MAGNETIC CHARACTERISTICS OF THE CUILCAGH DYKE, CO. FERMANAGH, NORTHERN IRELAND

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Abstract

The Cuilcagh Dyke in Co. Fermanagh forms part of the NW–SE trending Donegal–Kingscourt dyke swarm. Dykes in this swarm, along with others in the Irish Tertiary Igneous Province, are associated with negative magnetic anomalies. Segments of the Cuilcagh Dyke have these negative magnetic anomalies but some parts have been found to be associated with positive magnetic anomalies. Susceptibility measurements also show significant variations along the dyke. Palaeomagnetic investigations suggest that parts of the dyke formed during a period of reverse polarity, similar to the rest of the Irish Tertiary Igneous Province, and parts formed during normal polarity conditions. The Cuilcagh Dyke is unique in Ireland in that it is the only known dyke to possess both normal (positive) and reverse (negative) polarity magnetic characteristics.

Introduction

The Tertiary lavas of north-east Ireland (Fig. 1a) represent a major remnant of the British and Irish Tertiary Volcanic Province. They are predominantly basaltic with associated occurrences of intermediate and acid rocks (Lyle 1980; Lyle and Preston 1993). The presence of Tertiary dykes in Co. Fermanagh, some 50km to the west of the main outcrop of the Tertiary lavas has been commented on by Preston (1967) who interpreted them as part of a Tertiary basic intrusive centre with the dykes acting as feeders for tholeiitic lava flows, since eroded. Gibson and Lyle (1993a) used digitally processed aeromagnetic imagery to reveal the greater extent of the Fermanagh dyke swarm than indicated by surface outcrop and their results have been supported by the recent Tellus project (GSNI 2007). Analysis of aeromagnetic and gravity data shows that the dykes in Co. Fermanagh are located on or adjacent to a 20km diameter high-density magnetic circular body which is probably a subsurface igneous intrusion (Gibson 1993).

In this paper we report on one particular dyke from the Fermanagh swarm, known as the Cuilcagh Dyke, which displays a most unusual magnetic signature. Moving along a 5km length of the dyke from NW to SE, the dyke starts with a marked negative magnetic anomaly, which switches to positive then back to negative and again to positive. To help set this surprising observation in a broader context, we review the general magnetic characteristics of related Tertiary rocks, we examine the dyke's petrography and geochemistry and we measure its magnetic susceptibility and its palaeomagnetism at different locations.

The Cuilcagh Dyke crops out intermittently for around 10km on the northern slopes of Cuilcagh Mountain in Co. Fermanagh (GSNI 1991). While locally it belongs to the Fermanagh swarm, in a wider perspective it is one of a series of NW–SE trending dykes, known as the Donegal–Kingscourt swarm, which extend from Donegal in the north-west to Kingscourt in the south-east, and possibly on to Anglesey, a distance of 250km (Fig. 1a). These dykes typically crop out

