INSTITIÚID ÁRD-LÉINN BHAILE ÁTHA CLIATH
SCOIL NA FISICE COSMAÍ

Dublin Institute for Advanced Studies
SCHOOL OF COSMIC PHYSICS

GEOPHYSICAL MEMOIRS NO. 4

THE MAGNETIC SURVEY OF IRELAND FOR THE EPOCH 1950·5

BY

THOMAS MURPHY

DUBLIN
1953

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ABSTRACT

A magnetic survey of Ireland has been carried out in 1950 comprising measurements at 44 stations of declination, horizontal intensity and inclination, the mean errors being $\pm 0'\cdot 8$, $\pm 7\gamma$ and $\pm 0'\cdot 5$ respectively. 37 of these stations are identical with or very close to those occupied by WALKER in 1915.

Normal values for all the components have been deduced by a method of least squares and presented in the form of linear equations involving the latitude φ and longitude λ. The three important ones are

$$D = 0^\circ\cdot 248\,(\varphi-50) + 0^\circ\cdot 535\,(\lambda-5) + 11^\circ\cdot 21$$
$$H = -472\gamma\,(\varphi-50) - 47\gamma\cdot 8\,(\lambda-5) + 19\,011\,\gamma$$
$$Z = 448\gamma\,(\varphi-50) + 65\gamma\,(\lambda-5) + 42\,909\,\gamma$$

where λ and D are measured positive to the west.

The declination survey is shown to be in agreement with a survey of Great Britain made in 1948 and the deduced value for the vertical intensity is in good agreement with the Vertical Magnetic Survey of 1945 by the Irish Geological Survey.

In order to compare this survey with the previous one in 1915, the normal values for the latter have been recomputed by a method of least squares. The deduced anomalies for the components at each station for the two surveys show no change within the limits of the experimental errors. There are three exceptions, confined to declination. The method for deducing declination values since the survey of 1915 by applying a simple correction obtained from magnetic observations in England is shown to be quite accurate.

Line integrals of the horizontal force have been computed for the epochs 1915·0 and 1950·5 by a method used by SCHUSTER for WALKER's survey and it is shown that the corresponding earth-air currents have no significance.

INTRODUCTION

Measurements of the magnetic elements had been made at various places in Ireland in the first half of the nineteenth century and were collected by SABINE in 1870. Two, more complete, surveys were carried out by RÜCKER and THORPE (1890 and 1897), and WALKER (1919). A survey of the vertical component was carried out by the Geological Survey of Ireland and the results presented in the form of maps (1949) on a scale of one millionth. No absolute measurements were made in the latter survey.

Since 1915, the values for declination have been obtained by extrapolation of WALKER's measurements based on the rate of secular variation obtained from the magnetic observatories in England and, while this is accurate for short periods, after 35 years uncertainties arose and rechecking became necessary. The survey by the Geological Survey was carried out with variometers over a considerable period of time and, without absolute measurements, it was difficult to reduce the readings properly.

When the subject of the survey was first broached in 1949 it became apparent that no modern magnetic instruments of high accuracy could be obtained and, on being approached, the Carnegie Institution of Washington readily offered to place at our disposal one of the only absolute magnetometers available. To Dr. TUVE of the Institution's Department of Terrestrial Magnetism we are most grateful for this means of carrying out the magnetic survey.

Secondly we are indebted to Messrs. ARTHUR GUINNESS, SON & CO., Ltd., Dublin, for the gift of a motor van which was so generously given to the School of Cosmic Physics for this work.

Besides these we offer our thanks to numerous other persons and departments who lent us instruments and gave us considerable assistance : to the Astronomer Royal for the loan of a pocket chronometer and for the facilities and the help of his staff at Abinger Magnetic Station when the magnetometer was calibrated there ; to the Director General of the Ordnance Survey of Great Britain for the loan of a theodolite and for supplying details of the magnetic stations from his records ; to Irish Shipping Ltd., Dublin for the loan of a chronometer and to Messrs. Pye (Ireland) Ltd., Dublin for the loan of a portable radio ; and finally to the Irish Meteorological Service for the loans of a chronometer and a precision aneroid barometer, and for the permission to work and the facilities afforded us at Valentia Observatory.

We are further indebted to the Astronomer Royal for the supply of magnetic data from Abinger Observatory and to the Director of the Meteorological Office, London, for similar data from Eskdalemuir Observatory.

The work was carried out in co-operation with the Ordnance Survey of Ireland, Dublin and the Ordnance Survey of Northern Ireland, Belfast.

Most of the reduction of the data was carried out by Mr. S. G. MILLER during the period of a Scholarship at the School of Cosmic Physics.

THE STATIONS

Walker, in his survey, worked in conjunction with the Ordnance Survey of Great Britain and Ireland and for stations they chose " trigonometrical points " which they marked by " an earthenware pipe with a brass bolt set in cement covered with a tile 7 ins. by 7 ins. by $1\frac{1}{2}$ ins. and is $1\frac{1}{2}$ feet under the surface." The location of each station had to satisfy three conditions. It had to be close to the reputed points used by Rücker and Thorpe in their first survey ; secondly, there had to be a suitable " reference object " in sight for azimuth determinations and finally it had to be free from disturbing magnetic influences both at the time of the survey and in the foreseeable future. In Ireland 44 stations were set up and it speaks well for their foresight that only three, Bangor, Dublin and Limerick, had to be abandoned because of subsequent building.

The full descriptions of Walker's stations, reference objects and values of azimuths were preserved in the Ordnance Survey of Great Britain and a copy was supplied to us by the Director General. Similar data of the present survey will be also deposited there and additional copies are stored at the Ordnance Survey, Dublin and the School of Cosmic Physics, Dublin.

A preliminary reconnaissance indicated that nearly all of Walker's stations could be reoccupied if the marks could be found. Dublin and Bangor, the nearest station to Belfast, had, unfortunately, been built over. It was decided to remeasure, if possible, at each of Walker's stations with one exception. The latter, located at Cookstown Junction, was in a very disturbed region, the declination measured there being almost two degrees different from that expected. The cause of the disturbance is the extensive basalt sheet and a further measurement there or nearby would not be very fruitful. A new station was hence chosen about 20 miles to the west not on this magnetic rock.

It was also felt that the north-west part of Ireland was not fully represented with two stations, Strabane and Londonderry, within 15 miles of each other and none at all in Co. Donegal. Another new station was chosen at Dunfanaghy. Later, the mark at the Strabane station could not be located so that this station was omitted, thus preserving the total at 44 stations for Ireland.

With these exceptions efforts were made to reoccupy Walker's stations or, if this was not possible, to take measurements as close to the reported position as was feasible. At 22 out of the 44 the actual marks of Walker's survey were found. Incidentally, two of the temporary wooden pegs with the inserted brass pins, used in the earlier survey, were recovered intact. At ten other locations, including Strabane and Cookstown Junction, no trace could be found of the marks. This was very surprising. In the first instances of this kind accurate measurements to locate the mark were made and considerable allowances were made for possible misinterpretation of the details. In some cases areas up to 15 sq. yds. were dug up but without any success. Later, whenever the mark could not be found at the first trial no extended search was made.

It is extremely puzzling to understand the non-appearance of the mark in so many cases. The search party were skilled in this type of work and the separate checks were also made. Most of the stations were located in untilled land often in isolated districts and the descriptions " tied in " extremely well in all but one case. The latter was at Charleville where there was some uncertainty concerning a reference object used for location. It has been suggested that some of the marks were destroyed by curious people following Walker's survey which, in Ireland, took place during the First World War and this may be true in a few cases but it does not seem a likely explanation for all ten stations.

The possibility that the descriptions are in error was considered at the time but no mistakes were found in any other details. However, that this possibility may have some foundation arises from the fact that at the described locations there was no evidence of disturbed subsoil which could be expected from the establishment of the mark and from its subsequent destruction. In a private communication from the Ordnance Survey of Great Britain it is learned that in their resurvey of 1947–49, of the 83 stations looked for, 24 could not be found. This is in the same proportion as in the present survey. It would seem then as if for one reason or another one third of the stations will not be found in subsequent resurveys and to this must be added the destruction or interference by encroaching buildings and so an elaborate system of marking, such as was employed in Walker's survey, does not seem justifiable now or in future.

At the remaining stations various reasons prevented the use of Walker's sites but an effort was made to position the new one as close to the old one as possible. In four cases Bangor, Dublin, Killarney and Leenane the distances between the two sites are over one mile. At all the others, including those that could not be located, the separation was seldom more than a hundred metres. *Table* II in the *Appendix* gives the details. The positions of each of the new stations is marked by a concrete tile 7 ins. by 7 ins.

by 1¼ ins. at a depth of 18 ins. having at its centre a triangle and dot, similar to the tiles used in trigonometrical surveys, but to prevent confusion it has, in addition, the letter M stamped thereon.

In Dublin the station is situated in the Phœnix Park and marked by a granite pillar, one of a series known as " boundary " stones—an old name which bears no relation to their present position. The top of the pillar is 18 inches above the ground. This station was so chosen to facilitate rechecking other magnetic instruments.

In the *Tables* and the *Maps* in the *Appendix* the stations have been given the same numbers and names as in the 1886 and 1915 surveys except for the two new stations, Tobermore and Dunfanaghy Nos. 170A and 192A, which replace Cookstown Junction and Strabane Nos. 170 and 192. The names may, in some cases, differ from present day ones.

