, while Mr. McGowan, engineer at the London Docks, says that his house, some 250 yards away, was shaken to the foundation. Mrs. Ward, of the 'Three Suns,' New Gravel Lane, also experienced the shaking and heard a rumbling noise."

Before leaving the Metropolitan area, it will be convenient here to consider certain movements in the River Thames, which are said to have been observed on the day of the earthquake. Thus it was reported in the papers that a wave, estimated to have been about three feet high, was seen to cross the river, and to cause a vessel lying at St. Paul's Pier to roll heavily without any apparent cause. This account did not appear till four days after the shock (April 26th), and it is much to be regretted that no details respecting time and direction were given. Although the statement thus appeared devoid of any great scientific weight, it seemed to me desirable to obtain further information if possible, as it would certainly have been interesting to find that the Thames was influenced by the seismic disturbance while rivers and estuaries like the Colne, Blackwater, and Crouch, which were much nearer the focus, were not perceptibly agitated. I accordingly applied to the Hydrographic Department of the Admiralty, and in reply received the following communication from Staff-Commander H. R. Harris, R.N.:—

"In answer to your letter of the 28th inst., requesting information as to abnormal movement of the Thames on 22nd April last:—

"I am directed by the Hydrographer to inform you that no information of such movement has been received in this Department. A self-registering tide-gauge is maintained at Sheerness Dockyard." . . . . . .

Commander Harris was good enough to suggest that application should also be made to the Thames Conservancy, and

the following reply was received from Mr. Charles J. More C.E., Engineer to the Conservancy:—

"With reference to your enquiry addressed to the Secretary, as to whether a tidal wave was observed to cross the River Thames on the morning of the 22nd April last, I beg to inform you that none of the Conservator's officials engaged on the river noticed anything unusual in the state of the water on that date, nor did the automatic tide-recording instrument on the pier at Gravesend indicate any abnormal movement in the tide."

On application at Sheerness Dockyard, the Superintendent, Staff-Captain Dyer, was good enough to have forwarded to me a copy of the curve traced by the tide-gauge on April 22nd, accompanied by the remark, borne out by the curve itself:—"No disturbance of water or tidal wave." An inspection of the curve shows that the shock occurred very near the time of high water.

The evidence is thus, on the whole, adverse to the above-mentioned statement, and in the absence of confirmation I am disposed to believe that there must have been some error of observation.

Enfield.—Shock felt in some parts; furniture shaken. Mr. John Penfold, of Edgehill Lodge, informed me that his wife and another lady were seated at breakfast at about 9.15, in a room on the ground floor, and both heard a noise, proceeding apparently from the N.E. corner of the room. Mrs. Penfold immediately left the room to ascertain the cause, and the other lady, on the cessation of the sound, felt her chair rock slightly from E. to W. There was a short pause and then again a slight rocking movement; the articles on the table were not disturbed. Mr. Penfold himself, who was standing in his dressing-room on the first floor, heard the noise but felt nothing of the movement. The house is detached and stands in a high situation, partly clay and partly gravel.

Harrow.—Mr. W. R. Fisher reports that the earthquake was distinctly felt by a lady in bed about 9.15. Another correspondent also reports having felt two slight but distinct shocks between 9.10 and 9.20.

Isleworth.—Shock not felt, according to a report by Miss E. A. Ormerod, F.R.Met.S.

Northolt.—Lt.-Col. Samson, who has had experience of earthquakes in Jamaica and other parts of the world, writes from The Elms, Northolt, as follows:—

"On the morning of the 22nd April, at a point midway between Harrow and Southall, 9.25 a.m. (?), I was in bed reading a book, my feet pointing S.E., my right elbow resting on the bed, and the lower arm elevated to support the book with ease and comfort, when suddenly my book oscillated considerably between the two points N.E. and S.W. by my compass. The movement lasted from about 10 to 15 seconds."

Pinner.—Shock not felt; inquiries made by Mr. H. R. Leach.

KENT.

Beckenham.—Slight shock felt at 9.20, by Mr. J. Moore, of Oakwood, who was in bed at the time; doors and bed trembled; motion apparently N.E. to S.W.; duration about 5 seconds.

Canterbury.—Shock felt by several people along Sturry Road, between this place and Herne Bay.

Chiselhurst.—Shock felt by inmates of 'Walpole,' Manor Park. A lady was in bed reading, sitting propped up by pillows, when the bed was felt to heave and then rocked from side to side; a curtain by the bed side waved for some minutes. Time 9.18; motion apparently from E. to W. Another lady, in an adjoining room, felt the bed violently shaken and thought there must have been an explosion somewhere. In a third room, a servant sitting at work saw a large wardrobe move, and heard it creak in a peculiar manner; four bells in the same room were shaken but did not ring. Another servant thought she heard a sound like distant thunder. (Report from Mrs. A. Oldham).

Dover.—Mr. W. A. Smeeth, of 73, Castle Street, states that he was in bed asleep at the time, and distinctly felt the vibration, which awoke him. The movements seemed repeated twice, with a short interval.

Greenwich.—The following has been received from Mr. William Ellis, of the Royal Observatory:—

"I am requested by the Astronomer Royal to inform you that our earth-current registers both indicate that small movements of the respective needles occurred yesterday, April 22nd, at 9 h. 20 m. It happened that the circuits were interrupted at the time for determination of the zero positions of the needles. They were thus not under the influence of any earth-current, which makes the indication very certain. The earth-current needles are very light. There is nothing to be seen in the registers of the heavy magnets. The earthquake shock was distinctly perceived by myself, whilst sitting writing at my official desk. We are unable to give any indication in regard to direction of movement of the shock."

In a later communication (April 26th), Mr. Ellis adds:—

"You would understand that the motion of the earth-current galvanometers (slight vibration) at 9 h. 20 m. a.m., on April 22nd, mentioned in my letter of the 23rd, was not produced by earth-current, but was simply caused by the earthquake shock. Closer examination of the magnetic registers, those of declination and horizontal force, shows that those magnets were also put into very slight vibration."

At 28, Croom's Hill, Mr. T. V. Holmes, F.G.S., informs me that his wife, who was in bed at the time, distinctly felt the vibration of the bed, and was led to ask whether one of the chimneys in the adjoining house was being swept at the time (about 9.20). Direction apparently E.N.E. to W.S.W. The house is on Thames Valley gravel, 45 feet above Ordnance datum. Below the gravel is either chalk or Blackheath and Woolwich beds, according to the side of the fault that the house is situated upon; the position of the fault is here unknown owing to the covering of gravel.

Writing from 9, Maze Hill, Mr. F. A. Saw states that the undulating movement of the bed was felt both by his brother and himself, who were in bed on the fourth storey. Motion apparently E. to W. Time about 9.15 (?).

Herne Bay.—Crockery rattled and bells rung.

Lee.—Clock stopped at Holly Bank, Burnt Ash Hill, at 9 h. 19 m. 30 s. Pendulum swinging E. and W.

Lewisham. — Mr. R. McLachlan, F.R.S., writing from Clarendon Road, reports ('Nature,' June 19th, 1884, p. 170), that at the time of the disturbance he was sitting in his study and heard the creak of one or more of his insect cabinets; the door of the room, which had previously locked readily, would not lock that same evening, and a clock in a bedroom was stopped at the time of the earthquake, but it is not certain whether it was stopped in the morning or evening (time not given). Mr. McLachlan informs me that the pendulum was swinging about N.W.—S.E.

Maidstone.—Mr. E. Amies reports that he was in his office in Chancery Lane at the time, and felt the oscillation; a gas pendant five feet long was seen to swing to and fro; shock felt also by workpeople in the building.

St. John's.—Mr. W. Topley, F.G.S., states ('Nature,' May 15th, 1884, p. 62), that the shock was felt here by an invalid lying in bed.

Sheerness.—Shock rather sharply felt in many buildings and considerable alarm caused; house-bells rung: not felt by ships on the Medway.

Strood.—Oscillation felt in many buildings; the Board School shaken to such an extent that the masters dismissed their classes.

Tunbridge.—According to Mr. I. Plarr, the earthquake was felt by three persons here; a lady in bed felt the oscillation and saw the vallance swing; an Indian officer, standing leaning against the mantelpiece, felt the movement from about N.N.E. to S.S.W., and an invalid lady in bed also felt the movement. ('Nature,' May 22nd, 1884, p. 77).

Tunbridge Wells.—Consecutive tremulous rockings, such as would be produced by a heavy traction engine, felt on the third floor at the Circulating Library. Time about 9.20. (Report from Mr. St. John Colbran).

Westgate-on-Sea.—Distinctly felt in houses near the sea; in one house the bed of an invalid lady was shaken for about two seconds and bells in the kitchen were rung.

Whitstable.—Shock felt.

Woolwich.—Shock felt rather sharply in the eastern part of the Royal Arsenal. Mr. Wallace, manager of the Gasworks, felt the vibration of the ground; bottles, &c., on the shelves in his office were shaken; a clerk writing at a desk had his pen jerked forward; time about 9.20.

Surrey.

Battersea.—Shock said to have been felt by Mr. Clayton Woodhouse; bed oscillated and a bell-rope set in motion.

Brixton.—In Lambert Road and Coldharbour Lane the shock was felt distinctly, in both cases by persons in bed.

Croydon.—Shock felt.

Dorking.—Shock felt slightly at Bentsbrook on the Holmwood, by a person in bed in an upper room. Bed shaken two or three times (apparently E. and W.), then a pause and another similar shake; time about 9.20 or 9.25.; felt also by another lady in Dorking. (Letter from Mrs. Bernard to Lieut.-Col. Godwin-Austen, 'Nature,' June 12th, 1884).

Esher. — Vibration felt by a lady in bed, about 9.20. (Report from Mr. E. T. Dowson).

Kew.—Mr. G. M. Whipple, F.R.A.S., of Kew Observatory, reports as follows:—

"We have a good record of yesterday's earthquake, in our magnetograph traces. It took place at 9.17.18, a.m. G.M.T. deflecting the bifilar magnet, which moves N. and S., considerably, and the declination magnet, which swings E. and W., slightly. I cannot hear of any one in this neigbourhood having felt the shock. The clock was compared at 10.40 a.m., and we had both sun and star transits yesterday, so that the time is correct to a minute."

These facts indicate that at Kew the chief movement was N. and S., with a slight inclination E. and W.

Richmond.—Clock stopped at 9.20 at 6, Whitchurch Villas; pendulum swinging E. and W. (Report from Mrs. Hertslet).

Wimbledon.—At 'Elmhurst,' standing on a spur of Wimbledon Hill, the canopy of a bed in one of the bedrooms was seen to shake, and a clock was stopped in the dining-room,

between 9.15 and 9.20; pendulum swinging N. and S. (Report from Mr. Leonard J. Matow, B.A.).

Sussex.

Brighton.—Shock felt by Mr. W. Blake, in a bedroom on the third floor; two shocks, with a short interval.

Crowborough.—Rumbling sound heard about 9.20 by an invalid in bed; plants in pots in window seen to sway to and fro. (Mr. C. L. Prince, F.R.A.S., 'Nature,' May 15th, 1884, p. 57).

Eastbourne.—Felt at 'Freshfield,' Silverdale Road, in a bedroom at 9.20; clock stopped, pendulum swinging N. 10° W.—S. 10° E. (Report by Mr. L. Dyer). Felt also by a lady in bed in Lushington Road; room rather severely shaken.

Hastings.—Shock felt.

St. Leonard's.—Mrs. E. Rider Cook reports that she was in bed at the time and "suddenly felt the bed sway and rock to and fro." At 6, Markwick Terrace, in the highest part of the town, Mrs. H. G. Butt distinctly felt the bed rock gently in a N. and S. direction for a few seconds, and saw the brass end of the bedstead perceptibly raised.

Hampshire.

Farnborough Station.—Mrs. Edmund Wodehouse, of Minley Grange, reports that between 9.16 and 9.22 she was in bed and distinctly felt a vibration, followed by a rocking of the bed from side to side. The duration was estimated at about 30 seconds, and there appeared to be seven distinct heaves, the other movements being mere vibrations; the crockery on a marble washing-stand rattled; tea was tipped over to the west side of a cup which Mrs. Wodehouse had near her at the time; shock felt also by two of the servants and by another person in bed at Farnborough.

Portsmouth.—Shock felt; light furniture shaken.

Isle of Wight.—The Hon. Hallam Tennyson reports that at 'Farringford,' Freshwater, he felt the bed gently oscillate,

and saw the bed-hangings swing for about 15 seconds; the drawing-room clock was stopped, pendulum swinging N. and S.; time, 9.10 (?).

At East Cowes Mr. J. W. Woodruff reports that in a bedroom on the third floor he felt two distinct vibrations, lasting two or three seconds. The shock is also reported to have been felt at Ryde, but no details have been received.

Berkshire.

Hurley, near Marlow.—A lady in bed distinctly felt the oscillation at Hurley House at about 9.20.

Pinkney's Green, 2¾ miles S.S.E. of Great Marlow.—Mr. Alfred Heneage Cocks, M.A., reports that the shock was felt here.

Reading.—Two shocks, separated by a very short interval, felt by an invalid lady in bed, at about 9.15; bedstead and curtains shaken and a screen caused to totter considerably; a sound said to have been heard "as if the wind were rising."

Sulhampstead, near Reading.—Shock felt.

Somersetshire.

Street.—Shock felt by an invalid lady. (Mr. J. Edmund Clark, 'Nature,' May 1st, 1884, p. 19).

Mr. W. H. Gomm reports that nothing was felt in the neighbourhood of Somerton.

Devonshire.

Exeter.—A slight movement of the earth said to have been felt in the neighbourhood of this city by a lady lying on a couch. (Mr. E. Parfitt, on the authority of Dr. H. Kingdon; Trans. Devon. Assoc., vol. xvi., p. 657).

France.

Boulogne.—Mr. Symons reports:—

"Shock felt in several parts of the town at 9.30 a.m., Paris time (= 9 h. 20 m. 39 s., Greenwich time)."

BELGIUM.

Ostend.—Shock felt between 9 and 9.30; bed oscillated two or three times from N.W. to S.E., room shaken; duration about two seconds. (Report from Mr. Oliver Lodge, barrister-at-law, 14, Rue Louise; witnessed by Mrs. G. Charlton.).

The extreme limits of the shock in the southern area are thus: to the east Ostend, long. 2° 58′ E.; to the south Freshwater, lat. 50° 40′ N; and to the west Exeter, long. 3° 32′ W.

An estimation of the total area over which the sensible shock extended has already been given (see p. 22).[49]

VI. THE EARTHQUAKE IN RELATION TO GEOLOGICAL STRUCTURE.[50]

Effects of the Shock upon Underground Waters.

St. Peter's Well.—The temporary effects produced upon the water at St. Peter's Well, and upon the well of the coast-guard station at West Mersea, and the spouting forth of rills

[49] Since the foregoing descriptive portion of the report was presented to the Club a few additional facts have been communicated, and may be here conveniently recorded:—On the occasion of the Club's visit to Witham (July 25th, 1885), I was informed by Lord Rayleigh that at Terling Place the house bells were rung, and also the bells in Terling church. Mr. F. H. Meggy reports also that at a house on the London Road, about a mile out of Chelmsford, a little girl was playing the piano in a room facing S.E., the instrument standing against a wall facing N.E., and an old fashioned upright chime clock being at the opposite (S.W.) end of the room, with its pendulum swinging S.E. to N.W. At the moment of the disturbance the girl ran away frightened from the piano, which she declared had come towards her; and it was afterwards found that the instrument had been moved about 3 inches away from the wall towards the S.W., while the clock was also stopped. These facts indicate a movement more or less in a N.E. to S.W. direction.

[50] Some portions of this section have already been communicated to the Geologists' Association, and appear in the 'Proceedings' of that Society under the title:—"On some geological aspects of the East Anglian Earthquake," vol. ix., Feb. 1885, p. 2.

charged with sand at Cross Farm, have already been alluded to in the preceding portion of the Report (pp. 76 and 77). This action of seismic disturbances upon subterranean waters has been observed in all great earthquakes,[51] and it is not difficult to suggest, in a general way, how such effects may be produced. The case of a shallow surface well, like that of St. Peter's, calls for no other explanation than that of motion imparted from below to a mass of fluid having freedom to move in an outward direction only. The turbidity of the water temporarily produced in these two wells, was no doubt caused by the fine particles of clay, &c., detached by the grinding movement of the beds and carried into the wells by the momentary increase of flow caused by the jerk imparted by the shock.

Cross Farm.—With respect to the little streamlets which burst forth at Cross Farm, it may be suggested that the temporary squeeze to which the water-saturated beds were subjected by the passage of the wave of compression was the immediate cause of the water appearing at the surface, the crack opened by the disturbance at this place affording the easiest channel of escape. In the absence of any precise knowledge of the underlying beds, it has been somewhat difficult to arrive at a satisfactory decision respecting the source of the sand brought up by these streamlets. It appears from Prof. Bonney's report (p. 77) that not much light is thrown upon its origin by microscopical examination; nor could a chemical analysis be expected to give any further information. The nearest well-boring, which is at East Mersea, passes through the following beds[52]:—

[51] See for instance, Mallet's 'First Report on the facts of Earthquake Phenomena,' Brit. Assoc. Rep. 1850, p. 56 *et seq.*

[52] I am indebted to Mr. W. Whitaker, F.G.S., of H.M. Geological Survey, for the use of some of the proof-sheets of the Survey Memoir 48 N, containing the account of the above and other sections supplementary to those published in Mr. Dalton's Memoir, 48 S.W.

		Feet.
[Alluvium, 87 feet]	Red clay	15
	Black silt	22
[? Gravel]	Stone, with brackish water...	1½
	Pebbles "supposed old beach"	1½
[London Clay]	Red clay	15
[Reading Beds, 60 feet]	Green sand, very hard ...	30
	Black clay	30
	To Chalk	115
	Chalk	225
		340

After duly considering the local conditions, it appears quite unnecessary to us to suppose that this sand was brought up from any great depth. The farm is situated close to the junction of the London Clay with a patch of drift gravel, out of which the sand may have been washed. The soil is saturated with water just below the surface, and the ejected water would have to pass through the gravel on its way upwards and outwards; the finer particles of sand would thus be washed out of the gravel and carried away in the streamlet for a greater or less distance, and when deposited on the surface of the ground, separated from the coarser constituents, would not be recognized by those unaccustomed to consider the sorting action of flowing water, and would thus give rise to the impression that it had been brought up from some unkown and mysterious depth. In order to throw further light upon this question Mr. J. C. Shenstone was good enough to procure specimens of the gravel, which he forwarded, accompanied by the following remarks:—"We first dug about two feet deep, exactly at the point where the sand was washed up; here we came upon a gravelly sand, of which I send you a sample. We then went to some ground rather lower and about twenty feet distant from the place where we first dug; here we came on sand within ten inches of the surface: of this sand, which was more loamy, I send also a sample. I may mention that in the second place, within a few minutes of digging, water began to collect in the hole, and Mr. Cock, tenant at the farm, tells me that water lies near the surface in most parts of the Island." The

gravels forwarded by Mr. Shenstone were submitted to a series of washings in the laboratory, and after the removal of the clay a sand was at length separated from the larger pebbles, and this, in general appearance as well as under the microscope, closely resembled the specimen sent by Dr. Wallace. It seems most probable, therefore, that the latter was washed out of the gravel in the manner suggested, the first specimen of "gravelly sand" referred to by Mr. Shenstone being the most likely source, as the loamy sand obtained further from the place where the streamlets appeared required much washing before the clay could be removed.