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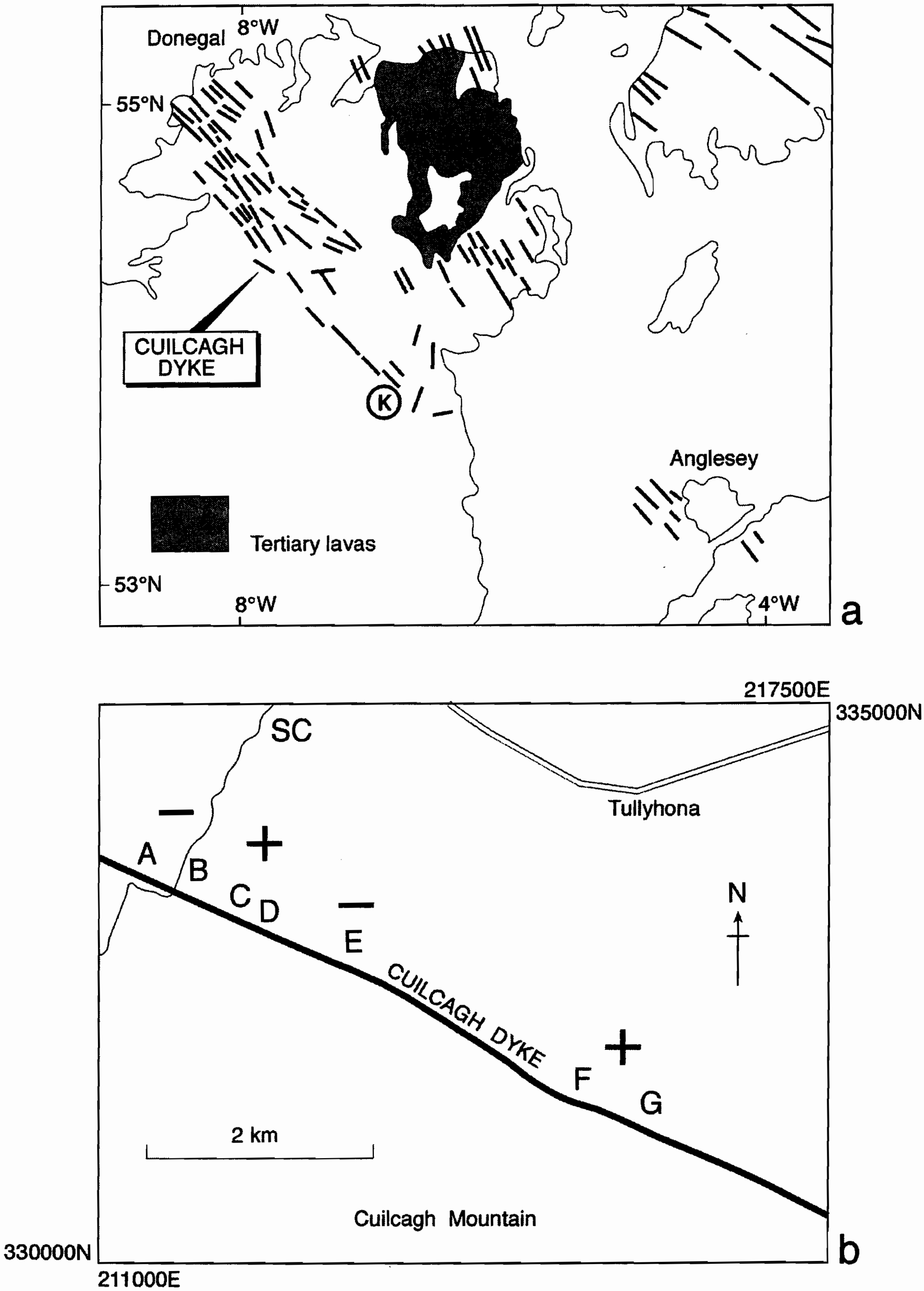

Fig. 1—(a) Location of Cuilcagh Dyke, K = Kingscourt. Modified after Johnston and Rundle (1993); (b) Location of magnetic traverses (A–G) across the Cuilcagh Dyke, shown in Fig. 4. SC = Sruh Croppa River.

intermittently along strike, are 5–100m in width and have been dated *c.* 58Ma (Bennett 2006).

Good unaltered samples of the Cuilcagh Dyke could only be obtained by the authors at three sites along the dyke (locations A, C and E, Fig. 1b).

Petrography and geochemistry of the Cuilcagh Dyke

Samples for petrological and geochemical analysis were taken from two parts of the Cuilcagh Dyke, Sruh Croppa (National Grid Reference (NGR): H114334, location A, Fig. 1b) and Monastir (NGR: H119331, location C, Fig. 1b).

Petrographically, the Sruh Croppa and Monastir dykes are very similar. They are medium-grained, comprising large ophitic-poikilitic augite plates with plagioclase laths. The pyroxenes are commonly 3–4mm in diameter with plagioclase generally 2–3mm in length, often showing signs of alteration to chlorite. Olivine is present as small (<0.5mm) unaltered grains, or more commonly as serpentine pseudomorphs.