EQUIPMENT AND METHODS OF MEASUREMENT

INSTRUMENTS.—The instrument used was the Carnegie Institution of Washington Magnetometer No. 13 with Earth Inductor described by FLEMING (1911) and FLEMING and WIDMER (1913).

The rest of the equipment consisted of a square pyramid type tent made to the dimensions given by HAZARD (1947) on page 47, a ship's chronometer, a pocket chronometer, a portable radio and a vertical magnetic field balance. All the sensitive instruments in their respective boxes were carried in suitable receptacles, lined with foam rubber, built into the motor van to minimise the effects of vibration.

PROCEDURE.—A work party from the Ordnance Survey travelled in advance to each station where either the original station of WALKER was restored or a new mark was put down. The marks were then covered over leaving a stake with its marked centre directly above the station. The description of each station was checked and added to if necessary and the reference objects for declination measurement picked out. Panoramic photographs were taken from each station and copies of these are preserved in the Ordnance Survey. If the station was different from that used by WALKER or if the reference objects were no longer visible new reference objects were chosen and their azimuths measured. The author and an assistant followed soon after and took the magnetic measurements.

MEASUREMENT OF AZIMUTHS.—For reference objects to define the azimuth for declination determinations, spires on churches or public buildings were used for preference or other marks thought to be reasonably permanent. In a few cases objects on dwelling houses had to be used. If possible, at least two reference objects were chosen for each station. The reference object had to be close to the horizon for the Kew magnetometer used by WALKER and the same limits, that is 30 minutes above or below the horizon, were used in choosing reference objects in the present survey so that no vertical adjustment of the telescope was necessitated during declination measurements.

In the 1915 survey the azimuth of each reference object was determined by observation of other trigonometrical points, the magnetic station was at one, and computation. In Ireland, however, this has proved not very satisfactory.

In the early topographical surveys in this country each county was mapped on its own coordinate system. When the results were combined together certain adjustments were necessary and uncertainties in the orientation of each county system arose. In recent years the adjustment has been recomputed by the Ordnance Survey of Great Britain and the Director General, who so kindly recalculated all the azimuth values of the 1915 survey for us, advised that the azimuths should all be redetermined astronomically as grave uncertainties could be present.

At all the new stations established in this survey and at others where the old reference objects were destroyed astronomical determinations of the azimuths have been carried out. The particular stations are given in *Table* II in the *Appendix*.

Both on account of the readjustment and the redeterminations there can be differences between the azimuth values used by WALKER and those used in this survey and hence in the deduced declination values. To obtain some idea of the size of the discrepancies, astronomical observations were taken at three stations occupied by WALKER. The comparison is given in *Table* I.

The astronomical observations were carried out by Captain P. G. MADDEN and Mr. J. O'HAGAN, of the Irish Ordnance Survey in the south of Ireland, and by Brigadier-General K. M. PAPWORTH in Northern Ireland.

TABLE 1

AZIMUTH OF A REFERENCE OBJECT FROM A MAGNETIC STATION

Station	From Triangulation	Astronomically	Difference
Armagh	220° 46′ 45″	220° 46′ 22″	23″
Cork	268 45 51	268 45 31	20
Donegal	186 39 38	186 39 14	24

Table 1 shows that there is a difference between the two methods of deducing the azimuths but not big enough to seriously disturb the values given for the declination. Although in the last column the differences have all the same size and sign it is not thought that this will hold for the remaining stations. We had hoped to carry out astronomical observations at every station, but it was found that weather conditions were not at all favourable for this work and redeterminations were postponed. The essential observations only were made and these were not all carried out in the interval from May to October 1950 at the same time as the magnetic observations. They were eventually completed in 1951, the rate being about one station per week. It was then decided that the cost and time of taking measurements at the seventeen remaining stations was not commensurate with the advantages gained by the higher accuracy. This part of the work was left until such time as magnetic remeasurements are taken.

MAGNETIC MEASUREMENTS.—The method followed was in general that described by HAZARD for the instrument used and will not be described here. Certain small changes in computation of the horizontal intensity were found necessary because of weather conditions. The routine normally followed consisted in taking the measurements in the following order : declination, horizontal intensity, declination and inclination. A complete set took about three hours and if travelling conditions permitted one set was carried out in the morning and another complete set in the afternoon.

Measurement of Declination.—A set of readings consisted of setting on the reference object before and after the magnetic measurements and with one setting eight readings were taken ; two with the magnet erect, four inverted and finally two erect. This took about ten minutes to carry out, and if the first and last readings agreed within 2′ the set was accepted. If they disagreed by more than 2′ they were rejected, and a complete new set was taken. If this set was not considered satisfactory a disturbed day was suspected. and the magnet was observed over a long period to determine if this were so. Two days were found in this way to be disturbed and no observations were taken on those days. After the measurement of horizontal intensity a further set was always taken. At some stations more sets were taken later in the day.

Repeat measurements of the declination were made on different dates at several stations throughout the survey to provide checks. In this way it was discovered that for a period the declination measured was wrong by 7′ at each station. The reason for the constant difference is not known. Torsion in the suspension fibre is suspected since on one occasion during this period it was found that nearly a complete turn appeared in the suspension. At that time the suspension fibre used had been obtained from a spool which came with the instrument. This fibre eventually broke and on inspection showed spots of corrosion. New fibres were obtained from Messrs. PYE of Cambridge, England, who supplied the original ones. These fibres proved most satisfactory. After this experience the torsion was checked more often and very little change in the torsion was detected thereafter. The stations affected by this error have all been corrected.

Measurement of Horizontal Intensity.—For measuring the period of oscillation a ship's chronometer giving ticks each half second, was used. This was placed on the ground close to the tripod ; if possible, directly underneath the instrument. With the chronometers used in these positions no magnetic disturbance could be detected. In the survey two chronometers were used both having rates less than one second per day when undisturbed. However, one of them became very erratic, its rate eventually increased up to 15 seconds a day. This was the result, presumably, of vibration while travelling because when it was returned to Dublin it settled down again after a few days with its previous small rate. In order to guard against random rate a pocket chronometer and a portable radio, to receive the Greenwich time signals, were carried throughout. It was also found that the chronometers stopped several times, again probably due to travel because both had been overhauled prior to the survey.

The number of oscillations counted was 170, broken down in the usual manner into ten sets of 90 oscillations each. The time for 90 oscillations was about five minutes and if one reading of the ten sets differed from the mean by more than 0·4 second this reading was rejected. This type of discrepancy is probably the result of an error of half a second in reading the second hand of the chronometer which moved in half second jumps. If the range in time between the ten sets was greater than 0·6 second another complete observation of 170 oscillations was carried out.

The temperature was read after each nine oscillations and if the initial and final temperatures differed by more than 1°C then the oscillations were repeated.

When a satisfactory set of oscillations had been taken the deflections were carried out. We endeavoured to measure the deflections for three different distances in order to check the values of P and Q and to reduce the errors due to temperature changes.

Great difficulties were encountered due to temperature fluctuations and necessitated much additional work. Mention has already been made of the oscillations having to be repeated because of this cause but the position was much more serious when taking the deflections. Because of the wind, in this country the measurements were always conducted in the tent and in conditions of overcast and light winds they proceeded smoothly. The worst conditions occurred on days of intermittent sunshine and showers, sometimes with hail, usually accompanied by moderate winds. On these days the temperature read on the thermometer in the box containing the magnet showed large fluctuations sometimes as high as 12°C in 15 minutes. Under such extreme conditions no satisfactory measurements could be made.

A set of deflections at any one distance took about nine minutes to carry out and it was found experimentally that if during this short period the temperature as read on the thermometer in the magnet box changed by 1°C then the readings were useless. The temperature coefficient of the magnet, q, is not large namely 0·000598 and one degree change in temperature amounts to a change of 0·00026 in the logarithm of the correction. This is small but when the temperature increased more than the 1°C limit it was found from experience that an error, often as high as five times this amount, was introduced even after correcting for the change in temperature. The expansion of the brass deflection bar cannot account for this discrepancy either. The explanation offered is that when the specified rate of 1°C in nine minutes is exceeded then the temperature read on the thermometer is considerably different from the temperature of the magnet. Under such conditions a temperature correction cannot be applied.

No solution to this problem of keeping the temperature constant was found. Repeated sets of deflections were made until at least two were inside the limits stated. Later when the reduction of the measurements was undertaken a more stringent check was made on the changes in temperature throughout the intensity measurements and if any set of readings was suspect on this account, it was eliminated forthwith.

Since the deflections were taken in such a manner, we departed from the usual method of combining the readings but corrected each set of oscillations and each deflection for temperature and worked each separately down to log HM and log H/M respectively. When all those readings which were doubtful because of temperature changes had been eliminated, it was found that the two values of log HM from two sets of oscillations and the three values of log H/M from the three deflection distances differed only seldom by more than 0·00050, normally by not more than 0·00020.

At the end of the field work with the values of log H/M for the various deflection distances, the correction for P, the distribution coefficient, was calculated as given by HAZARD on page 33 (Q for the magnet used was theoretically zero). This correction amounted to 0·35. The new value of P is $+7{\cdot}90$ and is used throughout the calculations.

At each station at least one value of the moment of the magnet was deduced and throughout the survey no significant change in this moment was observed. In all, 57 values were obtained ; the mean was $270{\cdot}70 \pm 0{\cdot}11$ c.g.s.

Measurement of Inclination.—The inclination was measured by means of an Earth Inductor in the manner described by HAZARD on pages 82–85. It was found that the commutator was best cleaned with a soft clean handkerchief without any solvent. No lubricant was used on the brushes.