Canterbury.—Perhaps the most striking illustration of the wide extent of the subterranean disturbance is furnished by the fact that at the Canterbury Waterworks, on the morning of the shock, two or three tanks had to be emptied, on account of turbidity, before the water was sufficiently clear to use. The water is drawn from Artesian borings about 600 feet deep, and is always bright and clear.[53]

Colchester Waterworks.—There are two wells here sunk into the chalk to a depth of 420 feet and passing through the following beds:—

Old well,[54] 1852.	Feet.	New well,[55] 1881.	Feet.
Soil	6	Made Ground	14
[River] Gravel	4	Blue [London] Clay	79
London Clay	70	Reading Beds	51
Reading Beds	63		
To Chalk ...	143	To Chalk ...	144
Chalk with flints (original boring)	210	Chalk with flints about	234¾
Since deepened	67	Since deepened	41¼
	420		420

[53] From a report made by Mr. Sidney Harvey, F.C.S,, of Canterbury, to a meeting of the East Kent Natural History Society. I am indebted to Captain Gordon McDakin, of Canterbury, for calling my attention to this circumstance.

[54] From the Geological Survey Memoir, 48 S.W, Appendix I., by W. H. Dalton, and information supplied by Mr. Charles Clegg, C.E., Surveyor to the Borough.

[55] From the proofs of Memoir, 48 N, containing supplementary Essex well-sections; kindly furnished by Mr. W. Whitaker.

Previous to the earthquake the water-level had been gradually sinking, and the Committee had decided that a deepening of the wells would be necessary, when the shock came and caused a rise of 7 to 7½ feet, this increased level being maintained for about six months, after which Mr. Charles Clegg, C.E., the Borough surveyor, informed me that the level had fallen 4 feet 9 inches. Whether this fall indicates a permanent relapse to the pre-seismic or some lower level cannot at present be decided, as the long drought had caused a general falling off in the water supply throughout the country.[56]

All the other wells in the neighbourhood of Colchester were affected in a similar manner, but, as no systematic measurements are made, not much is known beyond the general fact that the shock caused a rise in the level of the water. At the Castle Brewery well the water is said to have returned to its former level in November. Mr. Stopes reports that at the Eagle Brewery the water level in the well was 22 feet below the surface before April 22nd, but after the shock it had risen to within 18 feet of the surface, and continued at that level till the end of August, 1884, since which no measurements have been taken. Both these wells are sunk into the Chalk, and sections are given in the Geological Survey Memoir, 48 S.W.

Messrs. S. Courtauld's well, Bocking.—This well, which is sunk into the Chalk to a depth of 241 feet, passes through the following beds[57]:—

[56] [At the time of preparing this section finally for publication (August, 1885) I hear from Mr. J. C. Shenstone, that out of 7 feet rise caused by the earthquake, nearly 5 feet had been lost last autumn, as reported above, and that at the present time (Aug. 10th), the water is only 2 feet above the pre-seismic level. How much of this sinking is due to the long drought cannot now be determined, but it seems that the water is gradually falling back to its old level.]

[57] Mem. Geol. Survey, vol. iv. 'The Geology of the London Basin,' Part i., pp. 433—434. By W. Whitaker. 1872.

Soil, &c.	7	feet.
London Clay	71½	,,
Reading Beds	77½	,,
Thanet Sand	28	,,
To Chalk	184	,,
Chalk	57	,,
	241	,,

The earthquake also caused a rise in the level of the water in this well, and as systematic measurements of the level have been taken weekly for some years past, it is possible to represent the effect in a more precise form. The readings are taken on Monday mornings (holidays excepted), and are given in inches above the surface to which the water rises. At the request of Mr. Sidney Courtauld, the following table was kindly supplied by Mr. D. Radford Sharpe, of Braintree, who takes these weekly measurements on behalf of the Underground Water Committee of the British Association:—

Height of water about time of earthquake, 1884.		Height of water for about the same period in 1883.	
March 3rd	13 inches.	March 5th	11½ inches.
,, 10th	16½ ,,	,, 12th	16 ,,
,, 17th	12 ,,	,, 19th	15 ,,
,, 24th	11½ ,,	,, 26th	19 ,,
,, 31st	14½ ,,	April 2nd	13 ,,
April 7th	15 ,,	,, 9th	12 ,,
,, 14th	12½ ,,	,, 16th	13½ ,,
,, 21st	12 ,,	,, 23rd	14½ ,,
,, 28th	31½ ,,	,, 30th	16 ,,
May 5th	42 ,,	May 7th	15 ,,
,, 12th	44 ,,	,, 15th	14 ,,
,, 19th	49 ,,	,, 21st	13 ,,
,, 26th	49 ,,	,, 28th	13½ ,,
June 3rd	57 ,,	June 4th	13 ,,
,, 9th	56½ ,,	,, 11th	12½ ,,
,, 16th	52 ,,	,, 18th	14 ,,

These results show that the earthquake caused a rise of 19½ inches, the rise increasing up to June 3rd, after which the level was falling. Some later measurements forwarded to me by Mr. Sharpe indicate that this increased level has, with

certain fluctuations, been maintained since April 22nd, a reading taken on December 15th giving a height of 42 inches.[58]

This effect of an earthquake shock in raising the level of subterranean water has not often been recorded, although such results must have frequently been observed in earthquake countries. A somewhat remarkable instance of the kind was caused by an earthquake which occurred in Connecticut on Aug. 10th, 1884:—

"At Rocky Glen, where all attempts to obtain water by digging wells had always failed, there has been an abundance of water since the occurrence of the earthquake. Previous to that all water used in the houses and greenhouses was brought from a long distance, necessitating much labour and expense. The stream has continued unabated in quantity and is of excellent quality."[59]

Numerous conjectures as to the cause of the rise of the water in these wells have been advanced, such as the collapse of subterranean reservoirs, general alteration in the level of the land, &c., but none of these appear to us to bear the test of critical examination. We are disposed to accept the explanation first offered by Mr. C. E. De Rance, F.G.S.,[60] Secretary to the Underground Water Committee of the British Association, *viz.*, that the shock caused a widening of the fissures through which the water circulates in its course down to the lower chalk beds, and thus, by an increased flow,

[58] Mr. Sharpe has been good enough to supply me with a graphical representation of these measurements on ruled paper, which shows the sudden rise between April 21st and 28th in a very striking manner.

[According to the latest report from Mr. Sharpe (Aug. 11th, 1885), the water here, as at Colchester, appears to be gradually falling, although it is still considerably above its old level. The readings (monthly) from Aug., 1884 to the present time are 54, 52½, 42, 42½, 42, 42, 44, 41½, 46, 44½, 40, 38½, and 39½ inches. Some of this fall is probably due to the small amount of rainfall during the last few months.]

[59] From the 'Danbury News'; recorded in the 'Monthly Weather Review' for Oct., 1884, published by the U. S. Signal Office; forwarded by Mr. G. J. Symons, F.R.S.

[60] 'Nature,' May 8th, 1884, p. 31.

gave rise to a general increase in level in these water-bearing beds, from which the wells derive their supply.[61] The gradual return of the water to its old level may indicate that the widened fissures are being filled up by the infiltration of solid matter, or that they are closing up by the slow settlement of the disturbed strata.

The Damage in connection with the Superficial Geology.

When an extensive tract of country is shaken by an earthquake, it might naturally be expected that the different formations on which the buildings stand would exert some influence in determining the distribution of the damage. Thus, on a damp coherent formation like clay, it seems probable that the vibrations would produce a greater effect upon buildings than if these were situated upon loose gravel, among which the energy of the vibrations would be dissipated by the numerous internal reflexions and refractions.[62] An instructive illustration of the nature of the ground in determining the propagation of the vibrations has been furnished by Mr. Thomas Royle, F.C.S., who informs me that in his laboratory at Silvertown, which stands upon clay over peat, a heavy locomotive passing along the railway at a distance of forty to fifty feet causes the building to vibrate sufficiently to dislodge the bottles from the shelves, whereas in neighbouring

[61] According to information subsequently furnished by Mr. F. H. Meggy, a spring which supplies the lake at Boreham House has since the earthquake only given half its former supply. A similar fact was mentioned to me by Mr. T. Taylor, M.R.C.S., with respect to a surface well at Bocking. It is possible that these facts may indicate that the water formerly derived from supra-cretaceous drainage now partly finds its way into the Chalk through the increased cretaceous drainage, but here, as before, this interpretation of the facts is complicated by the long prevalence of dry weather.

[62] According to the results recently obtained by Milne with artificial earthquakes, it appears that, "in soft, damp ground it is easy to produce vibrations of large amplitude and considerable duration; in loose, dry ground an explosion of dynamite yields a disturbance of large amplitude, but of short duration; while in soft rock it is difficult to produce a disturbance the amplitude of which is sufficiently great to be recorded on an ordinary seismograph."—'Nature,' June 4th, 1885, p. 114.

buildings on piles or concrete sunk down to the gravel this disturbance is not experienced.[63]

In cases where the materials composing the soil of an earthquake-shaken tract are of very different degrees of hardness and elasticity, it might be anticipated, and experience has shown, that differences in the amount of damage are displayed according to the situation of the buildings, vibrations of large amplitude and destructive "acceleration" in soft coherent materials being eased off and rendered harmless on reaching hard rock. To mention one or two instances:—The destruction caused by the Lisbon earthquake of 1755 is stated to have been confined to the Tertiary strata, and to have been most marked on the clay, not a building on the secondary limestone or basalt having been injured.[64] Again, in 1692, the earthquake which wrecked Port Royal, Jamaica, is said to have exerted its most violent action upon those portions of the town built upon newly-formed sand, the surviving buildings having been all upon the solid white limestone.[65] On the other hand, buildings situated on loose alluvial tufas suffered less during the Ischian earthquake of 1883 than those built directly on the solid tufa.[66]

Now it happens, in the case of the earthquake with which we are concerned in the present report, that there is no such marked difference in hardness and elasticity in the surface-formations. The whole area of damage is on London Clay, covered here and there with occasional patches of drift sands or gravels and alluvium, so that we have not for comparison such heterogeneous materials as clay and basalt or sand and limestone, but only clay and drift-formations, which, from a seismological point of view, differ but very little from clay in elasticity. It seemed likely, however, in view of the dynamical

[63] Mr. Royle, whose experience on the earthquake at West Ham has already been recorded (p. 115), compared the effects upon his house with those produced upon his laboratory at Silvertown by the passing of a locomotive.

[64] Lyell, on the authority of Mr. Sharpe, 'Principles of Geology,' vol. ii., p. 148.

[65] Geikie, on the authority of De la Beche, 'Text Book of Geology,' p. 268.

[66] H. J. Johnston-Lavis, Brit. Assoc. Rep. Southport, 1883, p. 501.

considerations which have just been advanced, that if any difference of effect resulted from the situation of the buildings on the drift or on the clay, that the maximum destruction would have occurred on the latter; and we were not surprised therefore, on arriving at Colchester, to find that many of the residents had formed the opinion that the chief damage was confined to the clay. Our own survey enabled us to fully confirm this belief that the maximum amount of destruction had occurred on the clay-areas, a conclusion in which we are supported by Mr. G. H. Kinahan, F.G.S., of the Geological Survey,[67] and Mr. William Cheetham,[68] who also visited the earthquake district.

But although it happens that the buildings chiefly affected were situated on the clay, as at Peldon and Abberton, a certain amount of damage occurred on the drift, as at West Mersea and Colchester, and on the alluvium at Wivenhoe. We are disposed to conclude that there is in fact no distinct evidence at present in favour of any differential action between the clay and the drift as regards their effects upon the vibrations, and that the greater destruction occurring on the former was a pure geological accident arising from the fact, for which there is a considerable amount of converging evidence, that the initial blow was given beneath the London Clay in the Peldon-Abberton district. The larger amount of destruction on the clay thus appears to be geological, and not simply dynamical; and the only question that can be legitimately raised is whether the damage would have been equal, greater, or less, if, with the same disturbance, the villages most seriously injured had been situated on a thick bed of drift. The answer to such questions as this will no doubt be

[67] Mr. Kinahan's notes on the earthquake have since been published in the 'Proc. of the Roy. Dublin Society' for 1884, p. 318. I will take the present opportunity of acknowledging the assistance wnich I have received from the map of the superficial Geology (W. H. Dalton's, 48, S.W.), prepared by Mr. Kinahan during his visit so as to show the distribution of the damage, and kindly placed at my disposal for the preparation of this report.

[68] Mr. Cheetham's paper was read before the Leeds Geological Association on October 30th, 1884, but has not yet been published. I am indebted to the author for having kindly allowed me to see his MSS.

given in the future, when further advances have been made in experimental seismology.

Effects of Free Margins, Boundaries, Topographical Situation, and other Details of Geological Structure.

Junctional Vibrations.—When an earthquake-wave passes from one formation into another of different elasticity, a portion of the wave is reflected at the surface bounding the two formations, and the remainder becomes refracted in accordance with the general laws of wave-motion. The shock thus tends to become exaggerated along such boundaries, owing to the interference of the direct and reflected waves; and as such reflexion is most likely to occur along the lines of junction of different geological formations, we propose for brevity to speak of these effects as the result of "junctional vibrations."

A careful examination of the geological map of the area of structural damage rather favours the view that the destructive effects may have been in some instances increased by the situation of buildings near the junction of clay with drift-sand or gravel, although this part of the subject is surrounded by such difficulties that we by no means wish to put forward this statement as a positive assertion. It may, however, be pointed out that those portions of Colchester most severely visited are represented in the map as being situated on or near such junctions, and the same remark applies to Rowhedge and West Mersea. It is likewise possible to name numerous isolated buildings which may have suffered from the effects of junctional vibrations, but the evidence in such detached cases is of course less satisfactory than in the case of larger aggregations of houses. An attempt has been made also to connect the occurrence of the shock at the more distant stations with the situation of these places in reference to lines of junction, but the results are of a negative character. Some few towns and villages might be mentioned which, by their geological position, would favour the view that the shock experienced was the result of junctional vibrations, but their number is too small as compared with those stations far removed from lines of junction to warrant the assumption of any such

physical connection. Had such effects been produced, we might fairly have expected more numerous records from the various towns and villages situated all along the junction of the Tertiaries with the Chalk both north and south of the London Basin.

Marginal Vibrations. — When a large tract of country is shaken by an earthquake, the vibrations tend to make themselves felt with special distinctness along free margins, such as coast-lines, river-valleys, and lines of outcrop, because in these cases there is no resistance offered in one direction to the vibrating particles in their outward movements. The particles along such margins are in fact somewhat similarly situated to the last of a row of marbles placed in contact with one another, a blow delivered at one end of the series causing the last marble in the row to move outwards. The perception of a seismic disturbance at stations situated favourably with respect to the foregoing conditions may for brevity be ascribed to "marginal vibrations," although in the case of sea-coasts and river-valleys the effects may be in part due to reflexion and interference at the bounding surface of land and water, *i. e.*, to junctional vibrations. But although it may not be possible to discriminate precisely between these two effects at any particular station, it may be concluded generally that the disturbance is more likely to be felt at such marginal situations. This conclusion is in accordance with the laws of earthquake-motion, as will appear from the following considerations:—In spreading outwards from the *centrum*, the vibrations have to pass through the solid earth, the particles of which, owing to their constrained position, cannot oscillate with any degree of freedom till the surface-layer is reached. The motion is thus chiefly superficial, the maximum vertical displacement taking place at the *epicentrum*, where the greatest destruction occurs.[69] As the distance from the *epicentrum* increases the motion is chiefly horizontal, so that the condition of horizontal restraint here prevents the particles from

[69] Milne has found that at the bottom of a pit ten feet deep the motion during an earthquake of sufficient intensity to crack buildings was only one-fortieth of that at the surface.—'Nature,' July 16th, 1885, p. 261.

vibrating freely till some margin is reached where the shock may make itself felt for the reasons given, although but slight effects or none at all may be observed at intermediate stations. The resistance to horizontal movement which leads to the apparent exaggeration of the effect along free margins may be regarded as analogous to the resistance to vertical motion, which prevents the vibrations from producing any effect at or near the *epicentrum* till the surface-particles partake of the movement.

An examination into the records of former earthquakes in various parts of the world has convinced us that the tendency of the shock to make itself felt along sea-coasts and river-margins is a character of earthquake-movement which may fairly be ascribed to the foregoing conditions, although, with the exception of Milne,[70] our most indefatigable worker in seismology, no writer appears to have laid much stress upon this phase of the subject. As an illustration Milne refers to the earthquake of 1857, which affected the Alps from Geneva to the E.N.E. On reaching the edge of the deep glen between Zermatt and Visp the wave-movement caused large masses to be detached all along the margin, "and heavy falls of rock encumbered the western side of the valley." With reference to the Japanese earthquake of February 22nd, 1880, Milne states that in Yokohama, "out upon the flat ground in the settlement at a distance from the bluff, the destruction of chimneys was comparatively small, whilst at the foot of the bluff and upon the top of it there were but few buildings which had escaped. From the manner in which all the grave-stones lying near to the edge of steep declivities had been moved, whilst those which were further back were not disturbed, it seemed that it was near to the edge of the bluffs that the movement had been the most violent."

Without burdening this report with too many illustrations, we may refer to the memoir on the earthquakes of 1880 in the Island of Luzon, by Don José Centeno Y Garcia,[71] in which the author makes the following statement:—

[70] Trans. Seism. Soc. Japan. Vol. i., part. 2, p. 77.
[71] Trans. Seism. Soc. Japan. Vol. v., p. 55.

"In the first place, and as a general rule, it is worthy of notice that the greater part, if not all, the cracks which have opened in the ground, the upheavals of the surface, and even the depressions which have been observed in some places, have always taken place in the vicinity of rivers and estuaries (marshes) or the sea, ... and it may be set down as a general rule that the buildings situated in the immediate vicinity of these bodies of water suffered much more than those further away."