In terms of their major and trace element geochemistry, the Sruh Croppa and Monastir sections of the Cuilcagh Dyke fall within the range displayed by the Lower and Upper Basalt Formations of the Antrim Lava Group (Lyle 1985). They are quartz-normative tholeiites and Fig. 2 compares their rare earth element distribution with those of other Fermanagh dykes and a typical Lower Basalt and Upper Basalt from Antrim. Figure 2 shows that the two sections of the Cuilcagh Dyke are virtually identical in rare earth concentrations which are significantly enriched relative to the other Fermanagh dykes analysed.

Magnetic characteristics of the Tertiary rocks in Ireland

Palaeomagnetic studies of the Tertiary igneous rocks in north-east Ireland have consistently shown that they formed during a period of reverse polarity (Wilson 1959, 1961, 1970). Although there is a wide scatter of declination and inclination values, the mean declination is about 184° and the mean inclination is about -54°. Ground-based magnetometer surveys over a number of dykes in Northern Ireland also suggest that they were formed during a period of reversed magnetic field. Data collected by the authors show that three dykes in Co. Donegal from the Donegal–Kingscourt dyke swarm are all associated with prominent negative magnetic anomalies which vary in amplitude from about 120nT to 1,000nT (Fig. 3a, Bunbeg Dyke, 3b; Bloody Foreland Dyke; 3c, Derrybeg Dyke). The Doraville Dyke in Co. Fermanagh (NGR: H196563) is delineated by a sharply defined 2,000nT negative anomaly (Fig. 3d), the highest value recorded for a dyke

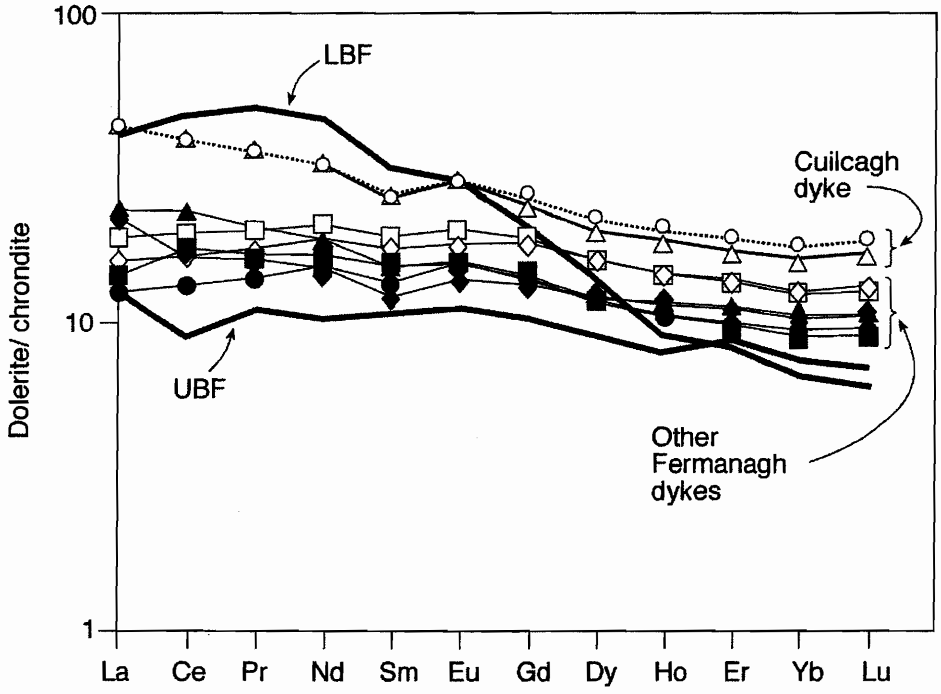

Fig. 2—Rare earth element profiles of Fermanagh dykes. UBF—Upper Basalt Formation; LBF—Lower Basalt Formation. The REE analyses are by inductively coupled plasma mass spectrometry, courtesy of J.N. Walsh, Department of Earth Sciences, Royal Holloway College, University of London. The chondrite normalised values were obtained using chondritic abundance data based on Nakamura (1974).

