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Geophysical evidence for ultrawide dykes of the late Carboniferous quartz-dolerite swarm of northern Britain

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SUMMARY

A compilation of the late Carboniferous quartz-dolerite dyke swarm of northern Britain has been made using existing geological maps, augmented by new ground and airborne magnetic surveys. Aeromagnetic data in the North Sea show that dyke anomalies can be traced eastwards on an arcuate trend for up to 200 km from the UK coast, as far as the western margin of the Central Graben. Individual dykes, which are generally up to 30 m wide onshore, attain widths of well over 1 km offshore. These are at least as wide as any known dykes. The swarm is probably as extensive and voluminous as the well-known and better-exposed Palaeocene tholeiitic swarm of NW Britain.

Key words: late Carboniferous, northern Britain, quartz dolerite, ultrawide dyke.

1 INTRODUCTION

1.1 Mafic dyke swarms and plate tectonics

An intracontinental dyke swarm is an excellent record of regional crustal strain. First, its trend is little affected by local inhomogeneities in the upper crust; secondly, most dyke rock is suitable for radiometric dating; and last, a swarm, once emplaced, may subsequently be buried and deformed, but it is practically impossible for the swarm to be eroded away. Even in the occasional case where dykes have invaded pre-existing joints and there seems to be no preferred orientation to the swarm, the difference in the two horizontal principal stresses must have been small (Tokarski 1990).

Precambrian dyke swarms (Halls 1982) imply the existence of a rather simple world-wide stress system (Morris & Tanczyk 1978), whereas Phanerozoic dolerite dyke swarms at passive margins were recognized by Scrutton (1973) to be of a similar age to that of the adjacent lithospheric plate break-up. Fahrig (1987), considering mainly the Precambrian mafic swarms of the Canadian shield, classifies swarms as either 'early passive margin' or 'failed arm', and therefore links both types to plate break-up processes. One outstanding problem alluded to by Fahrig is whether dyke propagation and magma movement is essentially horizontal, or whether the partial melt has ascended from the lower lithosphere directly beneath the dyke outcrop. If the former is the case, then dykes may not be crust-penetrating features. Gravity or magnetic modelling of a dyke provides little or no constraint on the depth to base of the body, other than that the base is at least an order of magnitude greater than the dyke width, which can usually be well constrained. So although potential field methods applied to dykes cannot tell us whether they have intruded vertically right through the crust, we can use these fields to infer trends, widths, and hence contemporary stress fields. The usefulness of a dyke, or better, a dyke swarm, thus lies in its plate tectonic implications.

1.2 The quartz-dolerite swarm of northern Britain

Russell (1976) first recognized the regional importance of this onshore dyke swarm as an indicator of late Palaeozoic rifting, and pointed out the extension of the Dunbar dyke magnetic anomaly offshore to the east. Francis (1978), in contrast, placed the dyke swarm in the context of the contemporaneous late Hercynian collision to the south. These rival and largely mutually exclusive hypotheses were discussed by Russell & Smythe (1983), who showed a small-scale sketch map of the extension of the swarm eastwards offshore to the margin of the Central Graben. The present paper details the evidence for the extent of the swarm, and in particular for the exceptional width inferred for some of the dykes. I have drawn on the complete archive in the British Geological Survey (BGS) of geological and geophysical maps. The Appendix summarizes the data sources used in the compilation. This includes commercially confidential data, unpublished field slips and hand-coloured sheets, flight-line location maps and posted value maps. I also had access to offshore commercial seismic reflection data (up to mid-1980s vintage) and to the BGS marine profiling data, which includes high-resolution reflection methods (sparker, pinger, echo-sounder), and marine magnetometer and gravimeter profiles.

2 DISTRIBUTION OF THE QUARTZ-DOLERITE DYKE SWARM

2.1 Onshore exposure

Figure 1 shows a compilation map of all the mapped and inferred dykes. The late Carboniferous quartz-dolerite dykes are sparsely developed in the west of Britain, where they trend at 110° (all azimuths are quoted clockwise from true north). They have not been traced beyond longitude 7° 30′W. The dykes trend at about 90° in the Midland Valley of Scotland, where they are generally continuous, and of the order of 30 m wide (Richey 1939). The swarm is regionally arcuate, because the dyke trend swings around to about 70° along the eastern seaboard of Britain. Local deviations from the regional trend occur in the vicinity of the Great Glen and Highland Boundary faults. The few contemporaneous quartz-dolerite dykes in Shetland, 500 km to the north (Fig. 1) trend at about 10° to 45°, subparallel to the present continental margin, and thus may not belong to the main arcuate swarm.