Mr. H. J. Johnston-Lavis has also called attention to the fact that during the earthquake at Ischia in 1883 "all the houses situated on the brink of a valley where the tufa was loose and incoherent, were in most cases quite destroyed from the fissures of an incipient or complete landslip."[72]

To give one other example, the earthquake which occurred in the West of England on October 6th, 1863, at Upton-on-Severn was "most violent in situations bordering on the river," and at Worcester, "in the streets nearest the river, the tremor appeared to be the greatest."[73]

With reference to the present earthquake there are numerous records which show that the shock may have been felt at many stations on account of their marginal situation. Thus Mr. E. A. Fitch, of Maldon, referring to the River Blackwater, described the effects "as though the shock followed the water," whilst in London the movement was especially distinct along the Strand, at Shadwell, and other places bordering the River Thames.

The area of structural damage offers along its coast-line nothing but alluvial flats and marshes, sloping very gradually down to the sea and to the numerous creeks and estuaries, thus rendering the physical features of this tract of country, which is devoid of any distinct line of outcrop or escarpment, most unfavourable for the observation of effects due to marginal vibrations. An examination into the records from the more distant places, where only the shock was felt, reveals, however, a certain preponderance of stations along lines of outcrop, and more especially along the escarpments

[72] Brit. Assoc. Rep. Southport, 1883, p. 501.

[73] 'Times,' Oct. 7th, 1863.

of the Cretaceous series, which favours the view that these places were shaken by marginal vibrations, reinforced possibly at some places by junctional vibrations. Thus, omitting Norfolk and Suffolk, where the precise western outcrops of the chalk and greensand appear to be somewhat doubtful, the shock was felt at Ely, Cambridge, Ashwell near Baldock, Masworth near Tring, Prince's Risborough, and Shirburn Castle near Watlington, all situated on or near Cretaceous outcrops.

The numerous records from places round the south and east coasts are also suggestive of the movement having been exaggerated at these stations, on account of their marginal situation. Thus the shock was felt at Portsmouth, Brighton, Eastbourne, Hastings, Dover, Westgate-on-Sea, Herne Bay, Whitstable, Sheerness, Shoeburyness, Southend, Bradwell-on-Sea (damage), Clacton-on-Sea, Walton-on-the-Naze, Harwich, Aldborough, Kirkley, Lowestoft, Gorleston, Lynn, Skegness, and other places on the Lincolnshire coast. (See map, Pl. III).[74]

The damage at Wivenhoe.—The large amount of damage at this place has already been described (p. 81), and may be further considered in connection with the geological aspects of the earthquake. That the damage here was excessive appears from the fact that at places to the S.W., equally distant from the focus (between Peldon and Abberton), the damage was comparatively slight, as at Salcot, Virley, and the Tolleshunts. Nothing certain is known of the details of structure of the deeper formations at Wivenhoe, and the

[74] To complete the idea of the effects of a free margin upon earthquake movement it will be instructive to take the following hypothetical case:—Imagine a large circular island of homogeneous geological structure with a town at the centre, a circular line of cliff round its coast, and villages scattered all over the island from the centre to the sea. If a seismic disturbance took place beneath the central town of just sufficient intensity to shatter the buildings, there would be, at a certain distance all round the *epicentrum*, a zone (A) of villages where the shock would be severely felt; outside this zone the shock would be less severe (zone B); and then again the villages round the coast would form a *marginal zone* (C), where the shock would be more strongly felt than in B, owing to the increased movement of the ground along the sea margin.

expression "fault line of the Colne Valley," made use of by Mr. Kinahan (p. 91), must only be taken in a general sense as referring to the break in the continuity of a formation caused by the excavation of a river valley through it. The village stands partly on alluvium, partly on London Clay, and partly on drift-sand and gravel, and it is possible that the damage was increased by junctional effects, as well as by the marginal situation of the buildings along the quay. But after allowing for these effects the damage still appeared to us to be greater than would have been expected from the situation of the village with respect to the centre of maximum action, and this, together with the circumstance that the damage towards the N.E. ended abruptly at Wivenhoe, led to the conclusion already expressed (p. 92), that the seismic wave may have undergone a large amount of reflexion at this place. In the absence of distinct evidence we cannot therefore connect the great destruction at Wivenhoe with any special geological conditions, but it may be suggested that the effects were purely mechanical, depending possibly upon the circumstance that the wave emerged along this valley at a critical angle with respect to the bounding surfaces of land and water.[75]

In connection with the present discussion of the damage at Wivenhoe, the apparent protection of some houses by the railway-cutting (see p. 86) may be here considered. The action of a trench in arresting earth vibrations has been observed by Milne and others. In some experiments conducted by Major Palmer, R.E.,[76] it was found that in a trench 8 ft. long and 8 ft. wide, dug in a coarse pebble-gravel 400 yards from a line of railway, a vessel of mercury was not thrown into vibration by the passage of a heavy goods train when the depth of the trench had reached 3½ ft. With respect to earthquake movement, Milne[77] has found that cuttings "are more or less effective in interrupting a disturbance." It is possible that in the present case the

[75] Mr. Whitaker has called my attention to the fact that at East Mersea the chalk was reached at a depth of only 115 feet (see p. 157), whilst at Colchester it is 144 feet from the surface. From the general

railway-cutting may have saved the buildings on each side by offering a break in the continuity of the ground, and thus preventing the free propagation of horizontal surface vibrations.

With reference to other details of geological structure, it has not been found possible to trace any distinct connection between lines of faulting and the distribution of the shock. The well-known fault which passes through Greenwich, for example, as far as can be ascertained, appears to have had no effect in modifying the disturbance. The relation of the main seismic axis to the known lines of faulting, &c., will be considered subsequently.

The connection between the main lines of jointing, the direction of coast-lines, and the occurrence of earthquakes is a branch of seismology to which special attention has been directed by Prof. J. P. O'Reilly,[78] but as we are in ignorance of the direction of the lines of jointing of the older rocks beneath Essex, it is difficult to apply these principles in the case of the present earthquake. It may be pointed out, however, that the direction of the main N.E.–S.W. axis of disturbance (p. 92) corresponds with the general direction of the coast-line at this place, a fact which is so far in accordance with the theory. In his earthquake map of the British Islands Prof. O'Reilly places the focus of the present disturbance on a great circle passing across England from the

southerly dip of the chalk it might have been expected that this formation would have been nearer the surface at Colchester than at E. Mersea; so that it is possible that there may be between these places a fault or some other disturbance bringing up the chalk abruptly. Whether such a disturbance exists, and, if so, whether it had any connection with the earthquake, cannot at present be decided.

[76] Trans. Seism. Soc. Japan, vol. iii., p. 148.

[77] 'Nature,' Oct. 26th, 1882, p. 629; also June 4th, 1885, p. 114.

[78] Proc. Roy. Irish Acad., vol. iii. (2nd ser.), pp. 295, 310, and 503; *ibid.*, vol. iv., p. 116; and 'Trans.,' vol. xxvi., pp. 611 and 641, and vol. xxviii., p. 285. The earthquake map of the British Islands above referred to accompanies this last memoir. Conclusions somewhat analogous to Prof. O'Reilly's have been arrived at by Richard Owen (Proc. Amer. Assoc. Montreal, 1882, p. 329).

north coast of Norfolk to Brighton, and through the following known earthquake and volcanic districts:—

Spain; Guadiana mouths.

France; mouth of Loire, St. Malo, Cherbourg Promontory.

Norway; valley of the River Tanie (volcanic).

Amur River, mouths.

Sagalin Islands; Jesso Island.

Solomon and Santa Cruz Islands; passes between these islands (volcanic).

New Caledonia (volcanic).

New Ulster (volcanic).

South Shetland (volcanic).

According to Mallet[79] the British Islands are not connected as a seismic region with Norway and Sweden, but the mean horizontal direction of our earthquakes "appears to be one from south to north, veering more or less to the east or west, but having on the whole a direction passing through the probable focus of the Lisbon earthquakes and of the Canary Islands." This direction corresponds rather with Professor O'Reilly's great circle passing through Kilkenny, the islands of Mull and Skye, and the eastern group of the Faroe Islands.

In concluding this portion of the geological report it must be pointed out that, as far as we have been able to ascertain, the earthquake has produced no perceptible alteration of level in the district most affected. Although no measurements have been undertaken with the object of taking the levels by the bench-marks, it is almost certain that any change of level, if only to a slight extent, would have been detected along the coast, which is intersected by numerous creeks, and is frequented by a maritime population accustomed to watch every movement of the tides.

Propagation of the Shock along the Older Rocks.

The velocity of propagation of earthquake movement depends, as has already been shown (p. 39), upon the elasticity of the rock material, and on the occasion of the

[79] Brit. Assoc. Rep. Leeds, 1858, pp. 3 and 6.

present earthquake geologists naturally called attention[80] to the older, harder, and more elastic rocks which underlie the newer and softer formations of this country. In suggesting that some kind of connection might exist between the distribution of the shock and the presence of the older rocks near the surface at any place, it is not intended to convey the impression that these older formations are in any way concerned with the *production* of the earthquake; of such casual connection there is at present no evidence, chiefly owing to the great difficulty attending the determination of the depth of origin of earthquakes. The connection suggested is in fact a purely mechanical one, depending upon the superior conductivity of the older rocks; or, in other words, in passing through such a material as clay more heat is developed, and the mechanical vibrations die out more rapidly than when a series of seismic waves traverse a stratum of hard crystalline rock.

After carefully considering all the facts available we think that it may be safely concluded that the westward extension of the shock was as it were exaggerated by the spreading of the older rocks in this direction. The connection in question is not, however, very clearly defined,—a fact which is not surprising when it is considered how slight were the effects towards the extreme limits of the disturbance—and can only be shown by a special method of treatment, which to many may appear arbitrary, but which, we are convinced, reveals a real physical connection between the extension of the harder rocks and the distribution of the disturbance.

In presenting the facts necessary for the present discussion it will perhaps be most instructive in the first place to give broadly the extreme western limits of the shock, because it happens that in this direction the older rocks come nearer to or actually crop out at the surface. Thus there are records from :—

[80] W. Topley, F.G.S., in 'Nature,' May 1st, 1884, p. 17; and Map, *ibid.*, May 15th, p. 61. See also a letter by "Seismos" in the 'Standard' of April 26th, 1884; and J. E. Taylor, F.G.S., in 'Hardwicke's Science Gossip,' June 1884, p. 122.

Cheshire, on the Trias.
Derbyshire, on the Trias and Carboniferous.
Leicestershire, on the Lias.
Staffordshire, near the junction of the Carboniferous and Permian.
Warwickshire, on the Trias and Lias.
Worcestershire, on the Trias.
Northamptonshire, on the Lias and Oolite.
Gloucestershire, on the Trias and Lias.
Somersetshire, on the Lias.
Devonshire, near the junction of the Carboniferous and Triassic.

Towards these western limits, on the view that the shock was spread in this direction along the underlying hard rocks, it might thus be expected that there would be more numerous records from localities where the older rocks come to the surface than from districts where great thicknesses of softer formations overlie these harder rocks. The geological structure of that portion of England over which the shock extended favours in a perfectly legitimate manner such a comparison as is here required, and the records thus compared, although the fair estimation of the facts has been a matter of considerable difficulty, show a large preponderance from the older geological districts, as will appear from the following analysis of the evidence:—

If the boundary of the Cretaceous formations be laid down on a map of England (see Map, Pl. III.), an irregular line will be shown, having a general direction N.E.—S.W., and extending from the corner of the Wash to the Bill of Portland, this boundary dividing the seismic area into two portions, one lying to the N.W. and the other to the S.E. The formations in the latter portion consist broadly of Chalk and the overlying soft Tertiaries, while the formations in the N.W. area consist of Triassic, Liassic and Oolitic strata, together with hard, crystalline, Palæozoic rocks. The rock materials of the N.W. area are thus on the whole harder and more conductive than the softer chalk and clay of the S.E. area, and it might therefore be expected that the vibrations would die out more rapidly in a S.W. than in a N.W. direction.

The true conditions will be made plain by the following sections:—

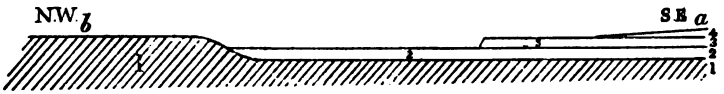

FIG. 14.—Imaginary section from Altrincham (*b*) to Peldon (*a*). Vertical heights not to scale. Horizontal scale approximately correct. 1, Palæozoic; 2, Oolitic-Triassic; 3, Cretaceous; 4, Tertiaries. Dip much exaggerated.

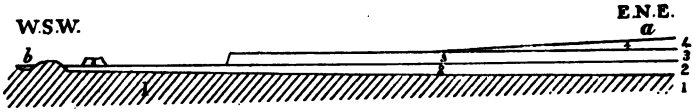

FIG. 15.—Imaginary section from Exeter (*b*) to Peldon (*a*). Vertical heights not to scale. Horizontal scale approximately correct. Dip much exaggerated. The numbers have the same meaning as in the last figure.

Before comparing the number of records from the two areas, it has been necessary to eliminate the effects of the direct shock, otherwise the large number of observations from places round the epicentrum would have given an overwhelming preponderance to the S.E. area. The disturbance having originated beneath the Tertiaries of the London basin, the fairest way of eliminating the records due to the direct vibrations[81] has appeared to us to take as a radius one of the extreme stations at which the shock was felt in the London basin, and with Peldon as a centre describing a circle with the given radius of about 86 miles, and passing through Reading. Outside this circle the two areas may fairly be compared, and a glance at the map will show that the records from the N.W. area are far more numerous. It will be of interest in the next place to consider these records in detail:—

[81] For remarks on the vibration of basin-like deposits resting on harder beds, see a paper by R. Mallet, "On the Dynamics of Earthquakes," Proc. Roy. Irish Acad., vol. xxi., part 1, 1846.

North-western area. Shock felt at—

1. Altrincham, Cheshire.—Keuper series; Carboniferous a few miles to N. and N.E.

2. Brassington, Derbyshire. — Yoredale Rocks; near junction of Lower and Upper Carboniferous.

3 and 4. Derby and Findern.—Keuper series; near outcrop of Upper Palæozoic.

5. Leicester.—Near junction of Triassic and Jurassic, Cambrian and Pre-Cambrian rocks of Charnwood Forest, a few miles to N.W.

6. Market Harborough, Leicestershire.—Lias.

7. Husband's Bosworth, Leicestershire.—Lias.

8. Ashby Parva, Leicestershire.—At junction of Lias and Trias. Old rocks a few miles to N.W.

9. Wolverhampton.—Lower Red; Bunter to W. and Coal-measures to E.

10. Sidbury, Shropshire.—Devonian over Carboniferous.

11. Birmingham.—Trias; Carboniferous and Permian a few miles to W.

12. Rugby.—Lias. Mr. Topley writes:—"Deep boring in Trias. Palæozoic rocks probably deep."

13. Leamington. — Trias. Mr. Topley states that the Palæozoic rocks are probably rather deep here.

14 and 15. Guildsborough and West Haddon, Northamptonshire.—Lower Oolite, near junction of Lias.

16 and 17. Watford Court and Weedon, Northamptonshire. —Lias.

18. Worcester.—Trias. Upper Silurian (Malvern Ridge), a few miles to W.

19. Banbury, Oxfordshire. — Lias; near junction with Lower Oolite.

20. Cheltenham, Gloucester.—Lias.

21. Bicester, Oxfordshire.—Lower Oolite.[82]

22. Oxford.—Middle Oolite.

23—25. Stroud, Dudbridge and Stonehouse.—Lias, near junction with Lower Oolite.

26. Bristol.—Trias. Carboniferous rocks in neighbourhood.

27. Street, Somersetshire.—Lias. Carboniferous rocks in neighbourhood.

28. Exeter.—Trias. Close to outcrop of Millstone Grit.

[82] The position of Bicester has been erroneously entered in the map (Pl. III.); it should have been outside the limiting circle.

South-eastern area. Shock felt at—

1. Sulhampstead, Berkshire.—Lower Eocene, near outcrop of Cretaceous.
2. Portsmouth.—Eocene, near Cretaceous.
3—5. E. Cowes, Ryde and Freshwater, Isle of Wight.—Eocene.

In the foregoing lists the superficial deposits have for the sake of simplicity been ignored and the deep formations only taken into consideration. This mode of treatment is justified by the fact that the greatest thicknesses of Drift formations overlie the country included within the circle.

The six extra-radial Lincolnshire stations have been omitted, because their position does not admit of their being fairly comprised within either area, and it is moreover possible that at some of these places the shock was felt on account of their marginal situation.

The records are thus 27 from the N.W. area as compared with 5 from the S.E. area, and of the latter every place but Sulhampstead is on the coast, and may have therefore experienced marginal effects. The complete absence of records from the great Cretaceous and Eocene areas of the south-west of England is certainly remarkable, when compared with the numerous records from the north-west. This absence of observations from the south-west cannot be ascribed to the want of large towns, since Winchester, Dorchester, Salisbury, Andover, Southampton, Chichester, &c., are all within this area.

The facts of the distribution of the shock appear to us therefore to favour the view that the disturbance spread more readily along the older (geological) portions of this country, and it will now be advisable, before proceeding to consider the special effects of the Palæozoic rocks, to anticipate certain objections which may fairly be raised against the present mode of treatment.

In the first place it may be objected that the 86-mile radius is quite arbitrary, and that some other circle might have been equally well taken as a boundary. In so far as it

is impossible to determine the true limits of the disturbance for each formation this objection is perfectly valid: it is not possible, for instance, to say where the sensible vibrations died out in the clay and were continued in the chalk, or where they ceased to affect the latter and were propagated along the subjacent harder rocks. If indeed it were possible to map out the actual limits of the sensible shock for each of the superficial formations over which it extended, we should certainly not have a set of concentric circles, but a series of curves of much greater complexity.

Although the position assigned to the limiting circle may thus appear arbitrary, it was obviously necessary to exclude a sufficiently extended area round the focus of the disturbance to clear the records from the effects of the direct shock as propagated horizontally along the Tertiaries and Chalk for a certain distance round this centre, and the radius taken appeared to fulfil this condition. It seems indeed that at about ninety miles from the epicentrum the sensible vibrations died out in the clays and gravels of the London Basin, and as the conductivity of chalk is probably not very different from that of clay the circle shown in the map may be considered to indicate the limits to which the shock would have extended if the whole of this country had been composed of homogeneous clay or chalk.

Any importance which may still be attached to the objection now being considered will, however, disappear on further examination of the facts. It will be seen that the radius may be increased or diminished by many miles—such, for instance, as by being made to end at the extreme apex of the London Tertiaries as an outward limit, or by terminating at Kew as an inward limit,—and the preponderance of records from the north-western area still remains. It has not been thought desirable to burden this report with a detailed justification of these statements, as their truth can easily be tested by means of the map (Plate III.).