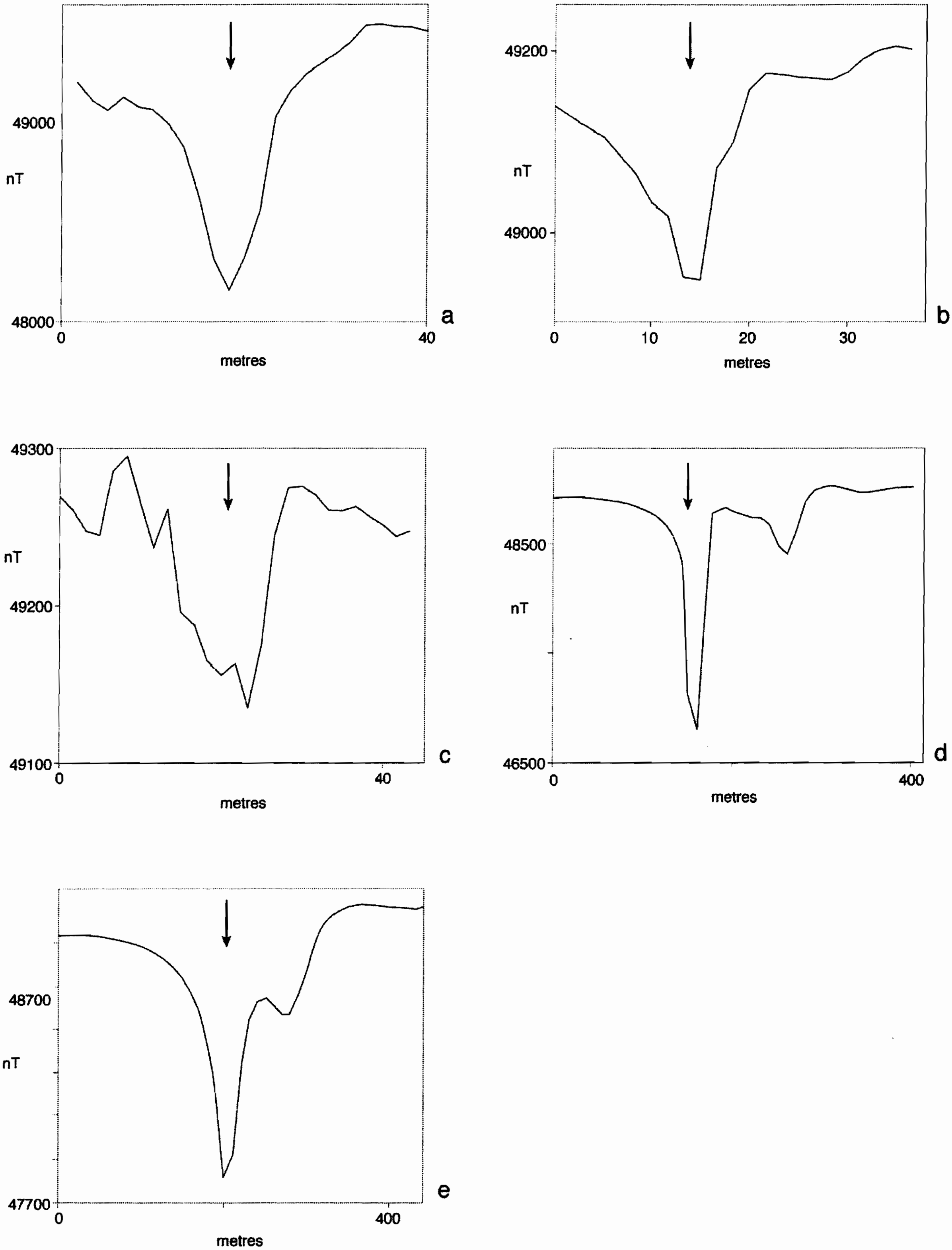

Fig. 3—Typical magnetic anomalies obtained by the authors from dykes in the Irish Tertiary Igneous Province. For locations see the text. Arrows mark the position of the dyke in each profile.

