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Notes on

# The Reading and Reduction of Ground Total Field Magnetic Data

## with particular reference to Ireland

by

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## 1. Introduction

Apart from commercial applications, the use of total field magnetometer readings in the interpretation of geological structure will be of increasing importance in Ireland as both the Geological Survey and the Universities expand their activities. The use of magnetic readings in academic geological interpretation in the Republic was largely initiated from the Institute for Advanced Studies (Murphy 1952, 1955), and it seems valuable at this time to publish some notes on the practical procedures at present used in the Institute.

The following makes no pretence to being a complete guide to the general conduct and planning of a survey, adequately covered in standard text books e.g. Parasnis, Griffiths and King, but to treat in detail some of the technical points which are not normally the subject of publication. The text has been kept brief and essentially in note form.

The magnetometers in present use at the Institute are 'Elsec' Proton Magnetometers manufactured by the Littlemore Engineering Company, Oxford, England.

## 2. Reading and Field Procedure

### 2.1 *Values*

An approximate value for any area can be found from the map of McWilliams and Byrne (1966) to which a secular rise of approximately 25 gamma per year should be applied. Except in extremely anomalous areas the field value should not depart more than 2–300 gamma from this.

### 2.2 *Stations*

Reading procedure depends considerably upon conditions and scope of surveys. Obviously with a close archaeological or field survey, single readings are taken, but for a general (say 1 per mile) survey at least three readings at each station are advisable at approximately 30 ft. apart. Bottle height should be at least 4 ft. Normal precautions about metal objects should be taken (see 2.3 below).

### 2.3 *Survey vehicles*

The magnetic effect of a vehicle (e.g. Land Rover) is probably greater than that to be expected from the equivalent mass of metal (Johnston and Stacey, 1968). Measurements at the Institute suggest that the effect is, in practice, negative, the anomaly having a form as in Fig. 1.

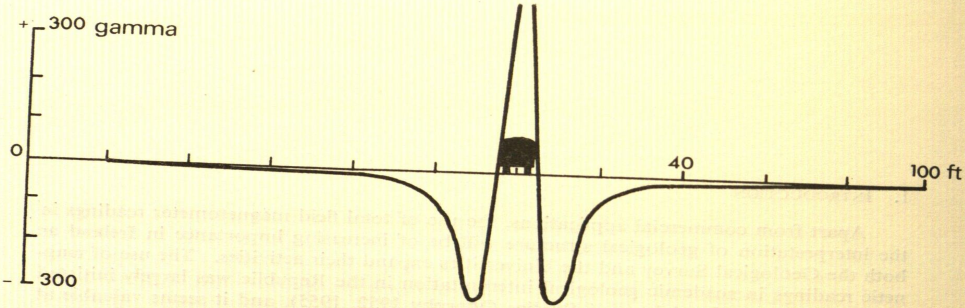


FIG. 1 : Total Field anomaly due to vehicle.

Values measured were (short Wheelbase L/Rover 1968):—

| | | | | | |
|---|---|---|---|---|---|
| 86 ft. | from vehicle | — | decrease of | 1 | gamma |
| 53 ,, | ,, | ,, | ,, | 4 | ,, |
| 31 ,, | ,, | ,, | ,, | 7 | ,, |
| 20 ,, | ,, | ,, | ,, | 64 | ,, |
| 10 ,, | ,, | ,, | ,, | 300 | ,, |

There was little or no difference depending upon the orientation or geographical position of the Land Rover with respect to the bottle. These results suggest that for a process in which the detector bottle is run out from a vehicle containing the magnetometer, 100 ft. of cable is necessary to reduce this effect to negligible proportions.

2.4 *Soils*

Disturbances due to soil conditions have been closely examined by Le Borgne (1955). His conclusions can be summarised as:—

(i) Magnetic susceptibility of the upper layers of soil is often much greater than the underlying mother rock. This appears to be determined by a humus bearing top layer (depth 0–25 cm). Susceptibilities of the order of $2{\cdot}6 - 0{\cdot}5 \times 10^{-3}$ emu/cc were measured.

(ii) There is no relationship between the soil susceptibility and the type of underlying rock, nor is there any noticeable difference between cultivated and uncultivated soils or between one vegetation type and another, except that values tend to be lower in very wet areas.

(iii) He concludes that the susceptibility is due to an iron oxide produced by a balance of organic action and water conditions where drainage is good.

(iv) Magnetic anomalies will not appear if the humus layer is homogeneous and continuous. However discontinuities either due to soil conditions, ditching, rubbish infill etc. will produce anomalies. He calculates that a large ditch could give an anomaly of 50 gamma at 3 ft. from the ground.