One other objection which may be offered is that some of the stations in the N.W. area are not situated on rocks of any great degree of hardness, but on softer beds of the Lower

Secondary strata. It may be pointed out, however, that the mode of treatment adopted is a purely statistical one, the whole of the sub-Cretaceous rocks being "lumped" for the purposes of the present comparison, because these are, *as a whole*, harder than the overlying beds. The few stations on the N.W. area which happen to be on softer formations do not therefore materially affect the comparison, and in nearly all cases the Palæozoic rocks—the hardest and most elastic of all rock materials—lie at no very great depth beneath the surface. The superior conductivity of these last rocks appears also to have exerted a distinct influence in spreading the shock widely round the centre in a manner which may now be considered :—

In considering the action of the older rocks as specially good conductors of the vibrations, it is assumed that these rocks underlie the whole of the seismic area, or, in other words, that the Palæozoic rocks which crop out at the north-west, west, and south-west of England, and in the north of France and Belgium, are in seismic and geological continuity. That such geological continuity exists was first surmised by the late Godwin-Austen in 1856, in a paper on the possible extension of the Coal-measures beneath the south-eastern parts of this country,[88] a view which receives ample support from the well-borings that have been made in the area under consideration. Thus the Palæozoic rocks have been proved to exist beneath Northampton; at Meux's Brewery, Tottenham Court Road, the Devonian rocks were reached at a depth of about 1066 feet; at Turnford (Cheshunt) a boring reaches the same formation at a depth of 980 feet; at Ware a boring 831·5 feet in depth reached Silurian rocks; and at Harwich carboniferous rocks were reached at a depth of 1025·5 feet. Of other borings in the London Basin, that at Kentish Town reached the Gault at a depth of 130·5 feet, and then passed through 188·5 feet of doubtful beds between the New Red series and the Carboniferous. The recent boring at Richmond (Surrey), at a depth of 1447 feet, terminated in red sandstone of Carboniferous or Old Red Sandstone age.

[88] Quart. Journ. Geol. Soc., vol. xii., p. 38.

Palæozoic rocks have been proved by boring also at Calais.[84] It may be safely admitted therefore that the Secondary and Tertiary formations of East Anglia rest on beds of harder materials, which are extensions of the older rocks of the West of England and of the Continent of Europe.

The action of the older rocks in spreading the shock is apparently shown by the circumstance that all the extreme stations are either on Palæozoic formations or very near the outcrop of these beds. This statement holds good in the case of Altrincham, the Derbyshire stations, Birmingham, Wolverhampton, Sidbury, Worcester, the Leicestershire stations,[85] Bristol, Street, and Exeter. It cannot of course be decided whether the vibrations at each of these stations were primary or secondary, *i. e.*, whether the place was shaken by the direct shock travelling along the primary rocks or by the waves transmitted through the Lower Secondary formations, or, again, by the vibrations communicated to the latter by the underlying Palæozoic bed. In places where a double shock was noticed it is possible, as has already been stated (p. 89), that both sets of vibrations may have made themselves felt in succession.

It may be useful, in dealing with this part of the subject, to consider a question of some interest which has been raised by geologists, *viz.*, whether the presence of hard rocks beneath any district can be inferred because the shock happened to be felt there. In reply to this it may be pointed out that, supposing we have a record from a station which is fairly beyond the radius where the energy of the primary vibrations may be supposed to have been spent in the softer rocks, the

[84] At a depth of 1098 feet from the surface Palæozoic rocks (probably Coal-measures) were reached.

[85] It is of great interest to notice the crowded records from Northamptonshire and Leicestershire, inasmuch as these stations are directly in the line of the Palæozoic outcrops of Warwickshire and Staffordshire. The greatest seismic conductivity appears in fact to have been in this direction. If any weight is to be attached to the seismological evidence, it might be inferred that an especially hard ridge either of Primary or Lower Secondary rocks extends in a north-westerly direction from the focus. The decision on this point must be left to the stratigraphical geologist.

seismological evidence is by itself valueless unless combined with geological and topographical considerations, and even then much doubt must necessarily exist. Thus it cannot be decided whether the vibrations felt at Ostend and Boulogne[86] were transmitted along the Palæozoic ridge or along the overlying softer beds. Again, with respect to the Wealden area, although the Palæozoic rocks may by faults, folds, anticlinal ridges, or the thinning-away of superincumbent formations, be brought nearer the surface in some districts, and thus cause the shock to be felt, it would be very unsafe, in the absence of geological knowledge, to predict the presence of these rocks under such stations from the seismological evidence only. Thus the shock was felt, among other places in this area, at Tunbridge and Crowborough; but it would be rash to assume on these grounds the existence of a sub-Wealden Palæozoic ridge, inasmuch as the shock was felt all over the Chalk in Norfolk at a distance extending even further north of the focus than these Wealden stations are south of this point; so that if the vibrations travelled northwards through the Chalk as far as, let us say, Fakenham, there is no reason why they should not have been transmitted southwards through the Wealden beds for an equal or nearly equal distance.

Summary.—As the foregoing discussion of the evidence concerning the action of the older rocks in spreading the shock has necessarily been somewhat lengthy, it will be advantageous here to briefly summarise the results. The seismic area has been regarded as being constituted broadly of a shallow basin of Palæozoic rocks containing, in ascending order, beds of intermediate hardness (Lower Secondaries), overlaid in turn by the softer Upper Secondaries and Tertiaries. The initial blow having been struck beneath the latter, the damage was confined to the London Clay and superficial deposits, but the vibrations were spread widely by the under-

[86] The situation of these towns will probably suggest that marginal (littoral) effects were experienced. This may have been the case, but, if so, the above statement is not in any way affected, as it will be seen on consideration that the effect of a free margin would be the same whether the district were shaken by primary or secondary vibrations.

lying harder rocks. Keeping to the analogy of a basin, it may be said that the effects were spread to the rim by virtue of the superior conductivity of the material composing the basin. The Palæozoic rocks are thus not to be regarded as being *necessarily* concerned in the production of the earthquake. It has not been possible to discriminate between the effects transmitted by the Palæozoics and the Lower Secondaries—all that it is necessary to consider is that these two series are harder and more elastic than the Cretaceous and supra-Cretaceous formations.

It will be instructive, in concluding, to present the general results in another way. If we imagine the newer formations of East Anglia to be extended eastwards across the German Ocean to the same distance as Street or Bristol in the west, the older rocks remaining at their present depth below the Chalk at Harwich, the disturbance probably would not have had an eastward extension equal to its present westward extension. In the present case, for instance, no records have been received from Holland. If, again, we imagine the seat of the disturbance to be transferred to the west,—say, near Bristol,—it is improbable that the effects would have been felt as far eastwards as those of the present shock extended towards the west. In fact, the majority of the earthquakes in this country which are reported to have been spread over a very wide area appear to have originated towards or at the eastern parts of England. As an instance may be mentioned the eastern earthquake of 1185, by which Lincoln Cathedral was "rent from top to bottom," and which, according to Holinshed, was felt "through all the parts of this land." The 1480 earthquake, again, which caused structural damage at Norwich, extended widely throughout the country. On the other hand, the western earthquake of 1248, which wrecked the Cathedrals of Wells and St. David's, and which appears to have been of equal or greater intensity than the present one, did not extend to any great distance eastwards. In the light of the evidence furnished by the present earthquake, these and similar facts respecting the distribution of British earthquakes may perhaps be explained by the greater

elasticity of the harder rocks which dip under the newer formations of East Anglia.

Miscellaneous Geological Observations.

In the absence of any reliable method of determining the depth of the origin of the present disturbance, and in view of the necessarily speculative character of the explanations of earthquakes in general, it has not been deemed advisable to advance any distinct views with reference to the origin of the present shock. That the disturbance had no immediate connection with plutonic agencies appears probable from the remoteness of volcanic centres.[87] The district shaken is not marked by any great phenomena of upheaval, but the evidence, as far as it has been read, points to a slow rate of depression.[88] The most feasible explanation, in so far as it is safe to hazard any explanation at all, appears to be that of the sudden rupture of deep-seated rocks under a state of strain, the snap and shock accompanying such a fracture being quite competent to produce the effects observed.[89] The precise formation in which this rupture may have occurred cannot even be conjectured; but the great extent of the shock on the one hand, and on the other the absence of any perceptible change of surface-level, appears to point to a tolerably deep-seated origin.[90]

[87] As a result of the discussion of 387 earthquakes in North Japan, Milne concludes that the seismic activity in the immediate neighbourhood of active or recent volcanoes is but small, or, in other words, that the seismic and volcanic activity are not directly related (Trans. Seism. Soc. Japan, vol. vii., part 2, pp. 76—77).

[88] "Subsidence in East Essex," by W. H. Dalton., F.G.S. Geol. Mag., vol. iii., 1876, pp. 491—493.

[89] See Milne's Report on the Japanese Earthquake of February 22nd, 1880. Trans. Seism. Soc. Japan, vol. i., part 2, p. 59.

[90] It is much to be regretted that we have had no opportunity of ascertaining whether any change of level is indicated by the Ordnance bench-marks, but this measurement may be here commended to the attention of the Ordnance Survey Office. In a tract of country presenting such an indented coast-line as East Essex, and watched so constantly by an experienced maritime population of fishermen, yachtsmen, &c., it is certain, as already mentioned on p. 172, that any slight change of level would have been detected. Our closest inquiries have, however, only

Although the earthquake cannot be distinctly associated with any known fault or other subterranean disturbance of the strata, it is essential, in order to complete the present portion of the subject, to call attention to the nearest known disturbances, as the connection of these with the earthquake may with the advance of knowledge become revealed in the future. Thus Mr. W. H. Dalton has recently pointed out[91] the existence of an undulation and fault, throwing down the Chalk, Reading, and Thanet Beds to the north, underlying Tiptree Heath. Of this disturbance Mr. Dalton states:—

"Those who care to investigate the origin of the undulation described above may be interested in hearing that a parallel undulation has been noticed in the Chalk-ridge above Royston, with an outward north-westerly dip of 60°; and that the prolongation of the line of Tiptree Heath coincides, near Deptford, with a fault bringing up the Chalk through the Tertiaries, and, in the opposite direction, we have Chalk coming to the surface in an abnormal way at Shelly (near Hadleigh) and at Ipswich; whilst farther away, in Suffolk, other points of disturbance have been noticed along a line nearly coincident with the Yarmouth branch of the Great Eastern Railway."

The author expresses his belief that these disturbances are confined to the upper 1000 feet of the earth's surface, and are due to lateral pressure in the Chalk; and that the deeper seated Palæozoic rocks are not affected. The possible existence of another disturbance in the Chalk under East Mersea has already been mentioned (p. 170, note 73).

elicited the opinion that no such alteration occurred, and for this reason we cannot concur in the view expressed by some geologists, that the earthquake resulted from the production or extension of a fault in the London Clay, since a disturbance of the intensity of the present shock would, as it appears to us, have left some permanent superficial record under these circumstances.

[91] Trans. Essex Field Club, vol. ii., p. 15. In a recent paper by Searles V. Wood, the younger (Trans. Essex Field Club, vol. iv., p. 76), this author has expressed the view that the Tiptree Heath boring passed through an undulation and fold, instead of through a fault. The precise character of the disturbance does not, however, materially affect the question, although Mr. Dalton's explanation appears the more probable to us. The full discussion of this question belongs rather to pure Geology, and need not be entered into in the present report.

Without asserting that the present shock is actually connected with the extension of any of these faults in the Chalk, it may be pointed out, as a fact of possibly great significance, that the line connecting the Deptford and Tiptree Heath disturbances, if prolonged, runs parallel with, or even joins on to, the main axis of the East Anglian earthquake, which, as already stated (p. 92), extends in a N.E. to S.W. direction from Wivenhoe to Peldon.[92]

VII. Miscellaneous Concluding Observations.

The Angle of Emergence.

It has been made sufficiently clear in the preceding pages of this report that none of the methods by which modern seismologists are striving to arrive at a more exact knowledge of the nature of earthquake-motion are applicable in the case of the present disturbance. When going over the area of structural damage it soon became evident that the angles formed by the cracks in fractured buildings gave no reliable data for determining the angle of emergence by Mallet's method, even if we had entertained any ideas as to the trustworthiness of this method. It must be admitted, however, that the method in question is by no means satisfactory, being based entirely upon the supposition that the fracturing is caused by the normal wave only, a belief which, to say the least, requires verification. The damage caused to a building by an earthquake cannot be ascribed to such a simple impulse as is required by Mallet's treatment, but is rather the result of the racking and straining to which the structure is subjected on account of the want of synchronism in the vibrating periods of its different parts. This principle of "relative vibrational periods" is well illustrated by Milne in the following extract:—

[92] The conclusions arrived at respecting the propagation of the shock along the older rocks would not be affected should it be hereafter established that the disturbance actually originated in the Cretaceous beds. It must be borne in mind that an earthquake-centre is a focus from which vibrations are propagated outwards *in all directions*.

"If a building were constructed of a material like steel, we can imagine that it might be set rocking to and fro, which, if it were shaken by an earthquake, it might do in a manner something similar to that of an inverted pendulum, without any danger of its being broken. It would simply rock back and forth with a definite period of its own. In ordinary houses, however, instead of having a single vibration of the whole building to consider, we have to investigate the vibration of a number of parts, the periods of which are all more or less different. These parts, although they are tied together in various manners, owing to differences in elasticity, height, thickness, and load they carry, do not tend to synchronise in their swings. Whilst one portion of the building is endeavouring to move towards the right, another is pulling towards the left, and, in consequence, either the bonds which join them, or else they themselves are strained or broken."[93]

In accordance with this principle, a crack in a building has no necessary relation to the line of emergence of the seismic wave, and the actual inspection of the damaged buildings led us to conclude that any number of angles of emergence, from 90° to the horizontal, might be found from the cracks in the solid masonry of the buildings round the main axis of disturbance. The angles of some of the more conspicuous cracks have been given in the descriptive report, but, for the reasons stated, we have not thought it advisable to give any calculations of the depth of the origin of the disturbance, being convinced that under the present circumstances such determinations would only give a fictitious semblance of certainty to the results.[94]

[93] Trans. Seism. Soc. Japan, vol. i., part 2, p. 71. The principle of relative vibrational periods was first enunciated by my present colleagues, Profs. Perry and Ayrton, in a pamphlet on 'Structures in an Earthquake Country,' published at the Imperial College of Engineering, Japan, 1878.

[94] The difficulties attending the determination of the depth of origin of an earthquake are well illustrated by the wide limits within which the determinations vary, even when instrumental records have been obtained by a skilled observer. Thus Milne found that the angles of emergence of the Japanese earthquake of February 22nd, 1880, as given by observations at Tokio and Yokohama, were 1·5°, 6·25°, 10·5°, 11°, 18°, 31°, or 45°, these corresponding to depths of 0·3, 1·6, 2·8, 3·2, 5·3, 9·7, or 16 miles.

Determination of the Epicentrum.

Time Records. — If by means of accurate clocks scattered about an earthquake-area the precise time of the shock could be registered at a number of stations, it would be possible to trace the disturbance to a station towards which all the time-records would point as being the focus at which the earliest movement occurred, or, in other words, the epicentrum. On account of the great velocity of earthquake-movement it is, however, evident that such records would have to be made with extreme accuracy. Taking the mean radius of the present earthquake as 135 miles (p. 22), and assuming from Mallet's experiments that the velocity of transmission is 1000 feet per second (p. 38), the entire radius of 712,800 feet would be traversed by the wave in nearly twelve minutes. An examination into the most trustworthy of the time-observations indicates, however, that the movement spread with much greater velocity than this. If we take the velocity in clay-rock as determined by Messrs. Milne and Gray,[95] for transverse vibrations we have the following results :—

Velocity $= 254 \times 10^8$ centimetres per second = about 8000 to 9000 feet per second.

With this velocity the entire radius would be traversed in about 1¼ minutes. In the present case we have no trustworthy record from the extreme stations, the furthest record being from Ashby Parva, about 100 miles from the epicentrum, whilst the majority of observations to which any weight can be attached are from stations much nearer the centre of disturbance. The time-observations, to be of any use in determining the epicentrum, should therefore have been correct to within much less than 60 seconds, a degree of accuracy to which no ordinary clock is kept. It appears, indeed, that there is a greater divergence than this between the records from Greenwich and Kew Observatories (pp. 150

He rejects as improbable the 1st, 6th, and 7th of these angles, and thus limits the depth to from 1½ to 5 miles. Prof. Milne adds :—This calculation for the depth of the shock, it will be observed, depends on a certain vertical movement, which was registered. *If this vertical motion is due to transverse vibrations, the calculation is valueless.*

[95] Phil. Mag., Nov. 1881, p. 365.

and 152), the former giving 9 h. 20 m. and the latter 9 h. 17 or 18 m.[96]

The accuracy necessary for determining the epicentrum by means of time-records can in fact be only attained by carefully regulated clocks, of which the error can be frequently determined by electric comparison with some standard timepiece or by the transit instrument as used in ordinary astronomical work. Even in such cases a slight error may be introduced in the absence of seismograph records, owing to different phases of the same shock being timed at different stations, instead of the same phase of the earthquake-motion. From the requirements thus shown to be necessary for exact observation in this branch of seismology, it is evident that it would be useless to make use of the present records for determining the origin of the disturbance with any precision; but it will nevertheless be of interest to give these observations, since a certain amount of information can be derived from them.[97]

The following list contains all the records which appear to be trustworthy; mere estimates as to the probable time or statements that the shock occurred "about" a certain time have, except in special instances, been neglected:—

1. Colchester .....9 h. 18 m. Mr. Hill's large regulator (p. 46).
2. Do. .....9 h. 20 m. Mr. Aberdein's 3 clocks (p. 49).
3. Do. .....9 h. 20 m. (nearly). Mr. W. Marriage's 3 clocks (p. 52)
4. Do. .....9 h. 20 m. Rev. Dr. Manning, St. Leonard's Rectory
5. Birch .....9 h. 20 m. (precisely). Mr. J. Wilkins (p. 58). [(p. 52).
6. Gt. Wigborough..9 h. 17 m. Rev. F. Watson (p. 72).
7. West Mersea....9 h. 18 m. Observed at White Hart Inn (p. 75).
8. Do. ....9 h. 15 m. Observed in School-room (p. 76).

[96] The Kew record is erroneously printed in the text (p. 152) as 9 h. 17 m. 18 s., instead of 9 h. 17 or 18 m. Mr. G. M. Whipple, the Superintendent of the Observatory, informs me that neither the Greenwich magnetograph nor their own is adapted for recording the time of the shock with the necessary degree of accuracy for seismological treatment. The time-scale of the Greenwich instrument is 14 mm., and that of the Kew instrument 16 mm. to the hour, so that the difference of 2 m. between the records is only about ¼ mm. on the scales, while the spot of light is more than a millimetre wide in both instruments.