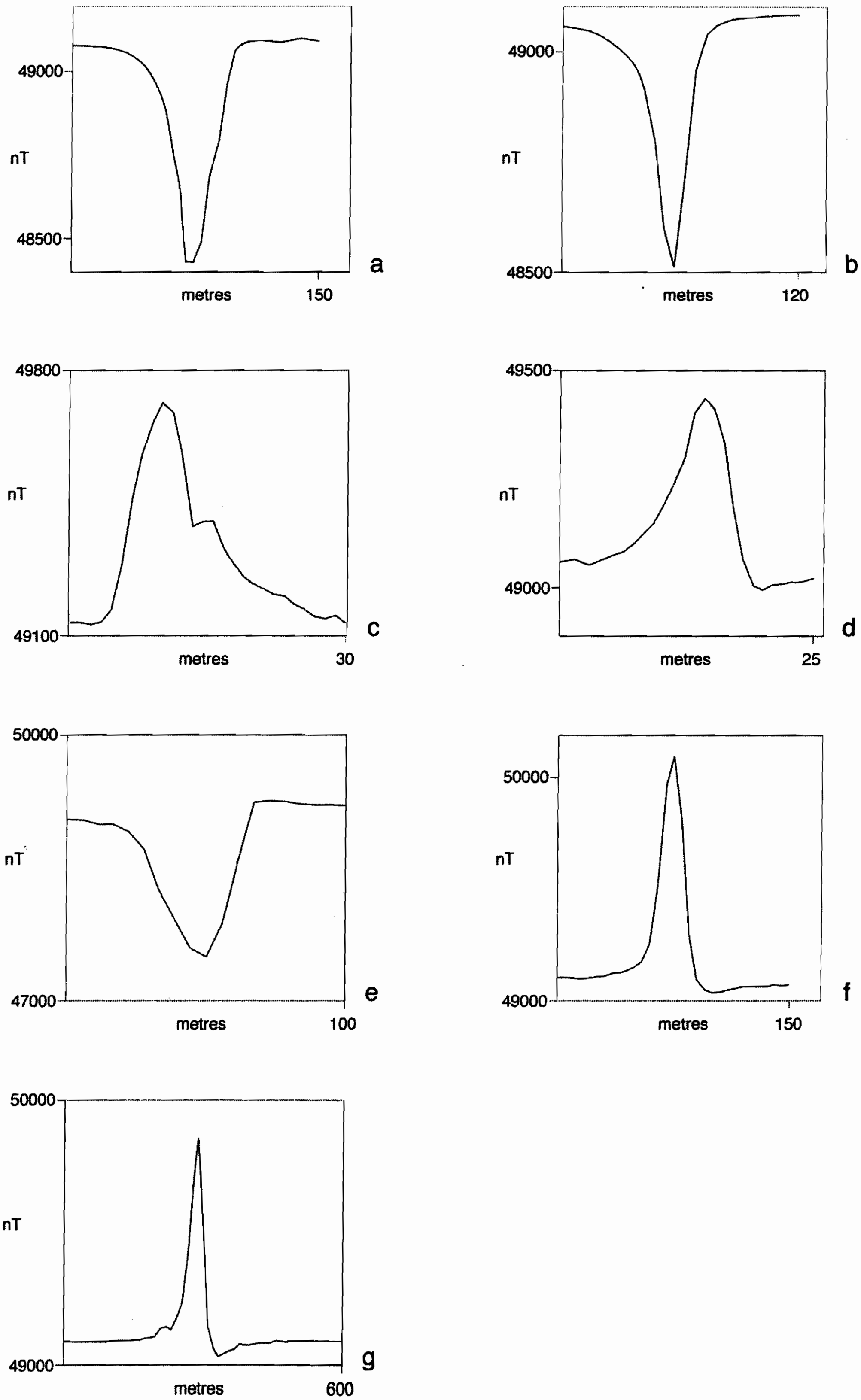

Fig. 4—Magnetic anomalies across the Cuilcagh Dyke; a, b, c, d, e, f and g are taken at locations A, B, C, D, E, F and G respectively on Fig. 1b.