The four determinations of the inclination usually agreed within 2′ and if one differed by more than this amount it was a sure sign that the commutator was not clean. Two sets of four readings were taken at each station within half an hour, the instrument being relevelled and the commutator cleaned between sets. If the means of the two sets agreed within 1′ they were accepted but they only seldom disagreed by this amount, the average difference being less than 0·5′.

CALIBRATION OF THE INSTRUMENT.—Before the instrument was sent from Washington it was calibrated at Cheltenham Observatory on July 18 and 19, 1949 by Mr. W. C. PARKINSON of the Carnegie Institution of Washington. The results are given in *Table* 2.

TABLE 2

CALIBRATION AT CHELTENHAM OBSERVATORY

Element	Correction
Declination . .	+1′·4
Horizontal Intensity .	+10γ
Inclination . .	−1′·4

On July 5 1950, in the middle of the magnetic survey a calibration measurement was carried out at Abinger Magnetic Observatory, England. In *Table* 3 the simultaneous values of the magnetic components as determined by the observatory staff from their continuous records and by the author with the Carnegie magnetometer are given. The value for the horizontal intensity determined by the latter is calculated using the value of 7·90 for the distribution coefficient *P* computed from the survey results.

TABLE 3

MEASUREMENTS AT ABINGER OBSERVATORY

Time G.M.T.	Element	Abinger Observatory Values	C.I.W. Magnetometer 13	Difference
h m				
9 23	Declination . .	9° 15′·3	9° 16′·0	−0′·7
11 15	Declination . .	9° 20′·8	9° 21′·4	−0′·6
11 34	Declination . .	9° 22′·7	9° 22′·9	−0′·2
10 10	Horizontal Intensity .	18607γ	18610γ	−3γ
14 04	Inclination . .	66° 43′·7	66° 43′·6	+0′·1
15 52	Inclination . .	66° 42′·4	66° 42′·7	−0′·3

The values for the horizontal intensity and the inclination are in very good agreement, and the differences in values of the declination are quite small and within the mean error of the measurements. It was decided that no correction should be applied to the figures for the various magnetic elements as measured by the C.I.W. magnetometer 13.

REDUCTION OF THE MEASUREMENTS

CORRECTION FOR DIURNAL AND SECULAR VARIATIONS.—There is no magnetic observatory in Ireland where continuous records of any of the magnetic elements are taken and when the survey was planned endeavours were made to secure suitable recording instruments but these were not successful. The observatories nearest to Ireland where such records are taken are at Eskdalemuir in Scotland, latitude 55° 19′ N., longitude 356° 48′ E., and Abinger in England, latitude 51° 11′ N., longitude 359° 37′ E.

The usual method of correcting for the diurnal variation is to deduct the instantaneous deviation of the magnetic element from the mean value as measured at a nearby magnetic observatory. By this means all the small fluctuations are allowed for. Both Eskdalemuir and Abinger are well to the east of the nearest magnetic station in Ireland and it is doubtful if this method could be employed because the short period fluctuations and disturbances are functions of universal time while the diurnal variation is a function of local time.

A simpler method of correction was used which allowed, at the same time, for the diurnal variation and the secular variation. Two assumptions were made, namely, that the diurnal variation is a simple function of the local time and can be obtained by drawing a smooth curve through the " Mean Hourly Values " for each day and secondly that the secular variations of the elements are the same throughout the area of the survey in Ireland as those measured at Eskdalemuir and Abinger. That the latter is permissible for declination over the small area can be seen from the secular variations deduced from the figures given by JOHNSTON (1951) for the various observatories in Europe but the same cannot be said for the other elements. VESTINE et al (1947), owing to the absence of data after 1938, indicates, on page 198, that at Valentia Observatory the horizontal and vertical intensities were decreasing after that date while at Eskdalemuir and Abinger they were both increasing. From information supplied by the Irish Meteorological Service it is now known that these intensities at that time both reached a minimum, as had occurred at Eskdalemuir and Abinger several years earlier, and are now increasing. The rate of increase is now similar to those at Eskdalemuir and Abinger which are small, less than 20γ per year so that if the second assumption is not quite true, at least the error is small.

The " All Day Mean " values of D, H and I were taken to represent the magnetic elements for the magnetic observatory for the epoch 1950·5. These are given in *Table* 4.

The combined correction for diurnal variation and for reduction to epoch was obtained as follows. If the value of the magnetic element in question (D_s) was measured at the station at a local time (t), then the value of the element (D_t) at the observatory at the same local time (t) was interpolated from the mean hourly values and from this was subtracted the " All Day Mean " value (D_m). Thus for declination

$$D \text{ (for station reduced to epoch 1950·5)} = D_s - (D_t - D_m).$$

TABLE 4

ALL DAY MEANS FOR 1950

Element	Abinger	Eskdalemuir
Declination . .	9° 19′·7	11° 33′·2
Horizontal Intensity .	18628γ	16569γ
Inclination . .	66° 43′·0	69° 52′·0

The diurnal variation is dependent on the latitude of the station and so Ireland was divided into three zones :—north of latitude 54° where the correction was obtained from the Eskdalemuir readings ; between latitudes 52°·5 and 54° where the correction was obtained from a mean of the Eskdalemuir and the Abinger readings and south of latitude 52°·5 where the correction was obtained from the Abinger readings.

Tests of the method of reduction were carried out, for declination, during the survey since a measurement of this element can be made in a short interval of time. An example for a sequence of readings on one day is given in *Table* 5 and a further example of readings taken on two days several months apart in *Table* 6.

TABLE 5

EXAMPLE OF CORRECTION FOR DIURNAL VARIATION

Time G.M.T.	Measured Value	Correction	Corrected Value
h m	° ′	′	° ′
11 25	14 22·7	−3·6	14 19·1
11 40	14 23·2	−4·8	14 18·4
11 45	14 23·7	−5·2	14 18·5
12 00	14 24·7	−6·4	14 18·3
13 15	14 25·7	−7·3	14 18·4
13 30	14 26·2	−7·9	14 18·3
14 30	14 27·2	−9·3	14 17·9

TABLE 6

EXAMPLE OF COMBINED CORRECTION FOR DIURNAL AND SECULAR VARIATIONS

Date	Time G.M.T.	Measured Value	Correction	Corrected Value
	h m	° ′	′	° ′
July 20 .	13 25	13 39·4	−5·8	13 33·6
July 20 .	15 33	13 40·4	−7·0	13 33·4
November 17	13 28	13 36·3	−1·9	13 34·4

The values of declination, horizontal intensity and inclination, as deduced by the above process, are listed in *Table* IV in the *Appendix*. The north, west and vertical components have been calculated from the foregoing thus: north component, $N=H \cos D$; west component, $W=H \sin D$ and vertical component, $Z=H \tan I$. D is measured west positive and so W is always positive.

ESTIMATION OF THE ERRORS IN THE MEASUREMENTS.—At all stations, two or more determinations of each element were made and in declination the extreme values, after correction for diurnal variation, seldom differed by more than 2′, and in inclination 1′. At eleven stations the horizontal intensity was measured on two separate occasions and the two corrected values never differed by more than 10γ. From an analysis of the individual differences at each station the mean errors in the determinations of the three elements declination, horizontal intensity and inclination are ±0′·8, ±7γ and ±0′·5 respectively. Since the components are derived from two of the measured values their accuracy is less. In the case of the vertical intensity if it is assumed H is measured to an accuracy of ±7γ and I to ±0′·5, then Z will be accurate to ±27γ.

These estimates of mean errors refer only to the relative values between the stations. The accuracy of the absolute values is not known. The absolute value of the declination depends on the determination of the azimuth of the reference objects. In the cases where astronomical observations have been made the accuracy in the azimuth is better than $\pm 0'\cdot 1$. At stations where the azimuths were determined by triangulation the accuracy is much less as *Table* 1 shows. At Abinger the differences in values of the elements as determined by the C.I.W. magnetometer and by the absolute magnetometers are within the limits of error just stated so that it would appear that the mean errors of the absolute values are about the same with the exception of some values of declination.

NORMAL VALUES OF THE ELEMENTS.—Each of the elements can be represented by a linear function of the latitude and the longitude of the station thus :—

$$E=A(\varphi-\varphi_0)+B(\lambda-\lambda_0)+C$$

where φ is the latitude north, in degrees and λ the longitude west. A, B and C are constants.