Further work by Le Borgne (1960) shows that fire on the surface can increase the susceptibility by a factor of 2–10 although only in the top 2–3 cms (see also Aitken p. 25).

Le Borgne's work seems to indicate that certainly in disturbed ground and possibly elsewhere, excepting swampy conditions, anomalies of $\pm$ 20 gamma from soil sources are not improbable. Surveys conducted by the Institute have observed local anomalies or 'noise' of this order in Ireland in areas where the known geology could not apparently provide any explanation of source. They usually appeared to arise from a shallow source and are assumed to derive from the soil as in Le Borgne, or from other superficial deposits e.g. drift, beach sands etc.

### 2·5 *Diurnal Observations*

Choice of diurnal correction stations depends upon numerous factors. Generally speaking where anomaly amplitudes expect to be only 50 gamma or less (small, magnetically quiet areas), it would be advisable to run a local continuous record. Where contours expect to be at nearer 50 gamma intervals (amplitudes > 100 gamma), the nearest Observatory gives sufficient accuracy. This is further discussed in 3.2 below.

### 2.6 *Local Non-Continuous Base*

As the proton magnetometer is not subject to drift, a periodic return to base is not essential. However in some circumstances a diurnal variation correction can be made by this method. This is generally less satisfactory than using an Observatory or continuous record for two reasons:—

(i) the daily variation is seldom regular and cannot often be approximated by straight lines even 1 hour apart.

(ii) the absolute value of a base station can only be satisfactorily established by averaging at least 24 hours of continuous record and comparing with a known Observatory, e.g. a base in Ardara (Donegal) was read 38 times in 22 days (none strongly disturbed) giving non-random distributed differences varying between 23 and 63 gamma with Valentia. Thus tying in a survey on this base with other regional surveys, could involve a systematic error.

## 3. Reduction of Data

### 3.1 *Magnetometer Count to Field Strength*

In the 'Elsec' magnetometer and other non direct reading proton magnetometers, the count of the magnetometer is the number of cycles of a 1Mc/s oscillator which pass through a 'gate' opened and closed by a predetermined number of cycles of the precession signal. On the 'Elsec' there are five different lengths of this gate period usable but the one most normally used is 1,024 cycles.

From the above it is clear that the time taken for gate opening $= \dfrac{Count}{100{,}000}$ secs

Whence, precession frequency $= \dfrac{1024 \times 100{,}000}{Count}$ c.p.s.

Now from Larmor's precession theorem:

$$f = \frac{\lambda F}{2\pi}$$

where $f$ = precession frequency
$F$ = field strength
$\lambda$ = gyromagnetic ratio of the proton

$$\text{whence } F = \frac{2 \times 1024 \times 100{,}000}{count \times 26751{\cdot}2} \text{ gauss}$$

$$= \frac{24051{\cdot}0}{count} \text{ gauss}$$

$$= \frac{24051 \times 10^5}{count} \text{ gamma}$$

Tables for this conversion can be easily drawn up. In Ireland a range from a count of 49,100 (48,984 gamma) to a count of 50,500 (47,626 gamma) is normally sufficient.

### 3.2 *Diurnal Variation of Magnetic Field*

The general shape of this variation in Ireland is as shown in Fig. 2, with a minimum at approximately 1130 GMT and a maximum at approximately 17–1800 GMT. The average daily range of total field is approximately 30–50 gamma, varying between 40–60 gamma in the summer and 10–30 gamma in the winter. Unusual disturbed days vary between 1 in 10 in peak sunspot years (1957, 1968) and 1 in 15 in sunspot minimum years, however they very often occur in consecutive groups of two or three. A range of over 100 gamma on these days is not unusual and ranges of over 500 gamma are observed 2 or 3 times per year (Meteorological Service).

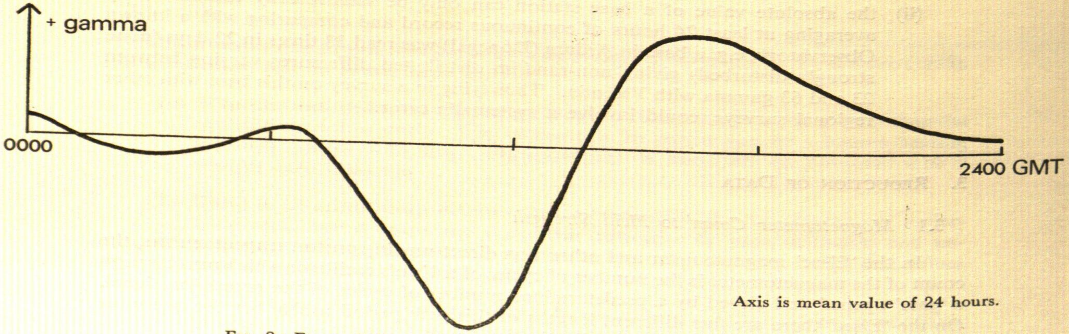


Fig. 2: Form of diurnal variation of Total magnetic field in Ireland.