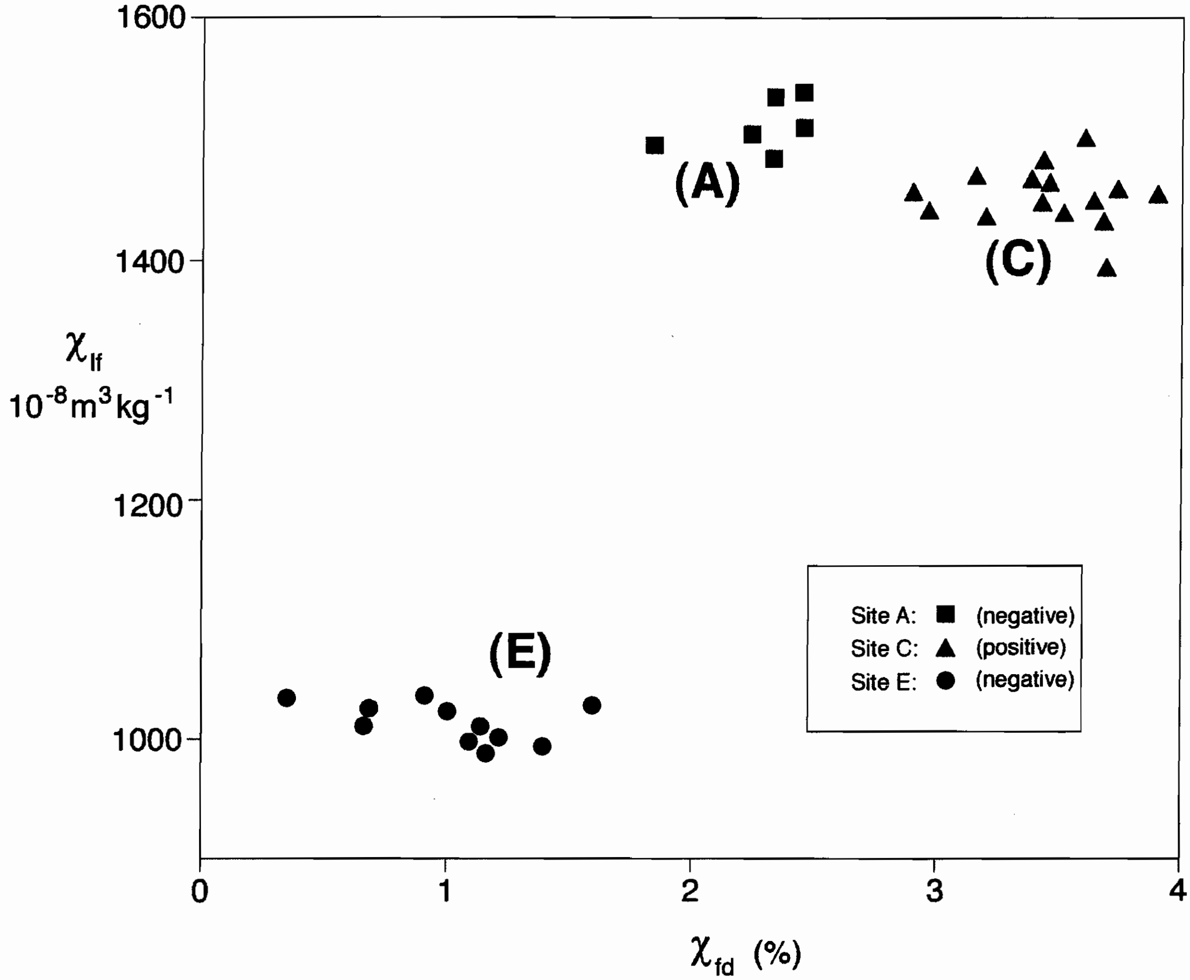

Fig. 5—Plot of low frequency susceptibility (χ_{lf}) against the percentage frequency dependent susceptibility (χ_{fd}%) for three locations along the Cuilcagh Dyke.