The age of the quartz-dolerite intrusions is 301 ± 6 Ma, as inferred from a K/Ar study of the Whin Sill (Fitch & Miller 1967). Two of the dykes on the Outer Hebrides give Rb/Sr ages of 284 ± 4 and 300 ± 4 Ma, respectively (Fettes *et al.* 1992). Chemically they are high in iron and titanium (Macdonald *et al.* 1981), and are analogous to the FETI-basalts of Brooks & Jakobsson (1974) which often occur at spreading centres and over hotspots. They are also chemically comparable to the tholeiitic members of the mafic lava suite of the coeval Oslo Graben (Weigand 1975; Macdonald *et al.* 1981). We might therefore expect to find intrusives of the same age in the intervening North Sea.

2.2 Magnetic anomalies

Ground-level field magnetic surveys and modelling have been carried out to demonstrate that particular linear positive magnetic anomalies do represent the late Carboniferous quartz-dolerite dykes. Details of all the dyke models are given in Table 1. Characteristically, the magnetic anomaly produced by the dykes consists of a positive peak approximately centred over (or slightly displaced to the north of) the dyke, with a small negative anomaly to the south (*cf.* Powell 1963). Fig. 2 shows a typical example (from Tyndrum, located in Fig. 1), based on a ground magnetic survey. It illustrates some of the problems of modelling, which are particularly apparent with an outcropping dyke. The top of the exposed dyke is only 2 m below the total field sensor bottle, and the edges of the dyke can be located to within a few tens of centimetres.

The dyke is modelled in quasi-three dimensions ('$2\frac{1}{2}$-D') as a simple vertical rectangular prism with a finite extent (half-strike length) in and out of the plane. The half-strike length and the depth to the base of the dyke are both defined as very large, so that the modelling is simplified further to two dimensions. Assuming a uniform magnetization leads to only limited success in modelling the observed anomaly, although the general southerly, steep dip of the total magnetic vector (the sum of a remanent and an induced component) is clearly well established. The inset to Fig. 2 shows how a south-pointing, downwardly inclined total magnetic vector **T** results from the sum of a flat-lying remanent vector **R**, appropriate to magnetization in equatorial regions during a geomagnetic reversed field epoch, and **I**, the induced component. I have not tried more sophisticated models, for example, by varying the magnetization within the dyke, since my aim is to map the