From a preliminary investigation of the solution of these equations by the method of least squares it was found that the station at Coleraine was in such disturbed surroundings (it is on the basaltic sheet) that it distorted the mean values for the equations. The final reduction was then carried out omitting Coleraine using the data from 43 stations. The values of φ_0 and λ_0 were chosen as 50° N and 5° W, so that the values of $(\varphi-\varphi_0)$ and $(\lambda-\lambda_0)$ were positive for each station. The declination D, is measured west positive. The results are as follows :—

D	=	$0°\cdot248\,(\varphi-50)$	+	$0°\cdot535\,(\lambda-5)$	+	$11°\cdot21$	(1)
$\pm0°\cdot16$		$\pm0°\cdot028$		$\pm0°\cdot021$		$\pm0°\cdot13$	
H	=	$-472\gamma\,(\varphi-50)$	−	$47\gamma\cdot8\,(\lambda-5)$	+	$19\,011\gamma$	(2)
$\pm69\gamma$		$\pm12\gamma$		$\pm9\gamma.0$		$\pm57\gamma$	
I	=	$0°\cdot722\,(\varphi-50)$	+	$0°\cdot082\,(\lambda-5)$	+	$66°\cdot151$	(3)
$\pm0°\cdot090$		$\pm0°\cdot016$		$\pm0°\cdot012$		$\pm0°\cdot074$	
N	=	$-476\gamma\,(\varphi-50)$	−	$84\gamma\cdot4\,(\lambda-5)$	+	$18\,646\gamma$	(4)
$\pm65\gamma$		$\pm11\gamma$		$\pm8\gamma\cdot5$		$\pm53\gamma$	
W	=	$-38\gamma\cdot5\,(\varphi-50)$	+	$146\gamma\cdot1\,(\lambda-5)$	+	$3\,766\gamma$	(5)
$\pm56\gamma$		$\pm9\gamma\cdot8$		$\pm7\gamma\cdot4$		$\pm46\gamma$	
Z	=	$448\gamma\,(\varphi-50)$	+	$65\gamma\,(\lambda-5)$	+	$42\,909\gamma$	(6)
$\pm99\gamma$		$\pm17\gamma$		$\pm13\gamma$		$\pm81\gamma$	

No attempt was made to use an equation of a higher order. In the cases of the components it is possible to find the normal value of the component for a station by using the normal values deduced from two of the other equations. The value so obtained is only very slightly different from the value calculated from the appropriate equation. For example, at Armagh, the normal value for the vertical component Z as calculated from *Equation* 6, is 44971 γ, and as calculated from *Equations* 2 and 3 is 44969 γ.

Beneath the terms in each equation the calculated values of the mean errors of the elements and the coefficients are given. The latter include the random errors in the original measurements, the errors due to correction for diurnal and secular variations and the errors in assuming the component is a linear function of the latitude and the longitude. The last is by far the greatest, since at each station there is a magnetic anomaly associated with the local geology which is, of course, independent of the latitude and longitude.

Equations 1—6 give the normal values for the elements and components of the magnetic field, and these are represented graphically on *Maps* I—IV in the *Appendix*. At each station the normal value (E_n) has been calculated and when deducted from the measured value (E) gives the difference " Observed – Calculated " (ΔE) :—

$$\Delta E=E-E_n$$

Values of " Observed – Calculated " (ΔE) for each component and element are given in *Table V* in the *Appendix*. These are sometimes known as the " anomalies," but in a limited survey of this kind the value is so dependent on the equations used, in this case very simple ones, that this term can only be applied in a very restricted sense. These values are also given on *Maps* I—IV for each station.

DISCUSSION OF THE RESULTS

COMPARISON WITH THE MAGNETIC SURVEY, EPOCH 1915·0.—WALKER reduced his survey by using a semiaverage method and in Ireland the stations were divided into two districts, stations north of latitude 54° constituted District IV and the remainder District VII. This method gives somewhat different results to a method of least squares (SCHUSTER, 1926), so that in order to make a fair comparison of the two surveys, equations similar to 1–6 were calculated by the method of least squares. As for 1950·5, Coleraine was omitted and so was Cookstown Junction, as the readings at the latter are not representative of the region as pointed out earlier. The resulting equations are as follows :—

$$\underset{\pm 0^\circ\cdot 12}{D} = \underset{\pm 0^\circ\cdot 030}{0^\circ\cdot 359\,(\varphi-50)} + \underset{\pm 0^\circ\cdot 022}{0^\circ\cdot 508\,(\lambda-5)} + \underset{\pm 0^\circ\cdot 14}{16^\circ\cdot 86} \qquad (7)$$

$$\underset{\pm 77^\gamma}{H} = \underset{\pm 14^\gamma}{-427^\gamma(\varphi-50)} - \underset{\pm 10^\gamma}{64^\gamma\cdot 0\,(\lambda-5)} + \underset{\pm 65^\gamma}{18\,960^\gamma} \qquad (8)$$

$$\underset{\pm 0^\circ\cdot 091}{I} = \underset{\pm 0^\circ\cdot 017}{0^\circ\cdot 65\,(\varphi-50)} + \underset{\pm 0^\circ\cdot 012}{0^\circ\cdot 122\,(\lambda-5)} + \underset{\pm 0^\circ\cdot 076}{66^\circ\cdot 400} \qquad (9)$$

$$\underset{\pm 71^\gamma}{N} = \underset{\pm 13^\gamma}{-439^\gamma(\varphi-50)} - \underset{\pm 9^\gamma\cdot 4}{111^\gamma\cdot 7\,(\lambda-5)} + \underset{\pm 60^\gamma}{18\,137^\gamma} \qquad (10)$$

$$\underset{\pm 59^\gamma}{W} = \underset{\pm 11^\gamma}{-40^\gamma(\varphi-50)} + \underset{\pm 7^\gamma\cdot 8}{123^\gamma\cdot 9\,(\lambda-5)} + \underset{\pm 50^\gamma}{5\,574^\gamma} \qquad (11)$$

$$\underset{\pm 93^\gamma}{Z} = \underset{\pm 17^\gamma}{414^\gamma(\varphi-50)} + \underset{\pm 12^\gamma}{118^\gamma(\lambda-5)} + \underset{\pm 78^\gamma}{43\,294^\gamma} \qquad (12)$$

When the two sets of equations are compared it can be seen from the corresponding left hand sides that the mean errors for D and I are almost identical while those for H are very close. This means that the fit of the equations is the same. They do not give however any measure of the relative accuracy of each survey. As before, values of ΔE have been calculated and these are reproduced in *Table* V along with the corresponding figures for 1950·5.

The equations have been derived in similar manner with similar data and the values of ΔE for each Epoch are comparable.

In *Table* V under the columns ΔD, a few large discrepancies occur. Some of these are at stations whose position in the two surveys were different, e.g. Bangor with a difference of 4′·9, and can be explained by the presence of a local disturbance at one or other of the two positions. However, at Coleraine, Kells and Valentia the differences are −10′·9, 4′·8 and −6′·7 respectively, well outside the limits of error. There are no correspondingly large differences between the ΔH and ΔI for the two epochs at these stations. It is not known what is the reason for the discrepancies.

In the columns, for ΔH and ΔI, there are no outstanding differences.

With the few exceptions just indicated the agreement between the results of the two surveys is good. The mean values for the differences, $\Delta E_{1915}-\Delta E_{1950}$, were calculated for each element and gave for declination ±2′·4, horizontal intensity ±16γ and inclination ±1′·4. The mean errors in these elements have been given as ±0′·8, ±7γ and ±0′·5 respectively and WALKER considered his values were correct to ±1′·0, ±15γ and ±1′. From these mean errors the values for the mean differences given above are reasonable and changes, if any, in the magnetic anomalies, which may have taken place in the interval between the surveys, do not stand out. WALKER reached a similar conclusion when he compared the results of his survey with that of 1886.

In *Table* III the values of the elements and components for 1915 have been taken from the publication by WALKER. This can be compared with *Table* IV which gives the values for 1950. The difference in declination which has taken place in the interval of 35 years is about 6°, being a little greater in the north than in the south. In horizontal intensity there has been practically no change in the south, and a small decrease of about 150γ in the north, while inclination shows no change in the north and a decrease of about 20′ in the south west. The changes can be expressed in the form of equations by subtracting the corresponding equations from 1 to 12.

$$D_{1950} - D_{1915} = -0^\circ{\cdot}11(\varphi-50) + 0^\circ{\cdot}03(\lambda-5) - 5^\circ{\cdot}65 \qquad (13)$$

$$H_{1950} - H_{1915} = -45\gamma(\varphi-50) + 16\gamma(\lambda-5) + 51\gamma \qquad (14)$$

$$I_{1950} - I_{1915} = 0^\circ{\cdot}07(\varphi-50) - 0^\circ{\cdot}04(\lambda-5) - 0^\circ{\cdot}25 \qquad (15)$$

The direction of the isogons of declination depicted on *Map* I are calculated from *Equation* 1 to be N.22°E. Similarly from *Equation* 13 the direction of the isoporic lines is E.24°S., in other words, they are almost normal to the isogons. This means that in the 35 year interval the isogons have moved nearly parallel to themselves.

Up to now it was the practice to deduce values of declination for Ireland by applying to the 1915 figures a correction derived from the magnetic observatories in England. From the values of declination at Abinger it can be shown that the change there agrees within a few minutes with *Equation* 13 so that during this period this method of prediction was quite accurate. This may be accidental as the change in declination (VESTINE et al., 1947), has been regular in the interval. On the other hand the figures for Eskdalemuir do not show such good agreement so that it would be unsafe to place too much reliance on the method. Until the next resurvey no doubt the values of declination will be deduced as heretofore and we hope that conditions similar to those which pertained from 1915 will continue in the future.

COMPARISON WITH THE DECLINATION SURVEY OF GREAT BRITAIN, EPOCH 1948·5.—A magnetic survey was carried out in 1948 by members of the Ordnance Survey of Great Britain when measurements of declination were made. Through the courtesy of the Director General and Mr. T. H. O'BEIRNE, formerly Scientific Adviser, a copy of the results of this survey was sent to us to enable a comparison to be made between the surveys.

O'BEIRNE, in the reduction of the survey, used a method of least squares and arrived at the following equation for declination

"Magnetic Variation (in minutes) at 1948·5 $= 778{\cdot}6 - 469{\cdot}0(\mathbf{E}/10^6) + 126{\cdot}4(\mathbf{N}/10^6)$ (16)
where **E** and **N** are National Grid coordinates in metres."