in Ireland by the authors. Farther along the strike, the same dyke is characterised by a negative anomaly with an amplitude >1,000nT (Fig. 3e). In addition, ground-based magnetic investigations of Tertiary dykes in Co. Antrim and digitally processed aeromagnetic data in Co. Fermanagh indicate that the dykes are reversely magnetised (Gibson and Lyle 1993a, 1993b). Many Tertiary dykes in Britain are also reversely magnetised (e.g. Wilson *et al.* 1974, 1982). Tertiary dykes with normal polarity do occur in Britain and in other parts of the world, though evidence for their existence in the Irish Tertiary Igneous Province is minimal, with the only reported normal polarity magnetisation being in a dyke from the Mourne Mountains swarm (Mussett *et al.* 1988).

Magnetic profiles across the Cuilcagh Dyke

Seven magnetic traverses were made over the Cuilcagh Dyke using a Geometrics proton magnetometer. The measurement interval varied from 1m to 10m. The area where data were collected is 'magnetically clean' in the sense that the measurements were taken large distances from any buildings or human activity and the dyke is intruded into non-magnetic Viséan limestone. A diurnal correction curve was produced by reoccupying a reference site at regular intervals. However, no corrections were applied as it only took approximately 30 minutes to collect the data for individual traverses and the acquired anomalies were two to three orders of magnitude greater than the diurnal correction values.

The course of the Sruh Croppa River is structurally controlled by the Cuilcagh Dyke. The river turns through a right angle to flow along the dyke for 300m. At this location (A, Fig. 1b) the dyke is associated with a negative magnetic anomaly of 650nT (Fig. 4a) like other dykes in Northern Ireland. A similar magnetic signature (Fig. 4b) was obtained 300m farther along the dyke (B, Fig. 1b). However, 200m further to the south-east, where there is a good unaltered 4–5m wide

Sample	Declination	Inclination	Jnrm	MAD	Polarity
A1	151	-56	263	3.8	Reverse
A2	174	-64	144	2.5	Reverse
A3	161	-61	139	4.9	Reverse
A4	146	-63	133	2.7	Reverse
C1	355	79	132	10.4	Normal
C2	43	75	102	3.3	Normal
C3	356	79	93	7.6	Normal
C4	343	69	144	3.5	Normal
C5	304	84	148	—	Normal

Table 1—Palaeomagnetic results: Samples taken from part of Cuilcagh Dyke associated with negative magnetic anomaly (A1–A4) and positive magnetic anomaly (C1–C5). Jnrm is the thermally demagnetised remanent magnetism intensity of each sample ($\times 10^{-6}$ Am^2kg^{-1}), declination and inclination in degrees; MAD is the maximum angular deviation in degrees.

exposure of the dyke (C, Fig. 1b), the amplitude of the anomaly remains similar (approximately 500nT) but it is positive (Fig. 4c). A similar positive anomaly is present 100m farther along the dyke (D, Fig. 1b and Fig. 4d). Moving south-eastward (E, Fig. 1b) the largest magnetic anomaly (1,500nT) associated with the dyke is recorded over a good exposure; though the signature is once again negative (Fig. 4e). Two further magnetic profiles were obtained on the Cuilcagh Plateau, where some rotted dolerite was exposed (F, G, Fig. 1b). The anomalies were of the order of 700–1,000nT and were once again positive (Figs 4f, 4g). Thus the magnetic polarity for the dyke changes along strike from negative to positive to negative to positive.