[97] The methods of employing time-data for determining the origin will be found fully described in Milne's papers (Trans. Seism. Soc. Japan, vol. ii., p. 69; vol. iii., p. 132; and vol. vii., pp. 1 *et seq.*).

9. Wivenhoe .....9 h. 18 m. Post-office (Greenwich time), Mr. J. E. Wilkins (p. 86).
10. Ardleigh.....9 h. 17 m. (as nearly as possible). Mr. D. E. Cardinall
11. Bocking .....9 h. 18 m. (G.M.T.). Mr. E. B. Knobel (p. 95). [(p. 94).
12. Buckhurst Hill ..9 h. 18 m. 15 s. (+ 45 to 75 s.). Mr. E. H. Bailey (p. 97).
13. Chelmsford ....9 h. 18 m. (?). Mr. R. J. Lawrence (p. 98).
14. Coggeshall.....9 h. 20 m. (?). Mr. G. F. Beaumont (p. 100).
15. Dedham.....9 h. 18 m. Mr. R. T. Cobbold (p. 101). [(p. 101).
16. Dunmow .....9 h. 20 m. (Greenwich time). Rev. A. B. B. Wright
17. Great Baddow ..9 h. 18 m. 30 s. (± 1 m.). Mr. H. Corder (p. 103).
18. Do. ..9 h. 20 m. Mr. J. Brittain Pash (p. 103).
19. Gosfield Hall....9 h. 23 m. Col. A. S. H. Lowe (p. 104).
20. Kelvedon .....9 h. 20 m. Mr. E. G. Varenne (p. 106).
21. Latchingdon ....9 h. 20 m. (2 clocks). Mr. E. A. Fitch (p. 106).
22. Little Waltham..9 h. 20 m. Mr. A. Goodchild (p. 107). [(p. 108).
23. Maldon .....9 h. 17 m. (about). Observation at Old Star Inn
24. Do. .....9 h. 20 m. (2 clocks). Mr. Float (p. 108).
25. Manningtree ....9 h. 18 m. Railway-station clock, Mr. Pinner (p. 109)
26. Romford .....9 h. 20 m. M. Kate Robinson (p. 110). [(p. 112).
27. Stebbing.....9 h. 18 m. (Greenwich time). Rev. A. B. B. Wright
28. Walton-on-Naze..9 h. 20 m. Mr. P. Brannon (p. 114).
29. Wanstead .....9 h. 20 m. Mr. J. Cousens (p. 114).
30. Woodford .....9 h. 20 m. Mr. R. Letchford (p. 116).
31. Barham .....9 h. 18 m. (– a few seconds). Rev. E. Ledger (p. 117).
32. Beccles .....9 h. 20 m. Mr. E. T. Dowson (p. 117).
33. Groton Rectory..9 h. 20 m. Two clocks stopped (p. 118). [p. 118).
34. Bury St. Edmnds.9 h. 18 m. Plumpton House; Mrs. W. R. Bevan
35. Claydon .....9 h. 17 m. 45—55 s. (shock began between). Mr. G. J. Symons's report (p. 118).
36. Haughley .....9 h. 17 m. 50 s.—18 m. 10 s. (between). Mr. Symons's
37. Ipswich .....9 h. 18 m. Western part of town (p. 120). [report.[98]
38. Do. .....9 h. 18 m. 15 s. (termination of shock). Dr. H. J. Benham (p. 122).
39. Do. .....9 h. 18 m. Mr. J. E. Taylor (p. 123).
40. Long Melford ..9 h. 18 m. Hill House; Dr. C. R. Bree (p. 124).
41. Mettingham ....9 h. 20 m. Mr. E. T. Dowson (p. 124).
42. Wetherden.....9 h. 18 m. (Greenwich time; ± a few seconds). Rev. C. J. Goodhart (p. 125).
43. Norwich.....9 h. 18 m. (clock-error allowed for). Mr. D. D. Day (p. 127).
44. Ely .....9 h. 18 m. (Cathedral clock). Rev. F. W. Joy (p. 128).
45. Shirburn Castle..9 h. 20 m. Countess of Macclesfield (p. 130).
46. Ashby Parva ....9 h. 19 m. (G.M.T. ± 1 or 2 m.). W. C. Ley (p. 134).
47. London .....9 h. 19 m. (Westminster clock). Major Mainwaring Jones (p. 137).
48. Do. .....9 h. 19 m. 30 s. (corrected). Chapel Street; Hon. R. Abercromby (p. 137).
49. Do. .....9 h. 17 m. Inverness Terrace; Surgeon-Major Eatwell (p. 139).
50. Do. .....9 h. 18 m. Kildare Terrace; Major-Gen. Hutchinson (p. 139).
51. Do. .....9 h. 18 m. G. W. R. Station, Paddington (p. 139).
52. Do. .....9 h. 19 m. (G.M.T. ± 15 s.). Addison Road; Mr. W. R. Gady (p. 140).

[98] This record was inadvertently omitted in the descriptive report (p. 119).

53. London .....9 h. 17 m. (Railway time). Haverstock Hill; Mr. A. B. Woodd (p. 141).
54. Do. .....9 h. 20 m. (– 1 or 1½ m.). Leadenhall Street; Mr. E. Gellatly (p. 145).
55. Beckenham ....9 h. 20 m. Mr. J. Moore (p. 149).
56. Chislehurst ....9 h. 18 m. Mrs. A. Oldham (p. 149).
57. Greenwich .....9 h. 20 m. (Royal Observatory). Mr. W. Ellis (p. 150).
58. Kew Observatory..9 h. 17 or 18 m. (G.M.T.). Mr. G. M. Whipple (p. 152).
59. Lee .....9 h. 19 m. 30 s. Holly Bank, Burnt Ash Hill (p. 151).
60. Richmond .....9 h. 20 m. Mrs. Hertslet (p. 152).
61. Eastbourne ....9 h. 20 m. Mr. L. Dyer (p. 153).
62. Boulogne .....9 h. 20 m. 39 s. (G.M.T.). Mr. Symons's report (p. [154).

Of these records, the greatest weight attaches to Nos. 1, 5, 9, 11, 12, 16, 25, 27, 31, 34, 35, 36, 38, 42, 43, 48, 52, 57, 58, 59, and 62. The tendency to make the time exactly 9.20 is most probably due to the "personal equation" which causes most people to fix the time of an event at the nearest whole division of the hour. The disturbance probably occurred at the epicentrum between 9 h. 17 m. and 9 h. 18 m. G. M. T. Of the selected records, No. 35 gives the time within 10 seconds, and No. 36 within 20 seconds.

Velocity.—(*A.*) Assuming No. 35 to be correct, and taking the time of the shock at Claydon as 9 h. 17 m. 50 s., the disturbance reached Norwich, according to No. 43, at 9 h. 18 m., or in 10 seconds. The distance from Claydon to Norwich is 37 miles, giving a velocity of propagation of 19,536 feet per second.

(*B.*) The mean of all the London observations is about 9 h. 18 m. 25 s. (Nos. 47 to 54). Taking Peldon as a centre, and describing an isoseismal circle passing through London, the distance from this circle to Boulogne, measured along a line connecting Peldon and this last place, is 35 miles. This distance, assuming the correctness of the Boulogne record (No. 62), was traversed by the disturbance in 2 m. 14 s., giving a velocity of 1379 feet per second. If record No. 48 be taken as of the greatest weight, the time of propagation becomes 69 seconds, and the velocity 2678 feet per second. The mean of the two velocities is 2028·5 feet per second.

(*C.*) Assuming records Nos. 1 and 38 to be correct, the movement travelled from Colchester to Ipswich, a distance of about 17 miles, in 15 seconds, corresponding to a velocity of 5984 feet per second.

The mean velocity deduced from these three observations is, in round numbers, 9183 feet per second, the greatest divergence from the mean being 10,353 feet for the highest estimate and 7155 feet for the lowest estimate.

According to the results obtained by Milne,[99] with more precise time-data the velocities of propagation of an earthquake along different lines vary from 4500 to 10,000 feet per second. The mean result of 9183 feet is therefore a probable rough approximation to the true mean velocity of the present earthquake.

Although it is known that an earthquake travels from its origin in different directions with different velocities, the divergence in the results is far too great in the present case to be attributable to differences in the conductivity of the rocks along different lines, but is doubtless due to the errors in the time-records. With this wide divergence it has appeared to us useless to attempt to fix the origin by the method of circles or hyperbolas, as adopted by Milne.

Observations on Direction.—Although during an earthquake a particle at the surface of the earth may vibrate in many azimuths (p. 33), the disturbance as a whole has a general direction of propagation. If, therefore, the general direction of the motion could be determined at a number of stations round the epicentrum, the lines representing the directions would intersect at the latter point.[100] In the absence of seismograph tracings, the only data available for such a determination are the direction in which bodies are thrown or moved, the direction of swing of suspended objects, and the direction in which liquids are splashed. In making use

[99] Trans. Seism. Soc. Japan, vol. vii., p. 11.

[100] That is of course on the assumption that the general direction of propagation coincides with the direction of oscillation of the normal wave. It is by no means uncommon, however, for bodies at particular stations to be thrown into oscillation in a direction at right angles to the known direction of propagation, in which case it is probably the transverse wave which produces the effect noticed. Milne has observed that three instruments placed at the corners of a triangle, of which the sides were 800 feet in length, give *different diagrams* of the same earthquake, although when placed side by side their results agreed (Trans. Seism. Soc. Japan, vol. vii., part 2, p. 5).

of these last observations it is essential to bear in mind that the value of the observation decreases with the length of the interval that is allowed to elapse between the disturbance and the recording of the direction of swing, as it is well known that most objects when set swinging gradually shift their plane of vibration owing to the friction of their supports. In other words, it rarely happens that the direction of the initial impulse coincides with the direction of least friction between the suspending hook, &c., and the loop or other support from which the latter is suspended.

Observations respecting the projection of bodies have also to be interpreted with caution. The mere overthrow of an object is useless in determining direction, not only because the particular phase of the movement which causes any particular object to topple over may not coincide in direction with the general direction of propagation, but likewise because the mode of support or attachment, the form, position of centre of gravity, &c., of the body all conspire in determining the direction in which it falls.[101] It is only when a body is distinctly projected[102] that any weight can be

[101] See Prof. Perry's "Note on the rocking of a Column"; Trans. Seism. Soc. Japan, vol. iii., p. 103. The old form of seismometer, consisting of a number of upright cylinders of gradually diminishing size standing in two rows at right angles to each other, has been found by Milne to be practically useless for determining direction, the same earthquake having caused the columns to fall in various directions. Trans. Seism. Soc. Japan, vol. iii., pp. 46—52; and Phil. Mag., Nov. 1881, p. 357. See also Ewing's 'Earthquake Measurement,' p. 67.

[102] The determinations of the maximum velocity of displacement of an earthquake, by means of measurements of the projection and overthrow of bodies, are based upon the erroneous assumption that the movement is of the nature of a sudden jerk, and are therefore of but little value (See Ewing's 'Earthquake Measurement,' p. 75). In his latest Report to the British Association on Japanese Earthquakes, Milne states that—"(1) An earth particle usually reaches its maximum velocity during the first inward movement. A high velocity is, however, sometimes attained in the first outward semi-oscillation. (2) The intensity of an earthquake is best measured by its destructive power in overturning, shattering, or projecting various bodies. (3) The value,—

$$V^2 = \tfrac{1}{2} g \sqrt{a^2 + b^2} \times \left(\frac{1 - \cos.\ \theta}{\cos.^2 \theta}\right)$$

used by Mallet and other seismologists to express the velocity of shock as

attached to the observation, and even in this case it is impossible to decide from a single observation as to the direction from which the disturbance comes, since the object may be thrown either *towards* or *away from* the origin.

Bearing these preliminary statements in mind, we will now proceed to discuss such observations as appear to be of use, giving in the first place simply a list of the records:—

1. Colchester. Mr. J. B. Harvey's gaseliers apparently swung S.E.—N.W. (p. 46).
2. Colchester. Mr. J. C. Shenstone's chimneys cracked at base round N., E., and W. sides, and one of them displaced towards the S. The movement here apparently had a N. and S. direction (p. 47).
3. Colchester. Lamps and chandeliers at Messrs. Joslin's observed to swing N.N.E.—S.S.W. (approximately). Sides of iron bedsteads resting against a N. wall fell over towards S. (p. 48).
4. Colchester. Chimney displaced towards E., and plates and other articles fell towards the E. at Messrs. Hart and Fromant's. House standing on slope from W. to E. Movement of house apparently E. and W. (p. 50).
5. Colchester. The specimen card of shells in the Museum (p. 51) *may* have been moved by an impulse from the S. The other objects that were moved give no indication of direction.
6. Colchester. Wooden girder fell towards S. at Messrs. Davey, Paxman & Co.'s (p. 52).

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determined from the dimensions of a body which has been overturned, is a quantity not obtainable from an earthquake diagram. It represents the effect of a sudden impulse. (4) In an earthquake a body is overturned or shattered by an acceleration, f, which quantity is calculable for a body of definite dimensions. The quantity, f, as obtained from an earthquake diagram lies between $\frac{V}{t}$ and $\frac{V^2}{a}$, where V is the maximum velocity, t is the quarter-period, and a is the amplitude. (5) The initial velocity given in the formula $V^2 = \frac{2a^2}{b}$ (for horizontal projection) used by Mallet as identical with V^2 in (3), are not identical quantities. (6) In discussing the intensity of movement I have used the values $\frac{V^2}{a}$. (7) The intensity of an earthquake at first decreases rapidly as the disturbance radiates; subsequently it decreases more slowly. (8) A curve of intensities deduced from observations at a sufficient number of stations would furnish the means of approximately calculating an absolute value for the intensity of an earthquake."—'Nature,' Oct. 1st, 1885, p. 527.

7. Colchester. Heavy books thrown towards N. at St. Leonard's Rectory, Hythe (p. 52). Clock with pendulum swinging N.—S. started into action. Ornament thrown towards N., and candlestick moved towards S. (St. Mary's Rectory, p. 53).
8. Colchester. Spire of Lion Walk Congregational Church fell to N. 35° E. (p. 54). Fall of chimneys to S.W. preceded fall of spire (Dr. Wallace's report, p. 55).
9. Colchester. Clock and mirror at Broom Hill thrown towards W.S.W. (p. 56).
10. Birch. Clock with pendulum swinging E.—W. set going. 180 slates capable of falling E. or W. caused to rattle, but not thrown down (Mr. Joseph Wilkins's report, p. 59).
11. Layer-de-la-Haye. Two chimneys broken on E. sides; chests of drawers moved towards W.; books shifted towards E.; hall-lamp swung E. and W.; leaden cistern moved towards E.; milk splashed up E. sides of pans. Doors of clock-case thrown open towards W. (Mrs. Dennis's report, pp. 62—63).
12. Langenhoe. Chest of drawers moved towards N.N.E. (Rev. W. Parkinson's report, p. 65). Piano at Moor Farm moved by an impulse approximately E. and W. or N.E.—S.W. (Mr. G. J. Symons, p. 69).[108] Lamp fell towards E.S.E. (*Ibid.*, p. 69).
13. Peldon. Lamp-glass projected towards W.N.W. (Mr. G. J. Symons, p. 67).
14. Salcot. Milk spilt to N. and S. (Rev. E. Musselwhite, p. 74).
15. West Mersea. Mullion of church-window thrown W.S.W., and chimneys fell to S.W. (Mr. G. J. Symons, p. 74). Chimneys thrown towards N.N.E. (p. 76). Cracks at St. Peter's Well and Cross Farm had an E.—W. direction (pp. 76 and 77).
16. East Mersea. Damage to church indicated a movement N.W.—S.E. (Dr. H. C. Sorby, p. 78).
17. Old Heath. Chimney-crack apparently indicating a movement S.W.—N.E. (p. 81).
18. Wivenhoe. Mr. J. E. Wilkins's chimney and gable thrown towards S.W. (p. 84). Brickwork from four chimneys at Wivenhoe Hall thrown N.E.—S.W. (p. 87). Dr. Sorby's yacht apparently moved E. and W. (p. 91).
19. Bocking. Water in a tank caused to oscillate in a direction parallel with N.W. 4° W.—S.E. 4° E. (Mr. E. B. Knobel's report, p. 95). Iron plates and pendent gas-burners oscillated in a plane N.W.—S.E. (*Ibid.*, p. 96).
20. Chelmsford. Bundle of linen rocked S.S.W.—N.N.E.; workman on

[108] By constructing a diagram showing the position of the piano before and after the shock, it will be seen that the movement which caused the shift mentioned must have had a direction more or less E. and W., or between E. and W. and N.E.—S.W.

a third floor thrown towards E.N.E. (Mr. R. J. Lawrence's report, pp. 98 and 99). Piano moved towards S.W. (Mr. F. H. Meggy, p. 155).

21. Coggeshall. Stool rocked E.—W. (Mr. R. M. Kirkham, p. 100).
22. Copford. Milk oscillated N.E.—S.W. (Mr. H. Laver, p. 100).
23. Dedham. Door of book-case thrown open towards S.W.; bells on wall facing S.W. rung; bells on wall facing N.W. not rung. Movement here apparently N.E.—S.W. (Mr. R. T. Cobbold's report, p. 101).
24. Dunmow. Movement approximately N.W.—S.E. (Rev. A. B. B Wright's report, p. 101).
25. Felstead. Pendulous articles swung E.—W. (Mr. J. French's report, p. 102).
26. Great Wakering. Pictures on N. and S. walls moved, but not those on E. and W. walls (Mr. S. W. Poynter, p. 103).
27. Heybridge. T-square oscillated in plane E.N.E.—W.S.W. (Mr. H. Hurrell's report, p. 105).
28. Little Waltham. Picture swung E.—W.; screen against E. wall thrown down (Mr. A. Goodchild's report, p. 107).
29. Maldon. Articles apparently swung N. and S. (Mr. S. Stratford, p. 108).
30. Stanway. Mangle tilted N.E.—S.W. (Mr. H. Laver, p. 112).
31. Stebbing. Pictures moved N.W.—S.E. (Rev. A. B. B. Wright's report, p. 112).
32. Thorpe-le-Soken. Vines swayed E.—W. (Mr. J. Y. Watson, p. 113).
33. West Colne. Clock-pendulum swinging N.—S. started (Mr. C. P. Wood, p. 115).
34. West Ham. Lustre-pendants oscillated N.E.—S.W. (Mr. T. Royle's report, p. 116).
35. Wetherden. Movement S.E.—N.W. (Rev. C. J. Goodhart, p. 126).
36. Norwich. Movement N.—S. (Mr. D. D. Day's report, p. 127).
37. Cambridge. Water made to oscillate E.—W. (Mr. A. H. Waters, p. 128).
38. Ely. Movement apparently E.—W. (Rev. F. W. Joy's report, p. 128).
39. Masworth (Tring). Flower-pots rocked E.—W. (Rev. F. W. Ragg, p. 130).
40. Great Marlow. Picture swung towards S.W. (Mr. A. H. Cocks, p. 130).
41. London and environs. Bed-curtains swung N.N.E.—S.S.W. in Claverton Street (Rev. W. Linton Wilson's report, p. 137). Pictures swung E.—W. at Hereford Gardens (Mr. G. Pringle, p. 138). Rattling of ornaments at Haverstock Hill indicated a movement N. 11° E.—S. 11° W. (Mr. A. B. Woodd's report, p. 142). Chandelier swung E.—W. in Russell Square (p. 143). In Montague Street pictures moved N.—S. and E.—W. (Mr. C. F. Hayward's report, p. 143). Lustre-pendants swung N.—S. at Hackney Downs (Mr. J. Earl's report, p. 146). Book oscillated N.E.—S.W. at Northolt

(Lieut.-Col. Samson's report, p. 149). Movement at Kew approximately N.N.E.—S.S.W. (p. 152); at West Ham N.E.—S.W. (p. 116).
42. Minley Grange. Tea spilt to W. (Mrs. E. Wodehouse's report, p. 158).
43. Ostend. Bed oscillated N.W.—S.E. (Mr. O. Lodge's report, p. 155).