The form in which the equation is given is not suitable for comparing with *Equation* 1 and there is no simple way of converting it into an equation involving latitude and longitude. Another reduction was made using a method of least squares but based on latitude and longitude in the same manner as for *Equation* 1. The result is as follows :—

$$D_{1948\cdot5} = 0^\circ{\cdot}216(\varphi-50) + 0^\circ{\cdot}533(\lambda+2) + 7^\circ{\cdot}78 \qquad (17)$$

with D in degrees, west positive, and λ, the longitude, measured positive to the west as for *Equation* 1.

To allow for the change of epoch a simple reduction is made by subtracting 14′ that is assuming there has been a uniform change in declination throughout the area in the period from 1948 to 1950. The longitude term is changed to bring it in accordance with *Equation* 1 and then the equation for declination for Great Britain at epoch 1950·5 can be written as

$$D_{1950\cdot5} = 0^\circ{\cdot}216(\varphi-50) + 0^\circ{\cdot}533(\lambda-5) + 11^\circ{\cdot}28 \qquad (18)$$

while *Equation* 1 is

$$D_{1950\cdot5} = 0^\circ{\cdot}248(\varphi-50) + 0^\circ{\cdot}535(\lambda-5) + 11^\circ{\cdot}21$$

In both equations the declination, D, and the longitude, λ, are measured positive to the west.

The coefficients in the corresponding terms of *Equations* 1 and 18 are almost identical. In *Fig.* 1 a sketch map is drawn of this area with lines of equal declination, deduced from *Equations* 1 and 18, drawn thereon. It can be seen that in the Irish Sea there is almost complete agreement while north of Ireland there are small differences which are not important since throughout this region, in Ireland and Scotland, there is considerable local magnetic disturbance.

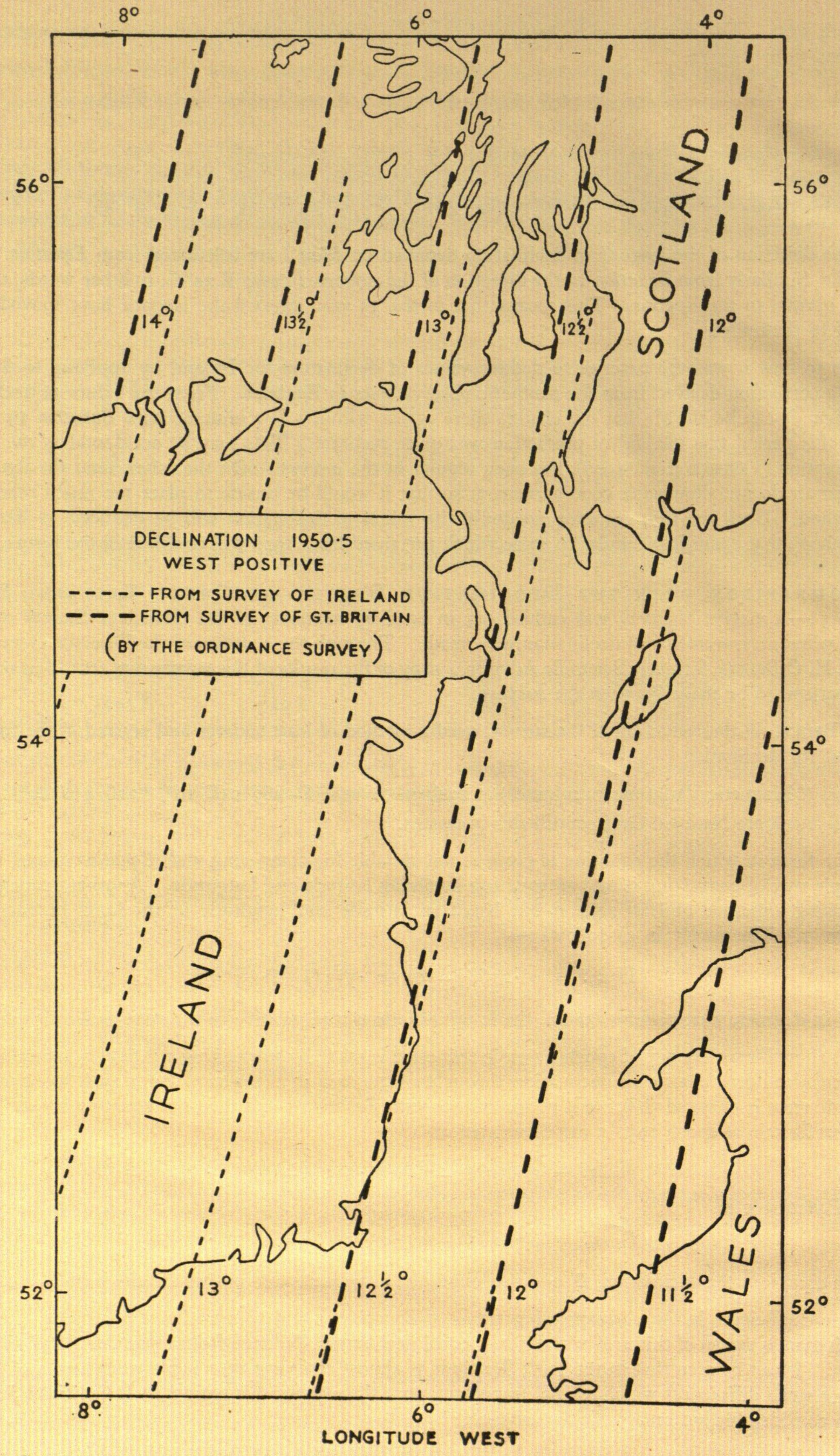

Fig 1—Comparison between the results of the two Declination Surveys of Great Britain and Ireland, Epoch 1950·5.

Comparison with the Vertical Magnetic Survey of the Geological Survey, Epoch 1945·5.—The Geological Survey of Ireland carried out a magnetic survey, during the period 1944—1946, using a vertical field variometer. The results were published in the form of maps in 1949.

A reduction of this survey was carried out as follows. Values at the intersections of a grid drawn at intervals of ten minutes in latitude and longitude were interpolated from the map for vertical intensity. These values, at 166 intersections, were reduced by a method of least squares to give the following result

$$Z_{1945\cdot 5} = 454\gamma(\varphi-50) + 69\gamma(\lambda-5) + 42\,828\gamma \qquad (19)$$

From Vestine et al. (1947) and Johnston (1951), the vertical magnetic field has increased at Eskdalemuir and Abinger by about 83δ. If *Equation* 19 is corrected by simply adding this amount and ignoring the change in declination in this period, then

$$Z_{1950\cdot 5} = 454\gamma(\varphi-50) + 69\gamma(\lambda-5) + 42\,911\gamma \qquad (20)$$

For comparison *Equation* 6 is rewritten

$$Z_{1950\cdot 5} = 448\gamma(\varphi-50) + 65\gamma(\lambda-5) + 42\,909\gamma$$

These two equations will give the same value for any point within reasonable limits, but this is in the nature of a coincidence since the fit of the equations to the data, particularly *Equation* 6, is not very high. However it can be said that the agreement is very good.

Part of the equipment of the present survey consisted of a vertical field balance and if time permitted, comparisons between the station and nearby stations of the Geological Survey's network were carried out. This could only be done at 11 stations. The mean difference between the two sets of readings was calculated as $\pm 39\gamma$.

At the other stations the value of the vertical field was interpolated from the readings at nearby stations in the Geological Survey's grid, if in undisturbed regions. The mean difference between the two sets of readings is $\pm 33\gamma$.

The mean error in the variometer readings is about $\pm 10\gamma$ and we have deduced that the error in the values of Z derived from H and I as $\pm 27\gamma$, so that one could expect the two sets of readings to have a mean difference of $\pm 29\gamma$.

The two surveys are thus consistent with each other.

Line Integrals and Earth-Air Currents.—Measurements of potential gradients and conductivity of the air indicate the presence of earth-air currents of the order of 10^{-6} amp. per sq. km, while line integrals of horizontal magnetic forces from various surveys yield figures for the non-potential part of the earth's field which are in complete disagreement with currents of this size (Chapman and Bartels, p. 112).

It is thought by Chapman (1942) that these discrepancies are attributable to errors in the values of D and H and he has suggested that evaluations of the line integrals might serve as a test of accuracy of determination of these two elements, which are derived independently, and of the consistency of two different surveys.

The results of the 1891 survey were used by Rücker in 1896 to deduce values of the earth-air currents. He used a graphic method of integration interpolating values from maps of the true isomagnetics and concluded that in Ireland : " The local irregularities in the North of Ireland are so great that the calculations based on the true isomagnetics in that country may be neglected as compared with the probably much better results obtained in Great Britain." The value he obtained in Ireland was $-0\cdot008$ amp. per sq. km , the negative sign indicating current into the earth.

Walker, in the process of reduction of his 1915 survey gives the values of the equivalent current for the non-potential terms in his equations for the north and west components. He used a method of least squares but the details of his calculations are not quite clear. One of the sub-divisions of his survey, District VII, consists of all the stations in Ireland south of latitude 54°, with the exception of station 166, and for this area he obtained a value of 0·040 amp. per sq. km for the current density.

Schuster in 1926, used Walker's values for the components, and by a method of least squares obtained a figure of 0·023 amp. per sq. km. for the current density in District VII. He calculated the probable error* to be $\pm 0\cdot105$ amp. per sq. km. which is much greater than the deduced current density.