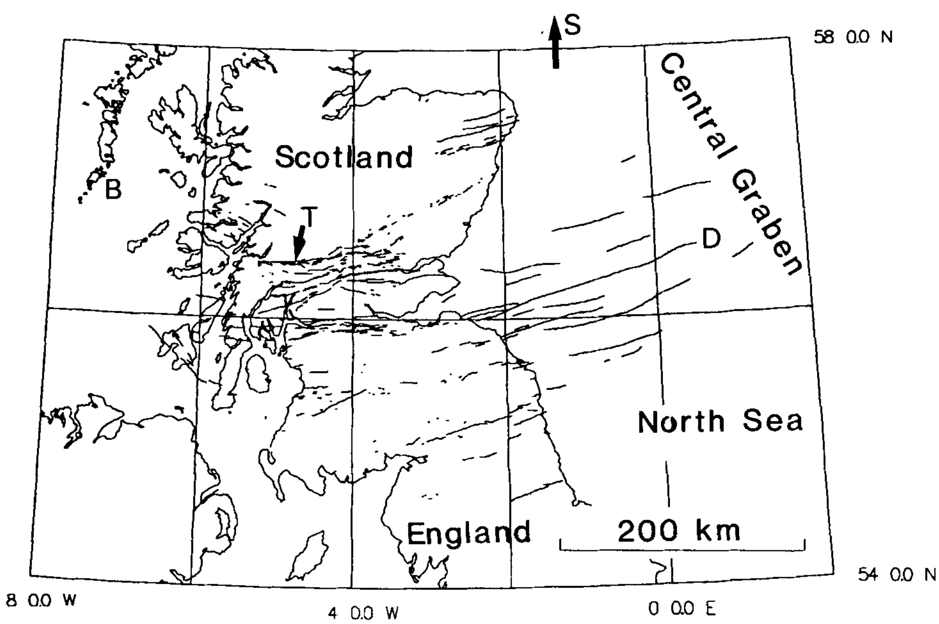

Figure 1. Stephanian (300 Ma) quartz-dolerite dykes of northern Britain compiled from various BGS geological and aeromagnetic maps. East of about 1° 30′W the anomalies are taken from a commercial aeromagnetic map of the North Sea. Data sources are tabulated in the Appendix. UTM projection, central meridian 3°W. B, Barra; T, Tyndrum; S, towards Shetland; D, Dunbar dyke anomalies.

Table 1. All dykes are modelled by vertical rectangular prisms extending to a large distance ('infinity') downwards and laterally. Magnetization is uniform within each prism. Modelling assumes finite remanence and no susceptibility, but the remanent vector tabulated below should be interpreted as **T**, the vector sum of a remanent component **R** and an induced component **I** (see inset to Fig. 2). Dual dimensions below (e.g. 14/65 m) represent the upper, thinner and the lower, wider components of a modelled dyke, respectively.

Locality	*Profile orientation (degrees)*	*Observation height (m)*	*Dyke No.*	*Remanent magnetisation (A/m)*	*Inclination (degrees)*	*Declination (degrees)*	*Width*	*Depth to top*	*Cumulative width (km)*	*Figure number*
Tyndrum	180	2	1	7.0	60	180	5.8 m	0.32 m		2a
			1	6.0	40	180	5.0 m	0.31 m		2b
Dunbar onshore profile AA'	180	2	1	1.0	70	180	87 m	54 m	0.26	4
			2	1.0	40	180	14/65 m	11/28 m		
			3	1.0	75	180	25/106 m	12/20 m		
Dunbar offshore profile BB'	140	300	1	0.5	40	180	0.79 km	0.67 km	2.91	7
			2	0.5	80	180	0.26 km	0.07 km		
			3	0.5	60	180	0.83 km	0.06 km		
			4	0.5	60	180	1.03 km	0.66 km		
Dunbar offshore profile CC'	180	300	1	0.5	90	180	1.01 km	0.54 km	2.11	8
			2	0.5	90	180	1.10 km	0.94 km		
Dunbar offshore profile DD'	180	300	1	0.7	68	-7	2.87 km	5.37 km	2.87	8

Modelling was carried out with the BGS 'Gravmag Plus' program, written in Fortran 77 with GKS graphics, ported to Unix by the author. Interactive visual fitting of modelled to observed anomaly was done until no improvement could be seen.

dykes using magnetic anomalies, and estimate an approximate width for them. The Tyndrum dyke could probably be better modelled as a composite dyke, with varying magnetization across it, but this would have to be justified by detailed magnetic and petrological sampling across the dyke.

The 30 m wide dykes running E–W across central Scotland are not generally revealed by the BGS aeromagnetic maps, because the amplitude of the anomaly at the 300 m flight height of these surveys is rather low—of the order of 10 to 15 nT—and is swamped by the complex anomaly pattern produced by the Devonian and Carboniferous lavas of the region. Furthermore, the E–W flight-line direction is not conducive to the contour mapping of linear E–W anomalies.

A number of ground magnetic traverses carried out by myself and with colleagues in the Midland Valley and the Grampian Highlands yield anomalies, such as that shown in Fig. 2, which are usually consistent with the exposed width of the dyke. The presence of a dyke is no guarantee of a magnetic anomaly, however, as a ground traverse of the solitary quartz dolerite on the Walls Peninsula of Shetland proved. Here no anomaly was observed, presumably because the original magnetite in this 18 m wide dyke has been completely altered.

Figure 3 shows the results of a small-scale ground survey carried out over the dykes at Dunbar (Francis 1962). The area of Fig. 3 is located in the solid rectangle in Fig. 6. This locality is crucial, because the exposed dykes here are in line with some prominent linear offshore shipborne magnetic and aeromagnetic anomalies, implying that the dykes become much wider offshore than as seen at outcrops onshore.