Before proceeding to discuss the foregoing observations, it must be remarked that their value is but slight from the point of view of the exact localisation of the origin, for the reasons already assigned. In cases where several records have been obtained from the same station, only the most important have therefore been selected. The records as given have in most instances referred only to the direction, without taking into consideration the point from which the disturbance came. This presents no difficulty, however, as the main axis of damage has already been localised (p. 92). It is obvious also that a body may be moved, as already stated, either *towards* or *away from* the origin by the same earthquake, but this does not affect the direction of the line of the movement. As the above observations are all more or less of a rough and ready character, and lacking the precision of instrumental records, the only way of treating them has appeared to us to give the mean direction[104] of the records where several are given from the same or neighbouring places. The directions thus found are entered in the map (Plate IV.), which shows at the same time the general distribution of the damage by depth of shading given by the size and proximity of the black dots. When isolated observations of direction bear no reference to the position of the known axis of disturbance, they have been neglected:—

Direction No. 1. Colchester.—Nos. 1, 3, and 7, as referring to swinging objects, appear to be of the most weight. No. 2 indicates a N.–S. movement, but may also have resulted from a movement many degrees E. or W. of N. and S. Nos. 4, 5, and 6 not sufficiently definite. No. 7 indicates an impulse from S.: the clock started shows a movement N.–S. No. 8 simply an overthrow.

Mean direction of Nos. 1, 2, 3, and 7:—N. 11° W.–S. 11° E.

[104] That is to say, the half distance (angular measure) between the two extremes.

Direction No. II. Birch and Layer-de-la-Haye. — No. 10 indicates a movement more or less E.–W., but not sufficiently definite. No. 11 (lamp swing) indicates more distinctly E.–W. movement.

Direction taken :—E.–W.

No. 12. Directions not sufficiently definite.

Direction No. III. Peldon. — Line of projection (No. 13), W.N.W.–E.S.E.

Direction taken :—W. 22° N.–E. 22° S.

No. 14 bears no reference to position of main axis. No. 15, mullion and chimneys probably cases of mere overthrow.

Direction No. IV. West Mersea.—Cracks in ground (No. 15) assumed to have opened at right angles to line of propagation.

Direction taken :—N.–S.

Nos. 16, 17, and 18 not sufficiently definite ; No. 18 much confused by reflexion. No. 19 prolonged falls quite outside area of damage, intersecting Direction No. I. just off Foulness and Direction No. IV. about two miles S.E. of Dengey ; both these positions improbable for epicentrum.

Direction No. V. Chelmsford.—Of No. 20 observations the rocking of the bundle of linen the most weighty. Passes through Abberton.

Direction taken :—N. 22° E.–S. 22° W.

No. 21, no observation of sufficient weight. In No. 22 the milk apparently oscillated *at right angles* to probable line of propagation (? transverse vibrations). No. 23 (taken as N.E.–S.W.) intersects Direction No. I. at Colchester ; this position for epicentrum improbable. No. 24 bears no relation to main axis.

Direction No. VI. Felstead. — No. 25 intersects Direction No. I. between E. and W. Donyland, and then passes through Wivenhoe (? reflected wave from that place).

Direction taken :—E.–W.

No. 26 intersects Direction No. VI. near Little Birch ; improbable epicentrum.

Direction No. VII. Heybridge.—No. 27, observation of great weight ; intersects Directions Nos. I. and IV. on each side of the Strood.

Direction taken :—E. 22·5° N.–W. 22·5° S.

Direction No. VIII. Little Waltham. — No. 28 intersects Directions Nos. I. and IV. at West Mersea.

The direction given by the swinging picture, E.–W., taken. Nos. 29 and 31 fall completely away from area of damage. No. 30 nearly at right angles to probable line of propagation (? transverse vibrations).

Direction No. IX. Thorpe-le-Soken.—No. 32, a direct continuation of No. VI. passing through Wivenhoe.

Direction taken:—E.–W.

Nos. 33 and 34 fall completely outside area of damage. Nos. 35 and 36 also fall away from area of damage, but directions given approximate to probable origin. Nos. 37 and 38 indicate origins in Suffolk, which are certainly incorrect.

Direction No. X. Maswortb.—No. 39 passes through Peldon.

Direction taken: E.–W.

No. 40 not sufficiently definite; gives origin in Norfolk. The London observations (No. 41) very conflicting; none of the directions given pass through area of damage. No. 42 bears no relation to main axis. No. 43 gives epicentrum in Suffolk, a little N. of Ipswich.

The ten directions entered in the map (Plate IV.) all depend upon fairly trustworthy observations, such as the swing of pendulous objects, the rocking of upright bodies, &c. As no observations of this character were made towards the S.E., so as to indicate the position of the epicentrum from this direction, we may be permitted to accept Dr. H. C. Sorby's estimate of the direction at East Mersea (p. 78), which, although founded on damage to buildings, agrees closely with the direction suggested by other considerations:—

Direction No. XI. East Mersea.—No. 16, as estimated by Dr. H. C. Sorby from damage to church (p. 78); passes through Langenhoe.

Direction taken:—N.W.–S.E.

The directions given converge towards the main axis of damage with as much accuracy as can be expected, considering the kind of observations which have been available.[105] It is of course possible that the blow may have been struck obliquely at some point under the German Ocean along a line at right angles to the origin given, but this seems improbable in the absence of any tidal disturbance. It is, moreover, certain that the origin was not a mere point, but a more or

[105] Owing to the necessarily rough character of these observations, it has been considered unnecessary to go to the trouble of inquiring in each case whether the direction given was compass-direction or true bearing.

less elongated line of disturbance. The observations summarised from the distribution of the damage (p. 92), combined with the eleven directions now given, confirm us in the belief that the N.E.–S.W. axis between Peldon and Abberton was the true line of disturbance.

Personal Experiences of Direction.—The mere impressions as to the direction from which the shock came, recorded by the various observers in the descriptive report, are of little value scientifically, and differ among themselves to such an extent that in the same town or village we found the inhabitants prepared to give almost every point of the compass as the true direction. With the knowledge of the probable direction of propagation at various stations as now indicated, it might perhaps be of interest to compare personal impressions with the supposed true direction, but want of space prevents us from undertaking such an analysis in the present report. Of the two recorded observations in which the actual passage of the earth-wave is said to have been witnessed, that at Colchester (p. 52) is unfortunately wanting in definiteness; but the statement that the wave travelled from S. to N. at Berechurch (p. 57) is fairly in accordance with the direction which might have been expected. Doubts have been expressed as to the possibility of the vertical displacement being sufficient to produce a visible wave, but, considering the softness of clay and drift, it seems not improbable that such a passage of the disturbance may have been witnessed, especially when traversing a meadow, where the grass-blades would assist the eye by magnifying the motion.[106]

Swaying of Buildings. — The observations of those who are reported to have seen the swaying of buildings do not appear to us to furnish any trustworthy information as to the general direction of propagation, although in some cases, as will be seen on reference to the descriptive report, the observed direction of swing corresponds with the expected direction of propagation. The same remarks which apply to

[106] "In soft ground vertical motion appears to be a free surface-wave, which outraces the horizontal component of motion." Milne's Report to the British Association at Aberdeen, 'Nature,' Oct. 1st, 1885, p. 527.

the swing of freely suspended objects are, however, applicable with even greater force to the present class of observations, and, when the general character of earthquake motion is borne in mind, it can no longer be expected that these observations would throw much light on the direction of propagation. There is, in fact, no reason for believing that the passage of an earth-wave, even supposing it to follow a rectilinear path, would necessarily cause every building to oscillate in the same plane, since the motion depends not only upon the direction of propagation of the wave, but likewise upon the position of the centre of displacement of the structure, to say nothing of the fact that the motion of the ground at any particular place may bear no relation to the general direction of propagation. Moreover, an observer looking at a building could not give an accurate statement of the direction in which it moved unless the plane of its oscillation happened to be *exactly at right angles to his line of sight:* if the plane of oscillation formed an angle with his visual direction the component of the motion in his line of view would either not be seen at all or else much underestimated. The only information of use would be furnished by an observer who could command a general bird's-eye view of a town or village, under which circumstances any prevailing direction of movement might be detected. It is stated, however, by a yacht captain at Wivenhoe, who happened to be high up on a ladder placed against the roof of his house, that the houses appeared rocking in various directions, "like a lot of boats during a gentle ground swell."

Order of Succession of Phenomena.—Some few observations have been given (pp. 61, 66, and 91), in which the direction of the passage of the wave has been inferred from the supposed order in which buildings were damaged, but such statements must be dismissed as of but little importance, since the experiences are not only in themselves contradictory, but, from the nature of the conditions, could hardly be expected to have been otherwise. Thus the actual time during which chimneys, &c., are falling is so exceedingly

short that it would be impossible to follow the course of the destruction along a village, especially when, as in all earthquakes, the event takes the inhabitants by surprise—in other words, the velocity of transmission is generally too great for the successive effects of the disturbance upon a number of houses huddled together to be discriminated. With a velocity of 9000 feet per second a village a mile long would be traversed in a little more than half a second, so that even with a clear view of this extent the observer would have to become impressed with the order in which the damage occurred within this interval. Such observations as those made at Wivenhoe (p. 91), in which case the observers were in the village itself and probably commanded an extent of view of much less than a mile, the destruction within their area of observation probably occurring in less than half a second, may therefore be disregarded. Where a long stretch of open country is under view, it is possible that the effects upon a distant village might be witnessed before the observer himself felt the shock, and the observations respecting the direction at Langenhoe (Mr. Parkinson, p. 66, and Mr. G. J. Symons, p. 71) appear to be worthy of further examination from this point of view.

According to Mr. Parkinson's statement, which need not be here repeated (see p. 66), the disturbance travelled from N.E. to S.W., the shock being felt on Fingringhoe Hill *before* Langenhoe Church was wrecked. According to the observation noted by Mr. Symons (p. 71), Langenhoe Church was wrecked *before* Peldon Mill was damaged, and this supports the previous observation that the disturbance travelled approximately from N.E. to S.W. If Mr. Symons's informant was correct in his observation, there is no escape from the conclusion that the wave actually travelled from the N.E., *i.e.*, from the neighbourhood of Wivenhoe, and *this would therefore be the reflected wave*, for the existence of which the evidence has already been given (pp. 91, 92, and 170; also Map, Plate IV.). If we admit, in accordance with this evidence, that Fingringhoe and Langenhoe were traversed by the reflected wave, the fact that Fingringhoe did not exhibit

the effects of such an intense action as Abberton and Peldon yet remains to be accounted for, and we can only offer the conjecture that Fingringhoe, being in the path of both the direct and reflected waves, *may have been an area of interference* in which the waves met in opposite phases, and to some extent neutralised each other's effects. On the other hand, at Langenhoe, further to the S.W., the phases of the waves may have coincided, and may thus have increased the destructive effects at that place. The same explanation will account also for the excessive destruction at Wivenhoe, if we suppose that at this place the direct and reflected waves coincided in phase.

So far the explanation offered appears to us to accord sufficiently well with the observed facts to warrant its acceptance as in some degree probable, but the complexity of the problem is too great for us to insist upon very great weight being attached to our interpretation. The difficulty in the case of Mr. Parkinson's observations is increased, as we have already hinted (p. 66), by the possibility of the observers having been unconsciously deceived as to the direction in the following manner :—

S.W. L F N.E.

In the above figure F represents the position of Fingringhoe and L that of Langenhoe. According to the experience of the observers the shock travelled from F to L, the distance between these points being about two miles. If we now suppose the general direction of propagation to have been the reverse, *i.e.*, from L to F (direct wave), the observer at F, looking towards the N.E., may have first experienced the preliminary tremors which, by throwing his body into oscillation, may have caused him to suppose that the ground in front of him was moving. The tremors would be succeeded by the shock-phase of the movement which in the present case caused the observer to turn round towards the S.W., where the dust arising from the damage to the church would have caught his eye, and at the same time he would notice the ruined tower, thus concluding that the effects witnessed

actually occurred at the moment when the church caught his glance, and that the movement consequently travelled from him *towards the church*. This counter explanation may at first sight appear somewhat strained, bnt we venture to think that it is sufficiently plausible and may be usefully introduced here, if only for the purpose of showing what great caution is necessary before coming to a decision as to the direction of propagation of an earthquake wave from such observations as have now been discussed.

From considerations similar to the foregoing we are disposed to believe that the accounts given as to the direction of propagation from the observed order of the destruction in the towns and villages are for the most part to be regarded rather as subjective interpretations of the phenomena than as records of their true succession. The houses within the range of vision are practically affected simultaneously, but when glancing rapidly, and in a state of alarm, at a number of falling chimneys, an observer would unconsciously imagine that the destruction had commenced at the place where his gaze happened to be directed at the instant, and as his eye glanced along, and he saw the continuation of the damage, he would erroneously conclude that he was following the actual course of the disturbance.

The Direction as given by Clock-stoppages.—On the supposition that a clock is more easily stopped by being tilted to and fro in a plane perpendicular to the plane of oscillation of its pendulum than in a plane parallel with that of the swing of its pendulum, it will be of interest to give the records which have been collected in the present report:—

Locality.	*Plane of oscillation of pendulum.*
Colchester	E.—W. (2 clocks), N.—S. (3 clocks). Mr. Millard, p. 46.
,,	N.—S. Bank, p. 46.
,,	S. 6° E.—N. 6° W. Mr. Hopwood, p. 46.
,,	E.—W. (6 clocks). Mr. Hill, p. 46.
,,	N.—S. Mr. Hildyard, p. 46.
,,	E.—W. Messrs. Joslin, p. 48.
,,	E.—W. Mr. Harwood, p. 48.
,,	N.E.—S.W. (3 clocks). Mr. Aberdein, p. 49.
,,	E.—W. Miss White, p. 49.
,,	E.—W. (2 or 3 clocks). Mr. Hart, p. 50.

Locality.	*Plane of oscillation of pendulum.*
Colchester	E.—W. (1 clock), N.—S. (2 clocks). Mr. Wilson Marriage, p. 52.
„	E.—W. Rev. F. Manning, p. 52.
„	W. 10° S.—E. 10° N. Post Office, p. 53.
„	W. 3° S.—E. 3° N. Mr. Johnson, p. 53.
„	E.—W. (1 clock), N.—S. (1 clock). St. Mary's Rectory, p. 53.
„	N.—S. St. Peter's Church, p. 54.
„	N.—S. (number of clocks not given). Rev. T. Cato, p. 55.
„	N.W.—S.E. (2 clocks). Mr. Harrington, p. 57.
Abberton	W. 18° S.—E. 18° N.; S. 5° E.—N. 5° W. Cottage, p. 61.
„	S. 17° W.—N. 17° E. Mr. Bawtree, p. 61.
Layer-de-la-Haye	E.—W. Mrs. Dennis, p. 63.
Langenhoe	S. 8° E.—N. 8° W., E.—W. Rectory, p. 65.
Salcot-Virley	N.—S. (number of clocks not given). Rev. E. Musselwhite, p. 74.
West Mersea	N.W.—S.E. White Hart Inn, p. 75.
„ „	N.W.—S.E. Schoolroom clock, p. 76.
Wivenhoe	N.—S. The Hall; Mr. Jackson, p. 88.
Althorne	N.E.—S.W. Mr. J. T. Rogers, p. 94.
Ardleigh	N.—S. Mr. T. Robinson, p. 94.
Bocking	N.E.—S.W. (2 clocks). Mr. E. B. Knobel, p. 96.
Buckhurst Hill	E.—W. Mr. E. H. Bailey, p. 97.
„ „	N.W.—S.E. Melrose Villa, p. 97.
Dedham	N.E.—S.W. Mr. R. T. Cobbold, p. 101.
Felstead	E.—W. Mr. J. French, p. 102.
Great Baddow	E.—W. (nearly). Mr. H. Corder, p. 103.
„ „	N.—S. Mr. J. B. Pash, p. 103.
Halstead	N.—S. (number of clocks not given). Col. Lowe, Gosfield Hall, p. 101.
Kelvedon	E.—W. Mr. E. G. Varenne, p. 106.
Latchingdon	E.—W. (2 clocks). Mr. E. A. Fitch, p. 106.
Maldon	N.—S. Old Star Inn, p. 108.
„	N.E.—S.W. (2 clocks). Mr. Eves, p. 108.
„	N.E.—S.W. (2 clocks). Mr. Float, p. 108.
Manningtree	E.—W. Station clock; Mr. Pinner, p. 109.
Rochford	E.—W. (2 clocks). Market Square, Mr. A. Wallis, p. 110.
„	N.—S. Board School, p. 110.
Southend	S.S.W.—N.N.E.—Royal Terrace, p. 111.
„	E.—W. (nearly). 3 clocks. Mr. H. Middleton.
Southminster	E.—W. (number of clocks not given). Mr. W. Page, p. 112.
Thorington	W. 35° N.—E. 35° S. The Parsonage, p. 113.
Walthamstow	E.—W. (3 clocks). Mr. David Howard, p. 114.
Wickham Bishops	E.—W. Rectory, p. 116.
Woodford	N.N.W.—S.S.E. Mrs. Dykes, p. 116.
„	E.—W. Mr. R. Letchford, p. 116.
Boxford	E.—W. (2 clocks). Groton Rectory, p. 118.
Ipswich	N.—S. (nearly). Mr. E. C. Gibbons, p. 122.
Kesgrave Hall	E.—W. P. 123.
Mettingham	E.—W. Mr. E. T. Dowson, p. 124.
London	N.—S. Mr. C. Shard, p. 138.
„	N.W.—S.E. Mr. G. J. Symons, p. 142.