The application of the diurnal variation to a distant area is normally done with a correction for local time differences. Present work at the Institute shows however, that this is by no means ideal and that there is probably a continent-ocean 'edge' effect which modifies both the timing and amplitude of this variation over the British Isles. Thus although the local solar time difference between Dublin and Valentia is 16 mins, for the days already studied the diurnal magnetic variation occurs at a time difference of less than 10 mins and in one case actually occurs later at Dublin than at Valentia.

From the preliminary work it would appear that the errors in Ireland are slightly reduced if NO time difference with Valentia is applied. The largest error however, comes from the differences of amplitude of the diurnal variation across the country. This error is largest in the middle of the day (1100–1300 GMT) and on smoothed diurnal curves produces a prediction of the field at Dublin from Valentia which is approximately 10 gamma too low. This is systematic rather than random and it is hoped that a reduction programme to remove it will be worked out.

### 3.3 *Reduction of Observatory Record for Total Fields*

Observatory records are at present in graphical form at a scale of 15 mm per hour with a line graph for $H$ and $Z$. These have to be combined to calculate $T$ and it is generally easier to use a binomial expression for this.

Thus $T^2 = H^2 + Z^2$ (1)

if $\Delta T$, $\Delta H$ and $\Delta Z$ are the values read above the baselines from the magnetograms, and $T_0$, $H_0$ and $Z_0$ are the baseline values.

$$(T_0+\Delta T)^2 = (H_0+\Delta H)^2+(Z_0+\Delta Z)^2$$

$$T_0^2+2T_0\Delta T+\Delta T^2 = H^2+2H_0\Delta H+\Delta H^2+Z_0^2+2Z_0\Delta Z+\Delta Z^2$$

Using (1) for $T_0$, $H_0$, $Z_0$ and dividing by $2T_0$,

$$\Delta T+\frac{\Delta T^2}{2T_0} = \Delta H\frac{H_0}{T_0}+\Delta Z\frac{Z_0}{T_0}+\frac{\Delta H^2}{2T_0}+\frac{\Delta Z^2}{2T_0}$$

as $\frac{\Delta T^2}{2T_0}, \frac{\Delta H^2}{2T_0}, \frac{\Delta Z^2}{2T_0} \rightarrow 0$

$$\Delta T = \Delta H\frac{H_0}{T_0}+\Delta Z\frac{Z_0}{T_0}$$

whence $T = T_0+\Delta H\frac{H_0}{T_0}+\Delta Z\frac{Z_0}{T_0}$

The factors

$$\frac{H_0}{T_0}, \frac{Z_0}{T_0}$$

can be easily calculated and combined with the scale factor of the graph (mm to gamma). The errors involved in this approximation are $\pm 1$ gamma. It should be noted that for Valentia magnetograms, $\Delta H$ is *Negative* and timing lines are always GMT.

### 3.4 *Regional Slope*

In general the intensity of the earth's magnetic field increases from the equator to the magnetic pole in each hemisphere (approx 60,000 gamma at the pole, 30,000 gamma at the equator). As the magnetic pole is to the north west of the British Isles, the direction of maximum increase is generally west of north and the slope is approximately 2·5 gamma per mile North and 0·3 gamma per mile west.

This has been investigated by McWilliams and Byrne for Ireland but to facilitate comparison with the aeromagnetic surveys of Northern Ireland and Great Britain, a regional calculated by the Institute of Geological Sciences in London has been used at the Dublin Institute. This is described on a duplicated sheet issued by the I.G.S. as GD/3/4 March 1966 and is summarised below. The procedure is detailed using Valentia as a diurnal base but could be extended analogously to other stations.

The regional slope (total field) for 1955.5 is:—

$$F_r = 47033{\cdot}4 - 0{\cdot}259E + 2{\cdot}1728N$$

where $E$ = Eastings (km) and $N$ = Northings (km) of the British Grid.

In general this plane is visualised as moving steadily 'upwards' at the same slope with secular variation so that points retain the same anomaly value. The anomaly value for Valentia can thus be found from 1955.5:—

$$\text{Anom} = \text{Value for 1955.5} - (47{,}033{\cdot}4 - 0{\cdot}259E + 2{\cdot}1728N)$$

Substituting for 1955.5 = 47,727, $E = -166{\cdot}194$ and $N = 258{\cdot}865$,

Anom = +88 gamma (cf. McWilliams and Byrne 1966, Anom. +55 gamma).