The ground survey shows several distinctive features of the mapping and interpretation of the anomalies. First, the amplitude of the linear positive anomalies can vary along strike by a factor of three or four over a distance of a few times the anomaly wavelength. This is a normal feature of dyke anomalies. However, at Dunbar two of the three modelled dykes have an upper extension from a much bigger hidden dyke at 20–30 m depth (Fig. 4, dyke nos 2 and 3). The modelled widths of the uppermost parts, hidden below drift, agree well with the widths of 20–30 m observed at outcrop 1–2 km along strike to the east (Fig. 3).

On the exposed foreshore, the most southerly dyke (Fig. 3; named the 'Big Dyke' by Xu & Tarling 1987) is accompanied by several subparallel stringers and apophysing thin dykes over a zone 100–150 m across. This is indirect evidence in support of the larger 100 m wide dyke modelled at depth (Fig. 4, dyke no. 3). However, no attempt has been made to model these thin intrusions, which are presumably offshoots from the parent body. If either of the two Dunbar dykes exposed on the foreshore were buried a little deeper (or the level of observation were higher above ground level than the 2 m used in this ground survey) then what could be inferred from the observed magnetic anomaly would only be the wider, deeper part of the dyke. The thin upper extension would probably not be recognizable.

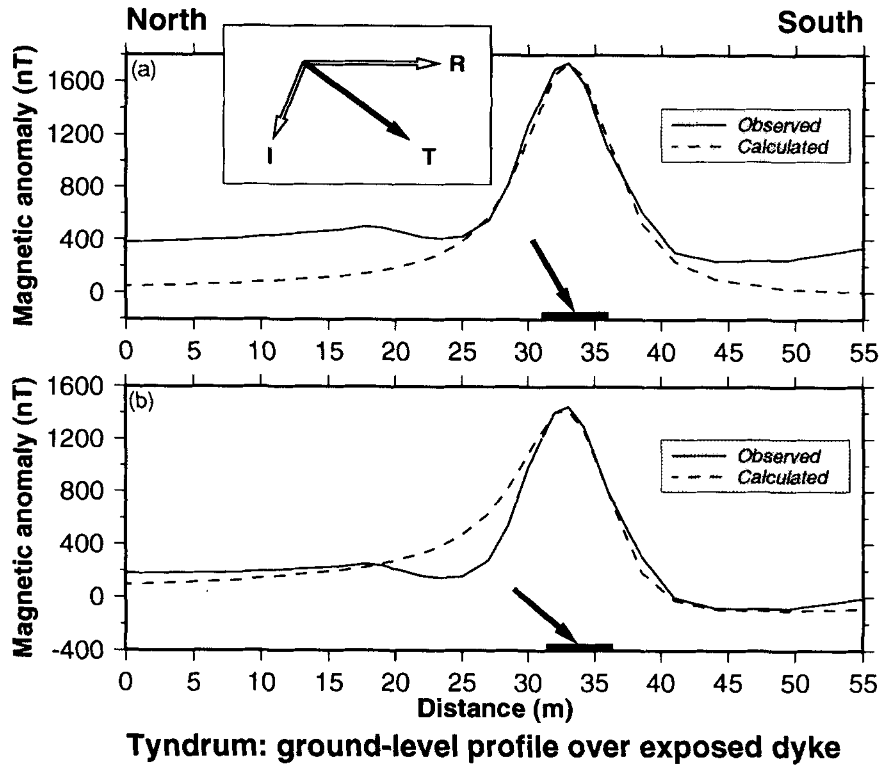

Figure 2. Typical quartz-dolerite dyke total field magnetic anomaly, Tyndrum (T in Fig. 1). Observation height 2 m above ground level. Dyke exposure (bar on horizontal axis) constrains the modelling, which then simplifies to finding the total field vector (arrow on the dyke bar; sum of the induced and remanent components). The inset shows the sum **T** of remanent (**R**) and induced (**I**) components. Two alternative models are shown; see text for discussion. (a) Good fit to both flanks of anomaly, but large mismatches to north and south. Inclination of **T** is 60°. (b) More acceptable overall fit (although poor between 20 and 30 m along profile) after removal of linear regional form observed profile and change of inclination from 60° to 40°.