Locality.	*Plane of oscillation of pendulum.*
London	N.—S. (nearly). Mr. E. Gellatly, p. 145.
,,	N.—S. Mr. A. Gerrard, p. 145.
,,	E.—W. (2 clocks). Mr. J. Spiller, p. 146.
,,	E.N.E.—W.S.W. Clapton; Mr. Ogden, p. 146.
Lee	E.—W. Burnt Ash Hill, p. 151.
Lewisham	N.W.—S.E. Mr. R. M'Lachlan, p. 151.
Richmond	E.—W. Mrs. Hertslet, p. 152.
Wimbledon	N.—S. Mr. L. J. Matow, p. 153.
Eastbourne	N. 13° W.—S. 10° E. Mr. L. Dyer, p. 153.
Isle of Wight	N.—S. Freshwater. Hon. Hallam Tennyson, p. 154.

Careful analysis of the foregoing records has convinced us that the data furnished by clock-stoppages are practically useless in determining the general direction of propagation. In but few cases do the perpendiculars to the planes of oscillation of the pendulum lead to the origin as determined by more trustworthy means. We are disposed to conclude from the evidence obtained that the stoppages of clocks are to be attributed rather to the local direction of the movement at the respective houses than to the general direction of propagation. To this source of uncertainty must also be added the different degrees of sensitiveness of the clocks according to the weight and mode of suspension of the pendulum, as well as the possibility of some clocks being even more readily stopped by an impulse coinciding in direction with the swing of their pendulums than by a movement perpendicular to this plane.

Twists of Chimneys.—Some observers have expressed views with reference to the general direction of propagation of an earthquake wave based upon observations of the direction in which chimneys, columns, &c., have been twisted by the shock. As many such instances of rotation were observed after the present earthquake, and have been recorded in the descriptive report,[107] it will be of interest to give in concluding some general considerations on this subject.

The twists observed in broken chimneys, &c., give such a strong impression of the displacement having been caused by actual rotation that many writers, both with reference to the present and to former earthquakes, have ascribed the

[107] Fig. 7, p. 70, is an excellent example.

phenomenon to a vorticose movement of the ground. In view of the complicated character of earthquake-motion as revealed by seismograph tracings, it seems not improbable that the rotation may in some cases be caused by such a twisting motion. Of the causes tending to produce vorticose motion may be mentioned the interference of direct and reflected waves moving transversely, the interference of the normal and transverse waves, &c.; but whatever cause may be the true one, it would be quite impossible to determine in such cases the direction of propagation from the direction of rotation of the chimney. It may here be pointed out that Mr. Kinahan's remark (p. 66, note) with reference to the chimney-twists at Langenhoe is fully in accordance with the conclusions at which we had arrived on other grounds (p. 202), *viz.*, that this place suffered by the interference of direct and reflected waves. At Wivenhoe, where the general direction appears to have been much confused, the chimney-twists may possibly have been also due to a vorticose movement.

But although a twisting motion of the ground may in some cases be admitted, it has been shown by Mallet (Proc. Roy. Irish Acad., vol. xxxi., part 1, 1846) that a simple rectilinear movement would be quite competent to produce the effects observed. Were this straight line motion the cause of the twists observed by us, it might have been expected, as pointed out by Milne,[108] that the rotation in the same locality would have been very frequently in opposite directions, as it is certain that the centre of friction could not be expected to bear the same relation to the centre of gravity in all chimneys. As we have already stated, however (p. 65, note 30), the effect of this opposite rotation was only occasionally observed during our visit of inspection, the majority of the chimneys in each district having been twisted in the same direction. It is probable, therefore, that a simple rectilinear movement played but a subordinate part in producing the twists observed after the present earthquake.

The best dynamical treatment of rotated columns, &c., that

[108] Trans. Seism. Soc. Japan, vol. i., part 2, p. 33.

we have been able to meet with is due to Mr. Thomas Gray, and as this mode of interpreting the results applies also to chimneys, we may here give the method in question, which will be found the more especially useful as Milne's paper, in which it was first published, is contained in a publication not readily procurable.[109]

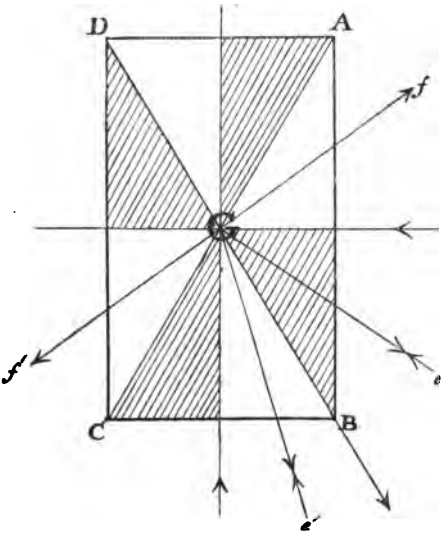


FIG. 16.—Gray's treatment of twisted columns.

In the above figure the basal section of the column is shown in plan, A, B, C, D. Shock at right angles to A B or C D would tend to tilt the object over on the edges A B or C D, according to the direction of the shock. Similar considerations obviously apply to shocks at right angles to A D, B C, and the corresponding edges. A shock in the direction of one of the diagonals, such as D B, would overturn the column on the corner B. If the shock has some intermediate direction, such as *e* G (G being the centre of gravity), the impulse may be supposed to be given towards *e*, and its effect would be to cause the body to bear heavily on B and at the same time to

[109] Trans. Seism. Soc. Japan, vol. i., part 2, p. 33.

rotate round B as an axis *in the direction of the hands of a watch, i. e.*, from right to left. If the direction of the shock had been along *e'* G, the rotation round B would have been *in the opposite direction, i. e.*, from left to right. We may also suppose G *e'* to be resolved into the two components, G B, G *f*, of which the former causes the column to bear heavily upon B, and the latter causes rotation round B. G *e* may also be resolved into the components G B, G *f'*, of which the latter causes revolution. Another way of stating these facts would be to regard the line of direction of the impulse, say from *f'* to *f*, and the perpendicular let fall upon it from A, as forming a couple having an arm A *f*, and causing the column to rotate from left to right, and so on for other directions.

From the foregoing considerations it will be evident that rectilinear impulses parallel with the sides or diagonals of a rectilinear column ought not to cause rotation. A shock having a direction passing through any of the *shaded* octants in the preceding figure would cause rotation from right to left, whereas if the line of direction passed through one of the *unshaded* octants the rotation would be in the opposite direction. Owing to the great instability of a chimney when tilted up on one of its corners, it is certain that a shock having a direction parallel or nearly parallel with one of the diagonals would cause rotation round the corner as an axis in one direction or the other. A shock parallel with one of the sides would probably cause displacement, either towards or away from the origin of the impulse. The chimneys at Colchester (p. 47) illustrate this effect.

It will now only be necessary to apply these considerations to a specific case of rotation produced by the present earthquake in order to justify the conclusion to which we have already given expression (p. 65, note 30), *viz.*, that the direction of rotation of chimneys is useless in determining the direction of propagation of the shock. Mr. J. E. Wilkins's square shaft at Wivenhoe (p. 85) was caused to rotate from right to left, so that the shock may have come from any point between N. & N.E., E. & S.E,, S. & S.W., or W. & N.W. It

is also possible, in accordance with the principles previously stated, that the shock may have been parallel with one of the diagonals, *i. e.*, N.–S., S.–N., E.–W., or W.–E. These conclusions, vague and useless as they appear to be, are based entirely upon the assumption that the impulse was rectilinear, and that the movement which twisted the chimney corresponded in direction with the general direction of propagation of the disturbance. But for neither of these assumptions is there any evidence—*the motion which caused the shaft to become dislocated and twisted may have been transverse to the line of propagation; there may have been an actual rotary motion of the ground, or the displacement may have been produced by the successive action of two shocks transverse to one another.*

VIII. General Summary.

We purpose, in concluding, to give here a general summary of the results, both positive and negative, to which we have been led in the course of the present report, in the hope that they may be found of use to observers in other local scientific societies, on those happily rare occasions when opportunities for such observations present themselves:—

1. The present earthquake is the most serious that has happened in the British Islands for about four centuries. The earthquake of 1580 may have approached it in intensity, but among previous records, neglecting those which appear to have been exaggerated, there are only about five shocks since the beginning of the 12th century which may have equalled or surpassed it in the amount of damage produced.
2. The county of Essex has, since the commencement of authentic history, been but rarely affected by seismic disturbances, and these only of the slightest character.
3. The sensible shock extended over an area of about 50,000 square miles.
4. The intensity of the shock was probably about one-twentieth that of the great Lisbon earthquake of 1755.

No data have been available for determining the maximum velocity of displacement.[110]

5. The earthquake occurred during a period of seismic activity which will probably be found to have been exceptionally great throughout the world.
6. No special meteorological conditions appear to have been connected with the disturbance.
7. In general character the movement of the ground during the present earthquake appears to have resembled that which has been registered by seismographs in Japan.
8. The duration of the shaking cannot be ascertained with precision, the estimate at different places varying between two and thirty seconds.
9. At many places, and especially at those some distance from the origin, two distinct series of vibrations were

[110] According to the scale of the Swiss Seismological Commission, the earthquake would be classed as a No. 8, or between 8 and 9. The Forel scale is as follows:—

1. Very faint; recorded by a single seismometer; noticed only by practised observers.
2. Registered on several seismometers of different construction; noticed by a few persons at rest.
3. Duration or direction noted; felt by a number of persons at rest.
4. Felt by persons while moving; shaking of movable objects, doors, windows; cracking of ceilings.
5. Felt by everyone; furniture shaken, and some bells rung.
6. Sleepers awakened; general bell-ringing, clocks stopped, visible swaying of trees; some persons ran out of buildings.
7. Overturning of loose objects; plaster falling, general fright; buildings not seriously injured.
8. Chimneys falling; walls cracked.
9. Partial or total destruction of buildings.
10. Great disasters; overturning rocks, forming fissures and mountain-slides.

M. Forel, who is one of the leading members of this Commission, writes of a severe earthquake as "ce beau tremblement de terre." Seismologists in this favoured country are fortunately not often required to pronounce judgment upon such a calamity as that which forms the subject of our report; but our earthquake will probably be looked upon by the Swiss Commissioners as a fairly "good case," although not entitled to take a front rank among such catastrophes.

felt. These may have marked the successive arrival of the disturbance, first through the harder rocks and then through the less elastic softer beds.

10. A distinct rumbling noise preceded the shock at most places round the origin, and slight rumblings were heard at some of the distant stations.
11. The seismic area was shaken by a previous shock on February 18th, 1884, and there may have been a slight succeeding shock on June 24th of the same year.
12. The usual concomitant effects of great earthquakes were experienced, such as the sudden blow given to ships, and the sensations of nausea felt by persons.
13. The number of buildings damaged by the shock was between 1200 and 1300, including 20 churches and 11 chapels.
14. The damage occurred in North-East Essex, within an area of fifty or sixty square miles. This localisation of the damage is probably due to the disturbance having originated beneath a clay area.
15. The main axis of damage had a general direction N.E.–S.W., extending from Wivenhoe to Peldon, with maxima of intensity at these two places.
16. No satisfactory evidence of the agitation of the water in rivers or the sea near the centre of the disturbance has been obtained.
17. The shock caused the water of many wells to become turbid for a short time, and also produced a rise in the level of the water in deep wells at Colchester and Bocking, this increased level having been maintained for many months, but afterwards apparently gradually falling.
18. In one locality (Cross Farm), where the soil just beneath the surface was saturated with water, the shock caused the spouting forth of temporary streamlets.
19. No perceptible change of surface-geology was produced by the shock, and no permanent alteration of level is known to have resulted therefrom. Slight cracks in the ground were opened in Mersea Island.

20. The chief damage occurred on the London Clay, a lesser amount of destruction having taken place on the drift and alluvium. There is no evidence to connect this different amount of damage with the nature of the ground, but it is probably due to the accidental circumstance that the initial blow was delivered below the London Clay.
21. At places near the origin the damage may in some instances have been caused or increased by the situation of the buildings at or near the junction of heterogeneous geological formations, such as clay and drift, clay and alluvium, &c.
22. The shock tended to make itself felt along free margins, such as river-valleys, lines of outcrop (especially the Cretaceous formations), and coast-lines.
23. The distribution of the shock does not appear to have been influenced by any known lines of geological faulting.
24. The general direction of the main axis of destruction corresponds with the general direction of the coast-line at this part of Essex.
25. The shock was probably spread widely round the origin and its extent exaggerated by the propagation of the vibrations along the better-conducting older rocks.
26. The main axis of destruction may possibly correspond in its direction with that of known lines of disturbance in the Chalk underlying Essex, Cambridgeshire, Suffolk, and, across the Thames, in Kent, but the evidence of such parallelism is not at present conclusive.
27. The seismic area is a region of slow subsidence. The earthquake cannot be referred to the immediate action of plutonic agencies.
28. The effects produced could have resulted from the rupture of deep-seated rocks under strain or pressure, such as the sudden production or extension of a line of faulting.
29. The observations made during and after the earthquake

furnish no data for determining the depth of the initial disturbance.

30. The shock occurred at the origin probably between 9.17 and 9.18 a.m. G. M. T., April 22nd, 1884.

31. Observations as to the time of the occurrence at different stations were not sufficiently accurate to have been made use of for determining the epicentrum.

32. The mean velocity of propagation of the shock, as deduced from the most trustworthy of the time-records, was about 9000 or 10,000 feet per second (nearly 7000 miles an hour). This calculation, owing to the uncertainty of the time-observations, must be regarded as only roughly approximative.

33. With reference to the general direction of propagation of the disturbance at different stations, the personal experiences of observers have not been considered sufficiently trustworthy evidence. The more important observations of the direction, as given by the swing of freely-suspended objects, the projection of bodies, &c., agree as fairly as might be expected in indicating an epicentrum coincident with the main axis of damage. The directions of propagation as deduced from the direction of twist in chimneys, and the plane of oscillation of the pendulums of clocks which were stopped by the shock, are of no value.

34. The shock probably originated beneath the villages of Abberton and Peldon, and apparently suffered a considerable amount of reflection at Wivenhoe.

Postscript.

The Earthquake recorded at Leeds.

While the foregoing report has been going through the press we have learnt, through a communication to the 'Leeds Mercury,' that the shock recorded itself in that town on the tracing-paper of a recording barometer, although, as far as we have been able to ascertain, the movement itself was not perceived by anyone. The following is the communication in question :—

"Having examined the diagram traced by our recording barometer to-day [April 22nd, 1884], we find that between 9.15 and 9.30 a.m. the ink-line thickened suddenly, whilst a general movement downwards is shown. A thickened line continued to be produced until 1.30 p.m., when the tracing regained its usual character. During this period of four hours six distinct undulations of the line are registered, the greatest of which measures ·025 in.—Reynolds and Branson."

As Leeds is about 171 miles from the focus, this observation is of the greatest interest; and on communicating with Messrs. Reynolds and Branson, this firm was good enough to forward the tracing, with an explanatory letter in which they state that the instrument was not observed till late in the afternoon, as they did not hear of the Essex earthquake before that time. It appears that the air-wave produced by the Krakatoa eruption of 1883 (see p. 27) was recorded by the Leeds barograph, as it was by similar instruments all round the globe,[111] and this led to the examination of the tracing on the present occasion.

An inspection of the tracing forwarded by our correspondents fully bears out this statement, the "wobbling" of the pen (or tracing-paper) having produced a series of six indentations in the line, of which the maximum and last was traced about 1 p.m. This result is of great importance from a seismological point of view, and we may take the present opportunity of pointing out its significance.

As an earthquake-disturbance spreads outwards from its origin, the vibrations become longer in wave-length and period, and decrease in amplitude, so that the short and rapid movements which cause damage at the focus become slow, wave-like pulsations of the ground at great distances from the focus. The slow oscillations thus produced at a distance from all great earthquake-centres may be aptly compared to the "after swell" observed upon a coast after a distant storm at sea, the movements caused by distant earthquakes generally revealing themselves only by the oscillation of the water in ponds, lakes, &c, The effects of the great Lisbon earthquake of 1755 upon the inland waters of this country

[111] See papers by R. H. Scott and Gen. R. Strachey, Proc. Roy. Soc., vol. xxxvi., pp. 139 and 143.

were doubtless due to such a slow surging of the solid ground (see pp. 14 and 180 of this report). That the undulations in the Leeds tracing were not due to atmospheric disturbances appears almost certain, both from the character of the indentations as well as from the fact that no other barograph has recorded them. On the other hand, it is not at all improbable that the Leeds instrument may, by its construction, be particularly sensitive to earth-shakes. It is of interest to consider, in connection with the present report, that the disturbance originating beneath our county was sufficiently intense to cause the ground 170 miles away to be tilted slowly to and fro for a period of four hours after the event.[112]

Displacement of the Equatorial in the Observatory, Crowborough, Sussex.

On November 19th of the present year, just as this last sheet was going to press, I received a letter from Mr. G. J. Symons, who was staying with Mr. C. L. Prince at Crowborough, requesting me to come down and inspect the equatorial telescope, which had been shifted on its base by the earthquake of last year. The Crowborough Observatory, which I visited on November 21st, is built on to the S.W. side of Mr. Prince's house, and has the form shown in the accompanying plan (Fig. 17), the walls being of massive brick and stone-work twenty inches in thickness.

The telescope itself is a 7-inch equatorial, resting on a triangular base, the whole instrument weighing more than a ton. The triangular base is not fixed, but rests by the whole weight of the instrument upon three piers, A, B, and C, the former being stone and the latter hard wood. The piers A

[112] One of the most recent instances of earth-tremors caused by a remote earthquake has been communicated to the Meteorological Society of Berlin by Dr. Börsch, who states that on August 2nd, when determining the longitude between Berlin, Breslau, and Königsberg, the level of the transit-instrument was so disturbed that the observations had to be discontinued. Inquiries at Breslau and Königsberg showed that the same disturbance had been experienced at both places. The oscillations were coincident with violent earthquakes in the interior of Asia.—'Nature,' Nov. 19, 1885. p, 72.

and B are cemented down to the timber balk, T T, which is about one foot square, and passes at each end into the wall of the Observatory, where it is firmly bricked in. The pier, C, rests upon, but is not fixed to, a similar balk, T′ T′, which runs as shown in the plan. Through the kindness of Mr. Prince we are enabled to give a figure of the instrument (fig. 18).