Magnetic susceptibility measurements on the Cuilcagh Dyke

Mass specific (also referred to as mass normalised) magnetic susceptibility measurements (Fialova *et al.* 2006) were made at two frequencies using a Bartington Instruments MS2 meter on samples from the three sites where it was possible to recover unaltered dolerite (A, C and E, Fig. 1b). In general, the measured susceptibility decreases with increasing frequency though for multidomain minerals the decrease is very small, less than 0.3%. If the sample contains ultrafine magnetic minerals (< approximately 0.03μm), then the percentage change in the susceptibility value obtained at the higher frequency will be greater (Dearing 1999). The percentage frequency dependent susceptibility (χ_{fd}%) is $100 \times (\chi_{lf} - \chi_{hf})/ \chi_{lf}$ where χ_{lf} and χ_{hf} are the susceptibility values obtained at the low and high frequency. A plot of χ_{fd}% against χ_{lf} for the three sample sites is shown in Fig. 5 and there are clear distinctions in the magnetic content for the dyke. Site C (positive anomaly) has average χ_{lf} values of 1450×10^{-8} m^3kg^{-1} and the highest χ_{fd}% values (3–4%). The χ_{lf} values for site A (negative anomaly) are slightly greater ($1,520 \times 10^{-8}$ m^3kg^{-1}) and χ_{fd}% values are less (2–2.5%). Site E (negative anomaly) is significantly different in that both the χ_{lf} values ($1,020 \times 10^{-8}$ m^3kg^{-1}) and the χ_{fd}% values (< 1%) are much lower than for the other two locations. These results indicate a varying magnetic grain size assemblage for unique parts of the dyke, suggesting different cooling conditions, which, along with the negative and positive signatures, support the view that sections of the dyke evolved separately.

Palaeomagnetic study

Four oriented samples were taken from location A (negative anomaly) and five from location C (positive anomaly) for palaeomagnetic study. Palaeomagnetic data for cores from the two samples were obtained using a Molspin spinner magnetometer, Table 1. The A samples are palaeomagnetically stable and show little variation in declination and inclination values which are similar to those expected for the British Tertiary Igneous Province during a reverse polarity period. The C samples are less stable and show a greater scatter of declination and inclination values. Above 200°C, the thermally demagnetised NRM magnetism became unstable. However, normal polarity directions were isolated from the higher blocking temperature component (>400°C) for C1 to C5.

Discussion

Although the petrography and geochemical analyses of sections A and C of the Cuilcagh Dyke are nearly identical, the results of the magnetic traverses, palaeomagnetic study and magnetic susceptibility measurements show that these parts of the dyke have different magnetic characteristics. Section A records reversed polarity, similar to that found in the rest of the Tertiary Igneous Province in Ireland, whereas section C records normal polarity conditions. Poor exposures prevented samples being taken from other locations for palaeomagnetic investigations, but the results of the magnetic traverses suggest that other parts of the dyke also formed under normal (D, F, G) or reverse (B, E) polarity.

The cause of this alternating polarity along the dyke's length is not known. In theory, self-reversal may be caused by chemical changes. However, petrological and geochemical analyses of the dyke show no evidence for such changes.

Dykes can be multiphase intrusions emplaced over time. Preston (1967) for example records a variety of dolerite types in the Fermanagh Doraville Dyke which he interprets as having crystallised from discrete magmatic pulses over time. The present results suggest that a similar process may have occurred in the Cuilcagh Dyke and that different sections of the dyke cooled and solidified under different field polarities and at different times. However, this possibility cannot be tested by radiometric dating of the dyke as such dating of Tertiary rocks typically contains errors of a few million years (spanning a number of magnetic epochs) whereas field reversals can occur over relatively short time periods (measured in thousands or tens of thousands of years). The Cuilcagh Dyke is the only known dyke in the Irish Tertiary Igneous Province for which positive and negative magnetic anomalies are recorded. While this unique situation may reflect the rare chance of capturing dyke injection during a magnetic polarity switch, it may be that the lack of magnetic data on the Irish Tertiary dykes is simply obscuring what may, with more data, turn out to be a more widespread phenomenon. In the latter case, the alternating polarity suggests local re-magnetisation of the dyke at some time after its intrusion, but how this could have happened without obvious change to the mineralogy and texture of the rock is unclear.

Conclusions

The magnetic characteristics of the Cuilcagh Dyke in Co. Fermanagh include marked differences along strike in polarity, mass specific susceptibility and percentage frequency dependent magnetic susceptibility. These features suggest that the dyke may possibly be a multiphase intrusion whose emplacement straddled a time interval when the polarity of the earth's magnetic field changed. The Cuilcagh Dyke is the only known dyke in Ireland with associated reverse and normal polarity characteristics.

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