2.3 Extension offshore

Aeromagnetic maps (Institute of Geological Sciences 1972) and marine geological surveys (Thomson 1978) show that the dykes continue into the western North Sea. Eastward from the Forth Approaches area the dykes are inferred from large symmetrical positive anomalies on the commercial aeromagnetic survey of the North Sea carried out by Aero Service Ltd in 1963. Since the flight lines run E–W at a variable spacing of 2–4 km, and the anomalies trend at 60°–70°, many smaller linear anomalies of that trend have probably been missed; however, the larger anomalies show up well on the digital shaded-relief aeromagnetic maps of northern England and southern Scotland prepared by the British Geological Survey (Lee, Pharoah & Soper 1990). Their maps include only data from the published aeromagnetic maps; the Aero Service maps are still confidential.

Thickening sedimentary cover prevents the tracing of the dykes beyond the western margins of the Central Graben (Fig. 1). The dyke anomalies do not reappear east of the graben, either because the dykes are absent, or possibly because they exist but are more deeply buried by the thicker post-Carboniferous cover of sediments than is present on the west side of the graben.

A 100 m wide tholeiitic dyke has been sampled on the sea-bed west of Scotland (Barber, Dobson & Whittington 1979). It trends at 95°, and since it is also in line with a late Carboniferous dyke in Jura, I prefer to assign it to the late Carboniferous suite, rather than the Tertiary age inferred by Barber *et al.* (the petrologically similar Tertiary dykes in Jura trend at 120°–150°). Note that their interpretation of the offshore solid geology in the area of the dyke (Fig. 2 in Barber *et al.* 1979) has since been superceded by the published BGS map (British Geological Survey 1986).

2.4 Unusual width of the dykes

The easterly extensions offshore of the Dunbar dykes (Figs 3 and 4) are seen on commercial multichannel stacked seismic reflection sections in the Forth Approaches, coincident with the location of the positive linear magnetic anomalies. Fig. 5 shows a good example, from a Western Geophysical Company survey (profile BB′, located in Fig. 6). The dykes are revealed by prominent diffraction patterns, which are probably reflected refractions (Day & Edwards 1983). If the dykes were really only 20–30 m wide, as they are onshore at outcrop, then they would simply be invisible on seismic reflection sections such as this example. Between this locality and the shore the dykes have also been mapped by sparker profiling (Thomson 1978). The mapped swarm is up to five members wide, cropping out on the sea-bed, cutting Carboniferous limestone.

I have quantitatively examined the Dunbar anomaly D (Fig. 1) to estimate the widths of the dykes offshore. First,