* In this section probable error is used instead of mean error to facilitate comparison with earlier work. The probable error is calculated as $0\cdot6745 \times$ mean error.

Two different methods were used in the present survey, the first due to NIPPOLDT, which uses the observed and not the reduced data, and the second after SCHUSTER.

The outlines of the various line integrals are given in *Fig.* 2. By NIPPOLDT's method around the complete circuit the current density was calculated as 0·65 amp. per sq. km and around the smaller circuit, equivalent to District VII, 1·12 amp. per sq. km. For SCHUSTER's method around District VII, equations for the north and west components similar to *Equations* 4 and 5 were calculated by the method of least squares from the data for the 31 stations. The current density so obtained was 0·0017 amp. per sq. km. Using SCHUSTER's expression (see later), the probable error was calculated as ±0·10 amp. per sq. km; that is sixty times the deduced current density. This is similar to what SCHUSTER found and commented upon.

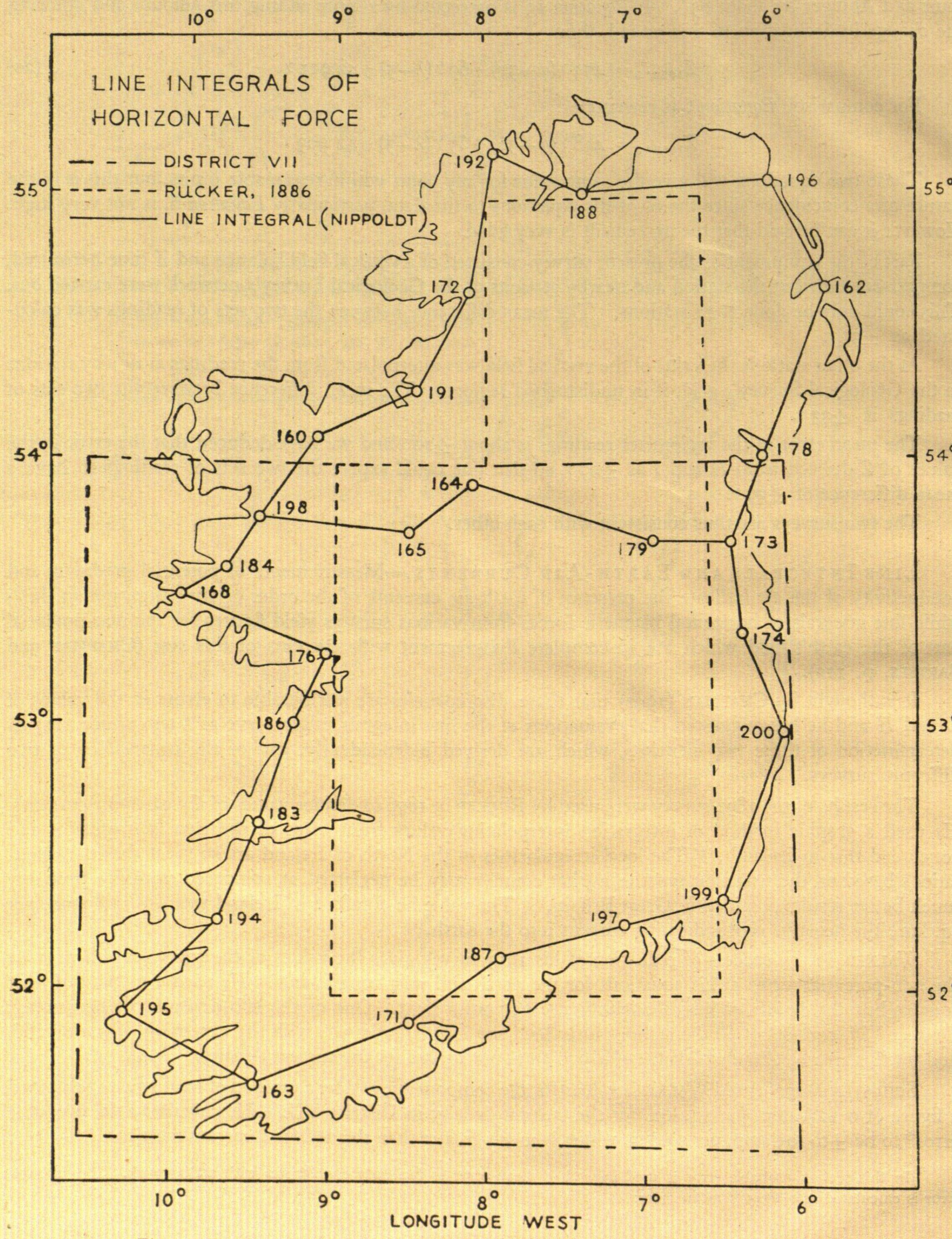

Fig. 2—Outlines of the areas for computation of the Line Integrals of Horizontal Force.

From *Equations* 10 and 11 and *Equations* 4 and 5, the current densities for the whole of Ireland calculated by SCHUSTER's method are 0·074±0·092 amp. per sq. km, and 0·053±0·084 amp. per sq. km for epochs 1915 and 1950 respectively.

TABLE 7

EARTH - AIR CURRENTS

(in amp. per sq. km)

	All Ireland		
1915	SCHUSTER's method	0·074	±0·092*
1950	SCHUSTER's method	0·053	±0·084*
1950	NIPPOLDT's method	0·65	
	District VII		
1915	SCHUSTER's value	0·023	±0·105*
1950	SCHUSTER's method	0·0017	±0·100*
1950	NIPPOLDT's method	1·12	

The very large value for the probable errors as compared with the deduced values for the earth-air current requires some explanation. SCHUSTER, *Equation* 11 on page 72, gives for the probable error

$$[\delta I]^2 = 11\cdot817 \left\{ [a]^2 + [\beta]^2 \sec^2\varphi \right\} + 10^{-6}[W_0]^2 \tan^2\varphi \qquad (21)$$

where the square brackets denote probable errors, a is the latitude term in the equation for N and β is the longitude term in the equation for W, φ is the mean latitude and W_0 is the mean value of W. In SCHUSTER's equations for N and W the values of φ and λ are in minutes. He points out that the last term is negligible. (Note.—In SCHUSTER's paper there is some confusion in the symbols due, presumably, to misprints).

The probable errors of a and β, as have been discussed earlier, consist of three parts the greatest of which is the " fit " of the experimental figures to the linear equations for N and W, *Equations* 4 and 5, and 10 and 11. Thus the probable error in the earth-air current and the actual value obtained for the earth-air current is more dependent on the " fit " of the experimental data to linear equations than on the experimental errors in the observations. Hence this method cannot be applied in this case, to testing the mutual consistency of the values of D and H as suggested by CHAPMAN (1942).

The high probable errors in the earth-air currents deduced by SCHUSTER's method also indicates that magnetic surveys of this type cannot give any evidence for the presence or absence of currents of the size inferred from atmospheric electricity measurements. This can only be done, if at all, as SCHUSTER suggested, by a survey in a limited area where the magnetic field is known to vary with sufficient regularity; a very difficult condition to fulfil in practice.

* Probable error.

REFERENCES

CHAPMAN, S. (1942): Notes on isomagnetic charts VI. *Terr. Mag. and Atmos. Elec.*, Washington, **47**, 1–13.

CHAPMAN, S. (1942): Notes on isomagnetic charts VIII. *Terr. Mag. and Atmos. Elec.*, Washington, **47**, 139–146.

CHAPMAN, S. and BARTELS, J. (1940): Geomagnetism, Vol. I. Oxford, Clarendon Press.

FLEMING, J. A. (1911): Two new types of magnetometers made by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. *Terr. Mag. and Atmos. Elec.*, Washington, **16**, 1–12.

FLEMING, J. A. and WIDMER, J. A. (1913): Description of the C.I.W. combined magnetometer and earth inductor. *Terr. Mag. and Atmos. Elec.*, Washington, **18**, 105–110.

HAZARD, D. L. (1947): Directions for magnetic measurements. Washington, United States Government Printing Office.

JOHNSTON, H. F. (1951): List of geomagnetic observatories and thesaurus of values. *Jour. Geophys. Res.*, Washington, **56**, 431–438.

NIPPOLDT, A., 1914 : in MUELLER-POUILLET, Lehrbuch der Physik, Braunschweig, **4**, 1348–49.

RÜCKER, A. W. (1896) : On the existence of vertical earth-air electric currents in the United Kingdom. *Phil. Mag.*, London, **41**, 99–106, and *Terr. Mag. and Atmos. Elec.*, Washington, **1**, 77–84.

RÜCKER, A. W. and THORPE, T. E. (1890) : A magnetic survey of the British Isles for the Epoch January 1, 1886. *Phil. Trans. Roy. Soc.*, London, **181A**, 53–328.

RÜCKER, A. W. and THORPE, T. E. (1897) : A magnetic survey of the British Isles for the Epoch January 1, 1891. *Phil. Trans. Roy. Soc.*, London, **188A**, 1–661.

SABINE, E. (1870) : Contributions to terrestrial magnetism.—No. XII. The magnetic survey of the British Isles, reduced to Epoch 1842·5. *Phil. Trans. Roy. Soc.*, London, **160**, 265–275.

SCHUSTER, A. (1926) : A review of Mr. G. W. Walker's magnetic survey. *Proc. Roy. Soc.*, London, **111A**, 68–82.

VESTINE, E. H. et al. (1947) : Description of the earth's main magnetic field and its secular change, 1905–1945. *Carnegie Institution of Washington Publication* **578**, Washington, D.C.