Assuming as above, the continuing reality of the regional slope, the value at any time at Valentia can be taken as always being 88 gamma above the regional at Valentia. The difference between any station value and the simultaneous or appropriate value at Valentia will therefore have to be increased by 88 gamma to give the value of the station above the *regional* at Valentia. The value of the regional at the *station* differs from that at Valentia, the difference being calculated as:—

$$+2{\cdot}1728(N - N_{val}) - 0{\cdot}259(E - E_{val})$$

where $N_{val}$, $E_{val}$ are the Northings and Eastings of Valentia.

Therefore the value of a station above the regional at that station (i.e. its anomaly) is given by:

$$A_p = F_p - F_{val} + 88 - \left[2{\cdot}1728(N - N_{val}) - 0{\cdot}259(E - E_{val})\right]$$

If the British National Grid values for Valentia are substituted, this becomes:

$$A_p = F_p - F_{val} + 693{\cdot}6 - 2{\cdot}1728N + 0{\cdot}259E$$

where $N$ and $E$ are the British National Grid coordinates of the station in km, $A_p$ is the anomaly of the station, and $F_p$ and $F_{val}$ are the equivalent total field values at the station and Valentia respectively.

British National Grid values can be calculated from latitudes and longitudes by the use of tables (Ordnance Survey, 1950). However, it has been found empirically, that due to the similarities between the British and Irish Grids, this formula can be replaced, accurate to the nearest gamma, by:

$$A_p = F_p - F_{val} + (236{\cdot}1 - 2{\cdot}1466N' + 0{\cdot}4416E')$$

where $N'$ and $E'$ are Northings and Eastings of the Irish Grid in km.

It is thus possible to construct master overlay sheets for Irish Grid squares at any particular scale showing the contours (straight lines) given by ($-2{\cdot}1466$) gamma/km North and ($+0{\cdot}4416$) gamma/km East. These can be applied over any part of the Irish Grid, only the actual *values* given by the bracketed section of the formula being recalculated for each area.

### 3.5 *Secular Variation*

The use of the above regional presupposes a steady uniform secular rise in total field over the whole country. In fact the rise is greater in the north, i.e. the Donegal area has increased in total intensity value from 1950–1965.5 by 46 gamma more than Kerry. The change that this produces in the local slope of the regional is not great but it can produce large differences in regional anomaly value. Thus using Valentia for the reduction of readings in 1968 in Donegal involved using the secular change of Valentia. However Donegal has been changing at a greater rate than this and the resulting values as compared with the aeromagnetic map of Northern Ireland (reduced to 1955·5) were 40–50 gamma high. Ideally to eliminate this error, the reducing observatory should be at a similar latitude to the survey. However, the discrepancy from this problem is only evident when surveys at different dates are compared. In the long run, secular variation is one of the greatest problems preventing the adoption of an International Magnetic Regional Formula. For Ireland, secular variation is being measured by the Meteorological Service (McWilliams and Byrne).

## 4. Summary of Random Errors

Considering that 3 readings are taken as in 2.2, and that the vehicle effect is avoided (2.3), the results of Le Borgne suggest that the averaging of 3 readings with soil noise will give a possible error from this source of $\pm 6$ gamma. Using a distant Observatory (say > 50 miles) for diurnal reduction on a normal day, $\pm 10$ gamma is the maximum error from this source. On a disturbed day this would probably reach $\pm 40$ gamma and prohibit the use of readings entirely.

In general the regional is read to the nearest gamma ($\pm 0{\cdot}5$ gamma) and the electronics of the magnetometer are quoted as giving $\pm 1$ gamma. The total maximum error on a normal survey is thus $\pm 18$ gamma. This means that contours at less than 50 gamma intervals are often meaningless.

The use of a local diurnal base will reduce the diurnal errors considerably, possibly to $\pm 2$ gamma. This reduces the total error to $\pm 10$ gamma. If no evidence of soil noise is found (i.e. all stations give extremely consistent readings) it might thus be possible to produce final results which are $\pm 5$ gamma maximum error. It would be dangerous to assume that much greater accuracy than this can be achieved without extremely rigorous control.

Some confirmation of the order of size of these figures has come from a series of magnetic profiles in the Mallow area. Here there was little or no observed variation within fields (soil noise) and the diurnal observatory (Valentia) was approximately 70 miles away. 150 readings over anomalies of c. 50 gamma were subjected to a statistical smoothing. Their deviation from the smoothed profiles had a marked 'normal' distribution (indicating random errors) and the standard deviation was $\pm 4{\cdot}64$ gamma.

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