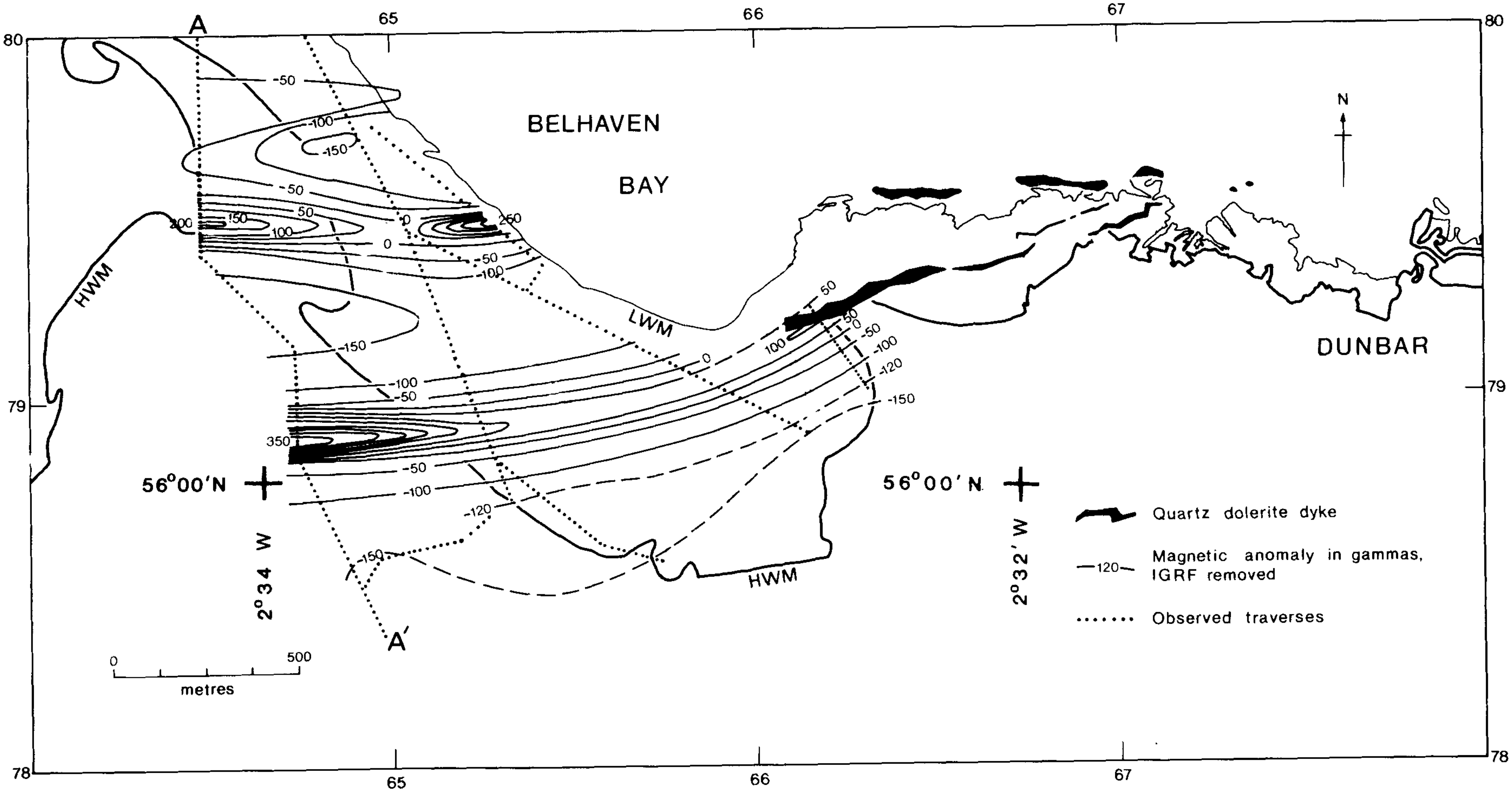

Figure 3. Total field ground magnetic survey (observation height 2 m above ground level) at Dunbar, showing the correlation between the 30 m wide quartz-dolerite dykes (outcrops taken from Francis 1962) and the symmetrical positive magnetic anomalies (IGRF and diurnal variation removed). HWM, high water mark; LWM, low water mark. The more southerly dyke exposed on the foreshore is the 'Big Dyke' of Xu & Tarling (1987), which cuts Carboniferous limestone. Map grid is National Grid 1 km squares. West of easting 66 the sandy Belhaven Bay and hinterland of sand dunes hides the solid geology. The location is that shown as the solid rectangle A in Fig. 6(a). Profile AA′ is modelled in Fig. 4.