WALKER, G. W. (1919) : The magnetic re-survey of the British Isles for the Epoch January 1, 1915. *Phil. Trans. Roy. Soc.*, London, **219A**, 1–72.

Vertical Magnetic Intensity Maps (1949) : Geol. Survey Ireland, Dublin.

DUBLIN,
JANUARY 27, 1953.

APPENDIX

TABLE I. LOCATIONS OF THE STATIONS

No.*	Name of Station	Latitude North		Longitude West		Six Inch Sheet Number		25 Inch Plan Number
		°	′	°	′			
157	Armagh	54	21·9	6	39·7	Armagh	12	6
158	Athlone	53	26·8	7	55·9	Westmeath	29	2
159	Bagnalstown	52	40·6	6	56·0	Carlow	16	14
160	Ballina	54	07·1	9	08·0	Mayo	30	12
161	Ballywilliam	52	26·1	6	52·9	Wexford	29	4
162	Bangor	54	38·7	5	38·7	Down	2	10
163	Bantry	51	40·0	9	28·9	Cork	118	10
164	Carrick-on-Shannon	53	56·6	8	04·5	Leitrim	31	6
165	Castlereagh	53	45·4	8	31·4	Roscommon	26	7
166	Cavan	53	59·6	7	20·6	Cavan	20	16
167	Charleville	52	21·1	8	39·9	Cork	3	9
168	Clifden	53	30·0	10	01·3	Galway	35	4
169	Coleraine	55	08·3	6	41·4	Londonderry	7	3
170A	Tobermore	54	48·1	6	44·7	Londonderry	36	13
171	Cork	51	54·5	8	30·1	Cork	74	6
172	Donegal	54	39·1	8	06·4	Donegal	93	16
173	Drogheda	53	42·6	6	22·3	Meath	20	11
174	Dublin	53	21·4	6	20·4	Dublin	18	5
175	Enniskillen	54	21·4	7	39·0	Fermanagh	22	9
176	Galway	53	17·2	9	01·8	Galway	82	15
177	Gort	53	04·3	8	47·6	Galway	123	9
178	Greenore	54	01·0	6	07·7	Louth	9	5
179	Kells	53	42·0	6	53·0	Meath	17	13
180	Kildare	53	09·8	6	52·2	Kildare	23	9
181	Kilkenny	52	39·1	7	15·9	Kilkenny	19	7
182	Killarney	52	04·5	9	33·5	Kerry	66	2
183	Kilrush	52	38·6	9	28·6	Clare	67	2
184	Leenane	53	36·6	9	41·0	Mayo	116	—
185	Limerick	52	38·7	8	38·9	Limerick	5	14
186	Lisdoonvarna	53	01·8	9	16·0	Clare	8	8
187	Lismore	52	09·1	7	54·6	Waterford	21	9
188	Londonderry	55	01·3	7	19·3	Londonderry	14	2
189	Oughterard	53	26·2	9	18·4	Galway	54	7
190	Birr (Parsonstown)	53	04·4	7	56·0	Tipperary	5	16
191	Sligo	54	16·5	8	28·0	Sligo	14	8
192A	Dunfanaghy	55	10·7	7	56·3	Donegal	16	13
193	Tipperary	52	28·6	8	12·0	Tipperary	66	4
194	Tralee	52	16·6	9	43·5	Kerry	29	10
195	Valentia	51	55·6	10	17·9	Kerry	79	9
196	Waterfoot	55	03·4	6	03·4	Antrim	20	9
197	Waterford	52	17·1	7	10·9	Kilkenny	43	13
198	Westport	53	48·3	9	29·5	Mayo	88	2
199	Wexford	52	21·6	6	27·5	Wexford	37	8
200	Wicklow	52	58·7	6	03·6	Wicklow	25	15

*The numbers are the same as those used by RÜCKER and THORPE, and WALKER.

TABLE II. COMPARISON BETWEEN STATIONS OF THE 1915 AND 1950 SURVEYS

No.	Name of Station	Relation to Stations of 1915 Survey				1915 Station	Azimuths Determined	
		Iden-tical	At position described	Within 50 yards	Distance away		Astrono-mically	From Tri-angulation
157	Armagh	√					√	
158	Athlone	√						√
159	Bagnalstown	√						√
160	Ballina	√						√
161	Ballywilliam	√					√	
162	Bangor				1 mile S.	Destroyed	√	
163	Bantry			√		Under crops	√	
164	Carrick-on-Shannon			√		Not found	√	
165	Castlereagh	√						√
166	Cavan	√						√
167	Charleville		√			Not found	√	
168	Clifden	√						√
169	Coleraine		√			Not found	√	
170A	Tobermore				20 miles W.	See text	√	
171	Cork	√					√	
172	Donegal	√					√	
173	Drogheda	√						√
174	Dublin				2½ miles S.W.	Destroyed	√	
175	Enniskillen		√			Not found	√	
176	Galway			√		Overgrown	√	
177	Gort			√		Under crops	√	
178	Greenore	√						√
179	Kells		√			Not found	√	
180	Kildare				250 yds. N.	Not found	√	
181	Kilkenny				350 yds. W.	Destroyed	√	
182	Killarney				1 mile N.	Overgrown	√	
183	Kilrush			√		Unusable		√
184	Leenane				¾ mile W.	Not found	√	
185	Limerick				150 yds. S.E.	Not found	√	
186	Lisdoonvarna	√						√
187	Lismore	√					√	
188	Londonderry				350 yds. N.	Not found	√	
189	Oughterard		√			Not found	√	
190	Birr (Parsonstown)	√						√
191	Sligo	√						√
192A	Dunfanaghy				31 miles N.W.	See text	√	
193	Tipperary	√						√
194	Tralee	√						√
195	Valentia	√						√
196	Waterfoot				250 yds. W.	Not found	√	
197	Waterford	√					√	
198	Westport	√						√
199	Wexford	√						√
200	Wicklow		√			Not found	√	

The mark(s) √ opposite the name of each station indicates the column heading(s) applicable to that station.

TABLE III. MAGNETIC ELEMENTS FOR EPOCH 1915·0*

No.	Name of Station	Declination West *D*	Horizontal Intensity *H*	Inclination *I*	North Component *N*	West Component *W*	Vertical Component *Z*
		° ′	γ	° ′	γ	γ	γ
157	Armagh	19 13·0	17028	69 22·6	16079	5605	45254
158	Athlone	19 28·4	17304	69 01·1	16314	5769	45122
159	Bagnalstown	18 52·5	17660	68 22·1	16710	5713	44532
160	Ballina	20 15·3	16744	69 44·9	15709	5797	45382
161	Ballywilliam	18 35·5	17650	68 25·5	16729	5627	44639
162	Bangor	18 37·0	16969	69 29·2	16081	5417	45353
163	Bantry	19 39·3	18017	67 58·1	16967	6060	44523
164	Carrick-on-Shannon	20 00·2	17130	69 18·4	16097	5860	45349
165	Castlereagh	20 12·1	17120	69 19·1	16067	5912	45351
166	Cavan	19 32·7	17021	69 19·1	16040	5694	45068
167	Charleville	19 36·2	17705	69 19·9	16679	5940	44562
168	Clifden	20 32·3	17077	69 17·3	15992	5991	45165
169	Coleraine	19 48·8	17138	69 18·7	16123	5809	45382
170	Cookstown Junction	17 20·0	16926	69 31·0	16157	5043	45311
171	Cork	19 22·1	17923	68 02·5	16908	5944	44454
172	Donegal	19 44·8	16948	69 32·7	15951	5726	45438
173	Drogheda	18 58·4	17277	69 00·1	16338	5617	45012
174	Dublin	18 46·0	17474	68 42·3	16545	5622	44830
175	Enniskillen	19 52·6	16887	69 37·3	15881	5742	45460
176	Galway	20 25·1	17320	69 03·1	16232	6042	45242
177	Gort	19 50·6	17449	68 50·0	16413	5923	45064
178	Greenore	19 10·5	17220	69 06·8	16265	5656	45126
179	Kells	19 17·8	17327	69 01·3	16354	5726	45190
180	Kildare	19 01·8	17515	68 37·2	16558	5711	44739
181	Kilkenny	18 50·6	17671	68 21·2	16724	5707	44526
182	Killarney	19 57·5	17908	68 12·1	16832	6113	44777
183	Kilrush	20 11·3	17549	68 42·1	16471	6056	45015
184	Leenane	20 24·4	16986	68 24·8	15920	5923	45222
185	Limerick	19 52·3	17660	68 31·3	16608	6003	44882
186	Lisdoonvarna	19 58·7	17486	68 48·5	16434	5974	45101
187	Lismore	19 06·3	17823	68 08·5	16841	5833	44429
188	Londonderry	19 48·8	16730	69 51·4	15740	5671	45610
189	Oughterard	20 37·3	17177	69 14·0	16076	6050	45298
190	Parsonstown	19 29·9	17422	68 48·7	16423	5815	44944
191	Sligo	20 05·8	16829	69 41·0	15804	5783	45454
192	Strabane	19 50·4	16789	69 47·6	15792	5698	45615
193	Tipperary	19 23·5	17724	68 21·9	16719	5885	44686
194	Tralee	20 10·6	17712	68 24·9	16625	6109	44770
195	Valentia	20 12·0	17911	68 08·9	16809	6185	44664
196	Waterfoot	19 22·4	16755	69 47·5	15806	5558	45518
197	Waterford	18 30·5	17809	68 12·6	16888	5653	44548
198	Westport	20 12·8	16921	69 38·6	15879	5846	45605
199	Wexford	18 16·5	17778	68 14·2	16881	5575	44531
200	Wicklow	18 20·7	17557	68 29·6	16665	5526	44556

* From WALKER, pages 32 and 38.