The three piers, A, B, and C, pass through holes cut through the boarding of the floor, of such a size as to allow the piers to be free from contact with the floor at any point. The height from the surface of the ground to the top of the stone slabs, A, B, is 34 feet, and the height of the piers above Ordnance datum is 822 feet, the Observatory being situated

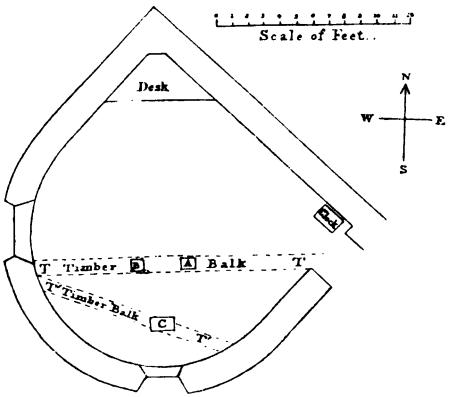


FIG. 17.—Plan of Crowborough Observatory.

on a hill 788 feet above Ordnance datum. The triangular base of the telescope rests on the piers upon three points; at A there is a conical metallic "leg" on the under side, and forming part of the base, this cone resting with its apex downwards in a depression in the stone slab; at B and C the base is supported by levelling-screws. At C the triangular base is provided with screws capable of moving the instrument in azimuth.

For twelve years this telescope had stood in this position without getting out of adjustment, and had occasionally been used after the earthquake for ordinary observations, without

anything wrong having been detected. About two months after the shock Mr. Prince had occasion to search for the planet Mercury in the usual way, by means of the position-circles. To his surprise the planet did not appear in the field after the necessary position had been secured, and he

Fig. 18.—The Crowborough Equatorial.

then searched for Venus, with a similar result; and finally he tried to find a star of known position, and also failed. Suspecting that his instrument had got out of adjustment he examined the base, and found that the telescope had been

moved round on the conical support at A as a pivot about one inch in an easterly direction, so that it had to be screwed back in azimuth the same distance towards the W. in order to restore it to a proper state of adjustment. The screws (azimuth) had not been moved for so many years that they had almost rusted into their sockets, and their old position was visibly marked by the circle of rust. A further examination showed that the piers had also been moved southwards so as to become jammed against the sides of the holes through which they passed, and they were seen to be no longer surrounded by the free margin. In the accompanying figure (Fig. 19) the position of the piers as seen at the time of my visit is shown by the dotted lines:—

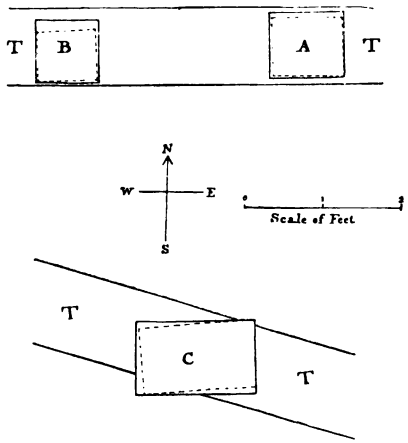


FIG. 19.—Southward displacement of the piers which were formerly exactly in the centres of the holes through the floor. The letters have the same meaning as in Fig. 17.

The conclusion that the instrument was shifted by the earthquake seemed the only possible explanation of the facts, and we have therefore given the evidence in detail. On arriving at Crowborough, Mr. Prince was good enough to have the floor of the Observatory taken up all round the piers in the presence of Mr. Symons and myself, and it was then found that the stone slab, A, had been tilted up at its N.E.

corner to a sufficient extent to allow the blade of a knife to be inserted between the stone and its bedding. B and C were not tilted, but they may have been slidden along the surface of the timber balk on which they rested. The only other explanation of this displacement is that the whole floor had moved northwards; but if this had been the case we should have expected to find that the planks had started away from the wall of the Observatory somewhere on the southern side. A careful examination failed, however, to reveal any such shift of the floor, and we concluded therefore that it was the piers which had been shifted.

The particular character of the displacement described does not give any distinct indication of the prevailing direction of the movement at Crowborough, but the fact that the stone at A was tilted up at its N.E. corner agrees exactly with the supposed direction from which the disturbance travelled towards this place. We may point out that the shock itself was actually felt here and in several other parts of Sussex (p. 153), and the position of the telescope, a massive instrument standing in the highest part of a building at a height of thirty-four feet above the ground, was eminently favourable for taking up any vibrations communicated from the ground to the building.[118]

Appendix.

British Earthquakes.

Since presenting the foregoing Report to the Essex Field Club, a short paper on the earthquake of 1884 has been published by Mr. Horace B. Woodward, F.G.S., of the Geological Survey, in the 'Transactions of the Norfolk and Norwich Naturalists' Society,' vol. iv., pp. 31–35 (read Nov. 25th, 1884). Mr. Woodward makes the following statement:—

"Probably we shall not be far wrong if we attribute the recent earthquake in Essex to one or more subterranean rents produced by shrinkage, which led to no material shifting of the rocks, and which, owing to the tenacious nature of the

[118] The drawings from which the figures 17 and 19 are produced were made carefully to scale for me by Mr. Symons. Fig. 18 is from a wood-block kindly lent by Mr. Prince

subsoil at Colchester, chiefly London Clay, did not manifest itself in any conspicuous manner at the surface."

This is fully in accordance with the views which we have already expressed (p. 183).

Through the kindness of Mr. G. J. Symons, F.R.S., we have been enabled to see a proof copy of a 'Catalogue of British Earthquakes,' compiled by Mr. William Roper, F.R.Met.Soc., and printed in Lancaster (October, 1885). This catalogue, which is very comprehensive, has enabled me to add several more to our list of the earthquakes which have caused structural damage (p. 3), and at the same time it has served to confirm us in an opinion to which we came when compiling our own catalogue, *viz.*, that the dates of most of the earlier British earthquakes are very doubtful, and require thorough revision. This task seems to have been undertaken to a considerable extent in Mallet's catalogue, and we have therefore in most cases given preference to his dates, stating at the same time the dates of other authorities when there was any discrepancy. As already stated, we have not thought the compilation of such a completely-revised catalogue essential for the present report, even if we could have found time for the task. The chief difficulty surrounding such an undertaking appears to be the discrepancies between the dates given by different chroniclers for what is apparently the same earthquake, and the consequent multiplication of the records of the same event. The clearing-up of these discrepancies would necessitate a large amount of bibliographical labour, which, although in itself interesting and important, belongs rather to the province of the archæologist. To give an illustration of the kind of difficulty which would be met with, we may refer to the earthquake of 1275 (p. 5 of this report), of which the date (September 11th) is given by Mallet on the authority of Matthew of Westminster, p. 364. In Mr. Roper's Catalogue, under the date September 11th, 1268, the same earthquake (St. Michael's, Glastonbury, thrown down) is recorded on the authority of Matthew of Westminster, vol. ii., p. 469. Under September 11th, 1275, Mr. Roper records:—"A great one felt in Newcastle, dreadful thunder and lightning, blazing star, and a comet with the appearance of a great dragon, which terrified the people." This is given on the authority of John Sykes, Newcastle, 1866, vol. i., p. 29, and Matthew of Westminster. In 1276 (same date) the same earthquake (St. Michael's, Glastonbury, levelled) is again recorded on the authority of Stone and of the author of the 'History of the Weather, &c.' (Dr. Short?), already referred to (p. 2 of this report). It is of course possible that St.

Michael's, Glastonbury, may have been twice damaged within the period referred to; but this hardly seems probable, and it is more likely that there is some confusion of dates. It would be necessary also, in undertaking such a revision of the British earthquake catalogue as is here indicated, to discriminate between earthquakes proper and other phenomena, as it appears from the early records that landslips, subsidences, great storms, &c., were mixed up, together with much that is fabulous, and chronicled as earthquakes.

Additions and Corrections to List of British Earthquakes which have caused Structural Damage.

A.D.

353. Edinburgh. Slight. Only nine or ten houses lost (Hist. of Weather, vol. ii., p. 166).

394. Wales. Made sad havoc (*Ibid.*).

707. Scotland. Did very great mischief (*Ibid.*).

743. In several parts of Scotland; did great hurt (*Ibid.*).

811. St. Andrews. Destroyed most of the town and 1400 people (*Ibid.*, p. 167).

1062. February 6th. A great one; did much hurt in many places (*Ibid.*, and 'Chronicles de Magdeburg'). Doubtful whether this caused damage in England; possibly refers to Swiss earthquake of February 8th of same year, recorded in Mallet's Catalogue.

1120. September. Vale of Trent. Many houses overthrown, "and buried their inhabitants in the ruins, for it gave daily 10, 17, or 20 shocks" (Hist. of Weather, vol. i., p. 113).

1180. April 25th. At Nottingham and throughout midland counties; many houses thrown down (Mr. Roper's Catalogue, on authority of E. J. Lowe).

,, September 29th. "An earthquake fatal to many great buildings in England, especially to Lincoln Church" (Hist. of Weather, vol. i., p. 128). This is probably the earthquake referred to under the date 1185, April 15th, 16th, or 17th (p. 4 of report).

1184. Lincoln. Same as preceding, recorded by Holinshed, vol. ii., p. 188.

1185. Probably the same earthquake, recorded again by Holinshed and by the author of the 'History of the Weather' (vol. i., p. 128).

1193. England. A great one that levelled edifices and trees with the ground. No locality mentioned (Hist. of Weather, vol. i., p. 130).

1268—1276. The discrepancies respecting the date of the shock which destroyed St. Michael's, Glastonbury, have already been alluded to.

1356. Ireland. Great loss of people (Hist. of Weather, vol. i., p. 178).

1585. April 2nd, about 6 p.m. Near York. This may refer to the 1580 shock, which, according to Baker's Chronicles, occurred in the

23rd year of Elizabeth (Hasted, in his 'History of Kent,' gives the date as the 22nd year of Elizabeth). It seems surprising, however, that an earthquake which appears to have been most severe in Kent, should have caused damage at York (see this report, p. 6). Most authorities fix the date of the 1580 shock as April 6th. Mallet gives no record under 1585. There is probably some confusion of dates.

1650. The Cumberland and Westmoreland earthquake of April, 1651, is dated 1650 by the author of the 'History of the Weather, &c.'

An Earthquake possibly felt at Colchester in 1760. — The following letter (anonymous) addressed to the 'London Magazine,' is dated from Diss, Norfolk, July 26th, 1760 :—

"On Wednesday, June 11th, about fifty minutes past four in the afternoon, as I was standing at an outward door, of a sudden I heard a very loud noise, like the explosion of a cannon fired near, and it seemed full as loud: I immediately stepped abroad, and found the noise appeared to be in the air; it seemed to burst westward of the place where I was, and gradually to roll towards the east: the day was very hot, the sun shone in its full splendour, nor was there a cloud to be seen, only a few light ones to the west; the wind was N.E., and had been so for some days; it blew then pretty fresh. We are more than twenty miles from Ipswich; it was likewise heard at Norwich, Bungay, Beccles, Southwold, Colchester, Bury, Sudbury, and Thetford, and in all probability at a greater distance. Whether it was a collection of sulphureous particles, or other homogeneous matter [!!], I hope some of your ingenious correspondents will satisfy us in."

This extract may refer to a slight shock of earthquake or to the bursting of a large meteor, and we give it here in order that local antiquaries may make further search into the records of Norfolk, Suffolk, and Essex.

The Earthquakes of 1580 and 1692 in Essex. — Through the kindness of our member, Mr. R. M. Christy, we are enabled to give two more references to slight shocks felt in the county. The earthquake of April 6th, 1580, which caused damage in London (p. 6), is mentioned in a black-letter tract printed in the year 1580, containing "Three Proper & Wittie familiar Letters" which passed between the literary critic, Gabriel Harvey, and his friend Spenser ("Immerito"), the poet. In reply to a letter from the latter, written in London and addressed "to my long approoved and singular good frende Master G. H.," inquiring as to whether the earthquake which had overthrown "divers old buildings and peeces of churches"

in London had been "also wyth him," Harvey, who was then dwelling in Saffron Walden, sent to the poet a "pleasant and pitthy discourse of the earthquake," detailing all that happened within his knowledge. The shock, "making a great loude noyse & much adoo," appears to have been strongly felt by all in the room with him, "affrighting the ladies and causing the table to move and rattle," upon which he sent out a man into the town and learnt that "the very like had behappened the next Towne too, being a farre greater & goodlyer Towne"; and he speaks of it later as having been also felt in "many neighbour Townes & villages about us." It it most probable that the "goodlyer Towne" referred to is Newport, which was then the market-town to Saffron Walden. A curious and lengthy treatise upon earthquakes in general follows the detailed description of his experience of the shock, in which he includes the erroneous explanations and ideas of the ancients as well as of his own time.

The other record furnished by Mr. Christy occurs in the MS. "Commonplace book of Rd. Symonds of Black Notley, in the county of Essex." The MS. is in the possession of Mr. Shirley, of Ettington Hall, Warwickshire, and gives "an account of an earthquake at Witham, in the county of Suffolk, on Sept. 8th, 1692." We have not been able to see the MS. referred to, but there can be no doubt that the Witham spoken of is the Essex town, to which Black Notley is an adjacent village, there being no place of the same name in Suffolk. The shock is probably the same as that recorded at Colchester (p. 11) and Coggeshall (p. 12).

Explanation of the Plates.

Plate I.—Map showing general distribution of the shock. Reprinted, with corrections, from Symons's 'Meteorological Magazine' for May, 1884.

Plate II.—Map showing the general distribution of structural damage over Essex. Reprinted from Symons's 'Meteorological Magazine' for May, 1884.

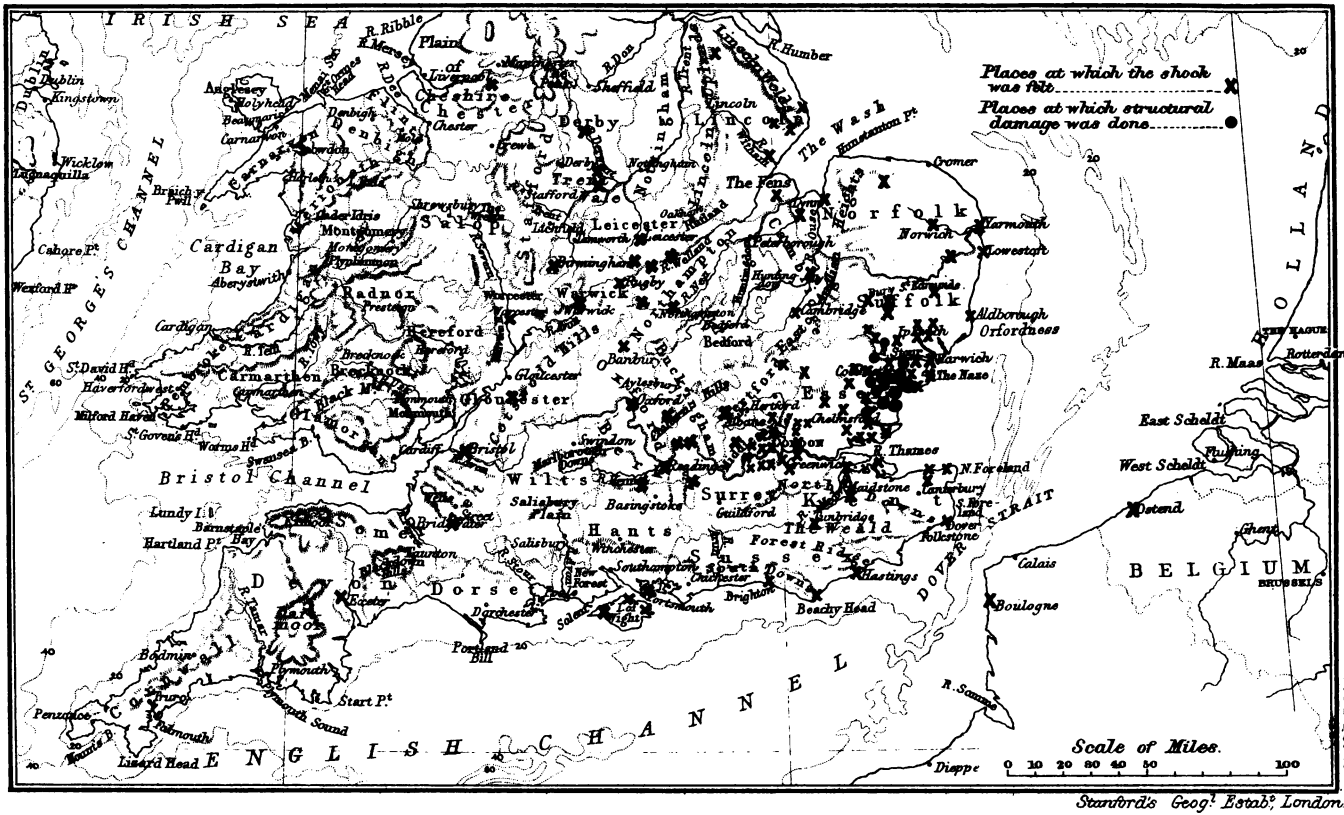
Plate III.—Map showing the general distribution of the shock, with reference to the solid geology of the seismic area. The coast stations at which the earthquake was felt are entered in this map, but the other places within the circle where the disturbance was felt have, for the sake of clearness, been mostly omitted as being unnecessary for the discussion of the principles illustrated by the map. Outside the circle the records are complete. Photo-transferred from a drawing by Mr. William White.

Plate IV.—Map showing the general distribution of intensity as indicated by the nature and amount of damage. The intensity is indicated by the size and approximation of the black dots. The drawing has not brought out with sufficient distinctness the N.E.—S.W. extension of the main axis of intensity from Wivenhoe to Peldon. This map serves also to show the distribution of the damage in Essex in connection with the superficial geology, together with the directions of propagation of the movement as given by the most trustworthy observations. The superficial geology is taken from Mr. W. H. Dalton's Survey map, 48 S.W. Photo-transferred from a drawing by Mr. William White.

Of the cuts in the text, Figs. 2, 5, 6, 7, 8, and 11 are reprinted from the 'Illustrated London News.'

WEST, NEWMAN AND CO., PRINTERS, 54, HATTON GARDEN, LONDON, E.C.

GENERAL MAP OF AREA OVER WHICH THE EARTHQUAKE OF APRIL 22ND 1884 WAS FELT.



Stanford's Geog.l Estab.t London

Special Memoirs. Essex Field Club. Vol. I. Plate I.

SITES OF STRUCTURAL DAMAGE BY EARTHQUAKE OF APRIL 22ND 1884.