TABLE IV. MAGNETIC ELEMENTS FOR EPOCH 1950·5

No.	Name of Station	Declination West *D*	Horizontal Intensity *H*	Inclination *I*	North Component *N*	West Component *W*	Vertical Component *Z*
		° ′	γ	° ′	γ	γ	γ
157	Armagh	13 12·4	16903	69 22·3	16456	3862	44902
158	Athlone	13 30·0	17259	68 53·7	16782	4029	44716
159	Bagnalstown	12 58·4	17606	68 15·4	17157	3953	44145
160	Ballina	14 12·7	16694	69 37·4	16183	4098	44945
161	Ballywilliam	12 40·8	17626	68 13·4	17196	3869	44120
162	Bangor	12 32·5	16818	69 30·5	16417	3652	45002
163	Bantry	13 59·0	18072	67 38·6	17537	4367	43940
164	Carrick-on-Shannon	13 59·6	17016	69 13·5	16511	4115	44854
165	Castlereagh	14 13·7	17076	69 10·4	16547	4196	44890
166	Cavan	13 29·6	16937	69 17·8	16470	3952	44815
167	Charleville	13 44·2	17727	68 06·0	17220	4209	44097
168	Clifden	14 38·4	17044	69 03·7	16491	4308	44544
169	Coleraine	13 48·9	16959	69 23·1	16468	4050	45083
170A	Tobermore	13 24·9	16699	69 42·9	16243	3874	45180
171	Cork	13 37·9	17963	67 45·9	17457	4234	43940
172	Donegal	13 41·2	16806	69 30·7	16329	3976	44978
173	Drogheda	12 55·7	17197	68 58·6	16761	3847	44745
174	Dublin	12 46·4	17388	68 39·3	16958	3844	44495
175	Enniskillen	13 49·3	16782	69 34·5	16296	4009	45065
176	Galway	14 29·8	17275	68 50·3	16725	4324	44626
177	Gort	13 55·4	17401	68 40·3	16890	4187	44566
178	Greenore	13 07·6	17099	69 06·5	16652	3883	44797
179	Kells	13 12·1	17229	68 59·3	16774	3935	44856
180	Kildare	13 05·6	17469	68 32·3	17015	3957	44435
181	Kilkenny	13 01·9	17652	68 13·1	17197	3980	44174
182	Killarney	14 12·6	17896	67 56·1	17347	4393	44150
183	Kilrush	14 20·2	17556	68 26·0	17009	4347	44417
184	Leenane	14 27·5	16956	69 15·7	16419	4234	44782
185	Limerick	13 50·4	17681	68 16·5	17172	4230	44374
186	Lisdoonvarna	14 09·1	17461	68 39·0	16931	4269	44670
187	Lismore	13 15·9	17835	67 55·8	17359	4092	43988
188	Londonderry	13 42·8	16578	69 53·0	16106	3930	45261
189	Oughterard	14 43·7	17146	69 05·5	16583	4359	44881
190	Birr (Parsonstown)	13 33·8	17398	68 39·0	16913	4080	44509
191	Sligo	14 02·1	16758	69 35·9	16258	4064	45057
192A	Dunfanaghy	13 54·9	16495	70 01·3	16011	3967	45373
193	Tipperary	13 32·9	17711	68 10·6	17208	4147	44228
194	Tralee	14 26·3	17735	68 10·0	17175	4422	44266
195	Valentia	14 35·1	17957	67 49·8	17378	4522	44068
196	Waterfoot	13 11·5	16585	69 53·5	16147	3785	45300
197	Waterford	12 37·6	17770	68 00·0	17340	3885	43982
198	Westport	14 17·3	16888	69 31·1	16366	4168	45213
199	Wexford	12 24·9	17764	68 06·4	17352	3820	44204
200	Wicklow	12 20·3	17505	68 24·9	17101	3740	44246

TABLE V. OBSERVED—CALCULATED

for Epochs 1915·0 and 1950·5

No.	Name of Station	ΔD		ΔH		ΔI		ΔN		ΔW		ΔZ	
		1915	1950	1915	1950	1915	1950	1915	1950	1915	1950	1915	1950
		′	′	γ	γ	′	′	γ	γ	γ	γ	γ	γ
157	Armagh	−3·3	1·8	40	33	−3·9	−3·9	43	30	2	21	−42	−69
158	Athlone	−6·8	−7·7	5	16	1·2	1·0	17	25	−29	−33	56	74
159	Bagnalstown	4·3	4·1	−32	−48	−0·5	1·0	−37	−51	8	7	−98	−88
160	Ballina	−11·0	−13·5	−191	−174	10·0	9·8	−160	−152	−122	−114	−104	−76
161	Ballywilliam	−5·9	−8·2	−148	−145	12·7	9·7	−130	−131	−81	−79	115	−1
162	Bangor	−14·6	−9·7	42	32	−1·3	−2·8	60	39	−48	−30	55	−29
163	Bantry	−4·8	−2·0	56	62	−4·0	−4·6	62	63	−2	10	10	−5
164	Carrick-on-Shannon	9·9	9·9	52	14	−1·9	−1·4	33	3	65	51	60	−20
165	Castlereagh	12·2	12·4	−9	8	2·8	1·4	−28	−12	54	59	86	71
166	Cavan	3·7	2·6	−82	−76	2·2	4·4	−83	−76	−9	−3	−155	−34
167	Charleville	2·2	−0·7	−15	2	−2·6	−2·8	−17	4	7	−2	−138	−102
168	Clifden	−7·6	−7·1	−65	−74	0·1	−1·5	−49	−64	−63	−57	−171	−257
169	Coleraine	15·0	25·9	483	455	−38·2	−36·7	429	412	234	234	−238	−237
170A	Tobermore	—	5·1	—	39	—	−2·6	—	30	—	37	—	8
171	Cork	2·6	4·8	3	21	−1·5	−2·9	−1	16	14	29	−43	−50
172	Donegal	−21·7	−20·0	175	140	−15·5	−15·0	202	161	−45	−65	−148	−215
173	Drogheda	5·1	4·1	−9	4	1·3	2·2	−18	−2	23	23	21	86
174	Dublin	1·4	1·1	48	26	−3·6	−1·7	43	24	23	11	−22	−4
175	Enniskillen	6·4	7·1	−41	−45	3·9	3·8	−49	−51	16	23	50	33
176	Galway	19·9	19·3	23	9	1·4	−0·8	−13	−15	102	95	112	−15
177	Gort	−2·8	−4·4	45	22	−1·6	−0·3	47	27	3	−15	51	36
178	Greenore	18·0	19·3	49	39	−2·2	−2·0	16	15	105	106	37	16
179	Kells	9·1	4·3	69	55	−0·8	0·8	51	49	69	36	143	168
180	Kildare	5·1	6·1	26	41	−3·8	−2·9	17	34	33	39	−84	−12
181	Kilkenny	−7·1	−2·6	−12	2	−2·7	−1·9	2	5	−40	−15	−132	−69
182	Killarney	2·8	3·1	120	83	−5·5	−5·1	107	74	59	40	93	17
183	Kilrush	6·3	4·9	6	7	2·3	0·6	−6	0	34	28	98	35
184	Leenane	−7·3	−8·8	−131	−126	5·8	7·4	−111	−112	−83	−78	−118	−47
185	Limerick	12·5	1·6	65	94	−2·6	−5·0	40	94	84	32	62	45
186	Lisdoonvarna	−8·2	−5·2	94	85	−4·9	−2·2	103	88	−6	−4	49	128
187	Lismore	−0·4	−1·9	−31	−21	−0·7	−0·7	−27	−16	−14	−17	−99	−73
188	Londonderry	−1·7	1·3	64	50	−5·4	−4·9	64	48	12	18	−35	−47
189	Oughterard	20·4	22·0	−38	−36	4·4	6·5	−72	−62	82	96	73	154
190	Birr (Parsonstown)	2·7	1·6	−36	−21	3·4	2·5	−38	−21	2	3	32	34
191	Sligo	−3·5	−5·1	−82	−68	4·9	4·8	−70	−59	−47	−44	−18	9
192A	Dunfanaghy	—	−8·8	—	70	—	−6·4	—	80	—	−29	—	−45
193	Tipperary	1·0	1·0	28	23	−2·1	−1·4	26	12	15	8	−11	3
194	Tralee	5·9	8·5	28	25	−2·4	−0·8	14	12	42	53	−24	32
195	Valentia	−2·6	4·1	114	109	−9·0	−8·6	109	97	33	56	−53	−46
196	Waterfoot	9·8	10·0	25	13	−1·6	0·3	6	−1	58	59	6	58
197	Waterford	−16·8	−18·8	−34	−57	3·5	1·3	−3	−33	−99	−112	51	−91
198	Westport	−17·7	−15·8	−125	−111	13·3	15·3	−87	−88	−130	−108	206	310
199	Wexford	−10·4	−9·4	−80	−63	7·5	8·0	−58	−47	−84	−69	88	144
200	Wicklow	−7·4	−10·4	−62	−49	1·6	1·7	−47	−37	−59	−67	−95	−65

GEOPHYSICAL MEMOIRS

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GEOPHYSICAL BULLETINS

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