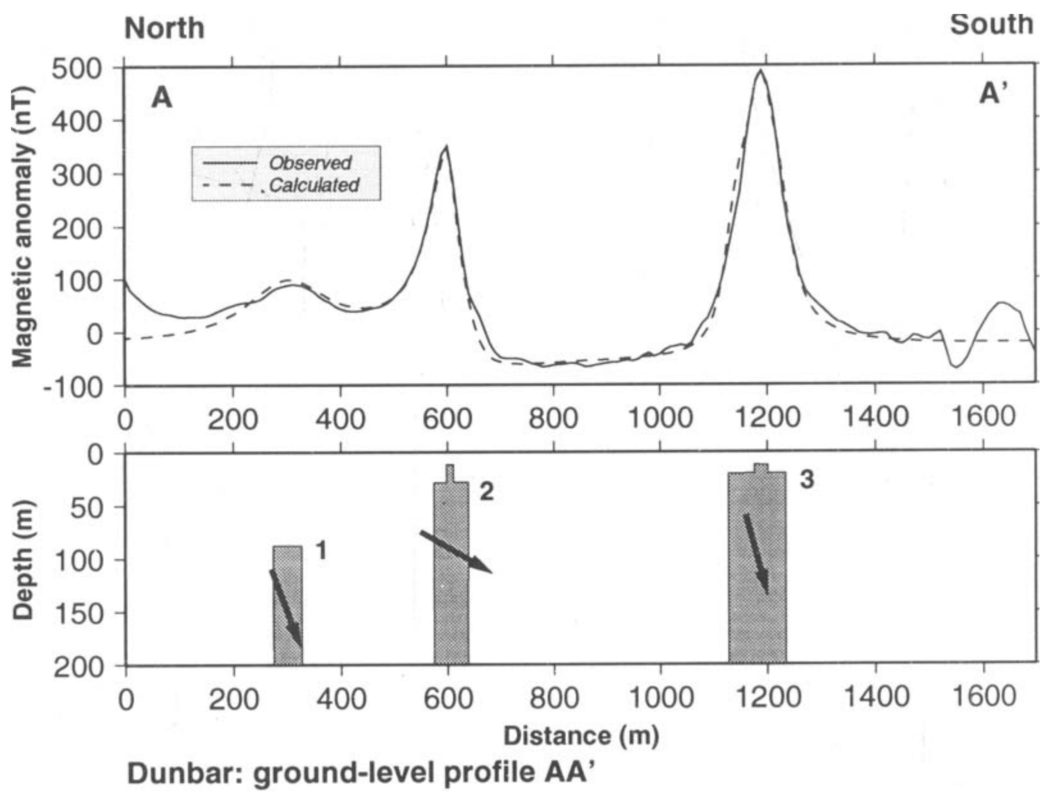

Figure 4. Observed and calculated total field magnetic anomalies along profile AA′ (Fig. 3) which has been projected onto a grid easting (nominally N–S). Observation height 2 m. The model anomaly is due to three 2-D prisms with a total (induced plus remanent) magnetization vector **T** in the directions shown by the vectors. Model space has a vertical exaggeration of ×2. Model prisms extend to 'infinity' downwards and normal to the model plane.

Fig. 6 shows a visual comparison of four profiles along the anomaly (Fig. 6a), all drawn to the same horizontal and vertical scales. The Dunbar onshore profile AA′ has been upward continued from its 2 m observation height to 300 m, to enable a fair comparison with the offshore aeromagnetic data, and is shown as the inset to Fig. 6(b). Going eastwards along the anomaly and comparing profiles A, B, C and D in consecutive pairs, the amplitudes of the anomalies increase by factors of 6, 1 and 0.3 respectively. Similarly, the wavelengths increase by factors of 6, 2 and 2 from one to the next. These figures suggest that the dykes themselves increase in size by a factor of 20 or so from the coast to the margin of the Central Graben. The lower amplitude of profile DD′ (Fig. 6d) indicates deeper burial compared to the more westerly part of the anomaly. Profiles BB′, CC′ and DD′ have been modelled, and are discussed in turn.

Modelling of the three peaks of profile BB′ suggests that there are three main dykes, with one subsidiary dyke (Fig. 7). The cumulative width of the four dykes is about 2.9 km. Some 30 km further east the Dunbar anomalies have merged (Fig. 8, profile CC′), and can be modelled by two dykes with a total width of about 2.1 km. At the easternmost limit of the anomaly the simplest model assumes one deeply buried dyke about 2.9 km wide (Fig. 8, profile DD′). However this fit is poorly constrained, and there appears to be a regional step in the anomaly, down to the north. A similar quality of fit of modelled to observed profile can be obtained by assuming two dykes about 3 km apart, with a cumulative width of about 2.7 km. An even better fit than with either of these models can be obtained with a dyke feeding a large sill system extending far to the south. Postulating a large sill system is not unreasonable, as the dyke swarm onshore feeds such a large system. All the models for profile DD′ require a total magnetic vector vertically downward-pointing, or down to the north in the direction of the present-day field.

Another possibility, which could explain at least part of the regional step in the anomaly, is that there may be a normal fault cutting the basement–sediment interface. Without independent constraints, for instance from seismic reflection data, further modelling along these lines is pointless. The BIRPS deep seismic reflection data (Klemperer & Hobbs 1992) reveal no definite imprint of the dykes (nor of any basement step), although the eastern end of the Dunbar anomaly is crossed by the deep seismic line Mobil-2. Here, between shot-points 1250 and 1350, there is a subvertical column of hyperbolic events apparently extending into the strongly reflective lower crust. Unfortunately the velocity indicated by the hyperbolic tails suggests waterborne events; in other words they originate as side-swipe from very shallow features.

Along the Dunbar dyke anomaly the modelled total vector direction appears to swing systematically from steeply southerly inclined (onshore and profile BB′) through vertical (profile CC′) to a northerly inclination (profile DD′). The inset vector sum diagram in Fig. 2 provides a

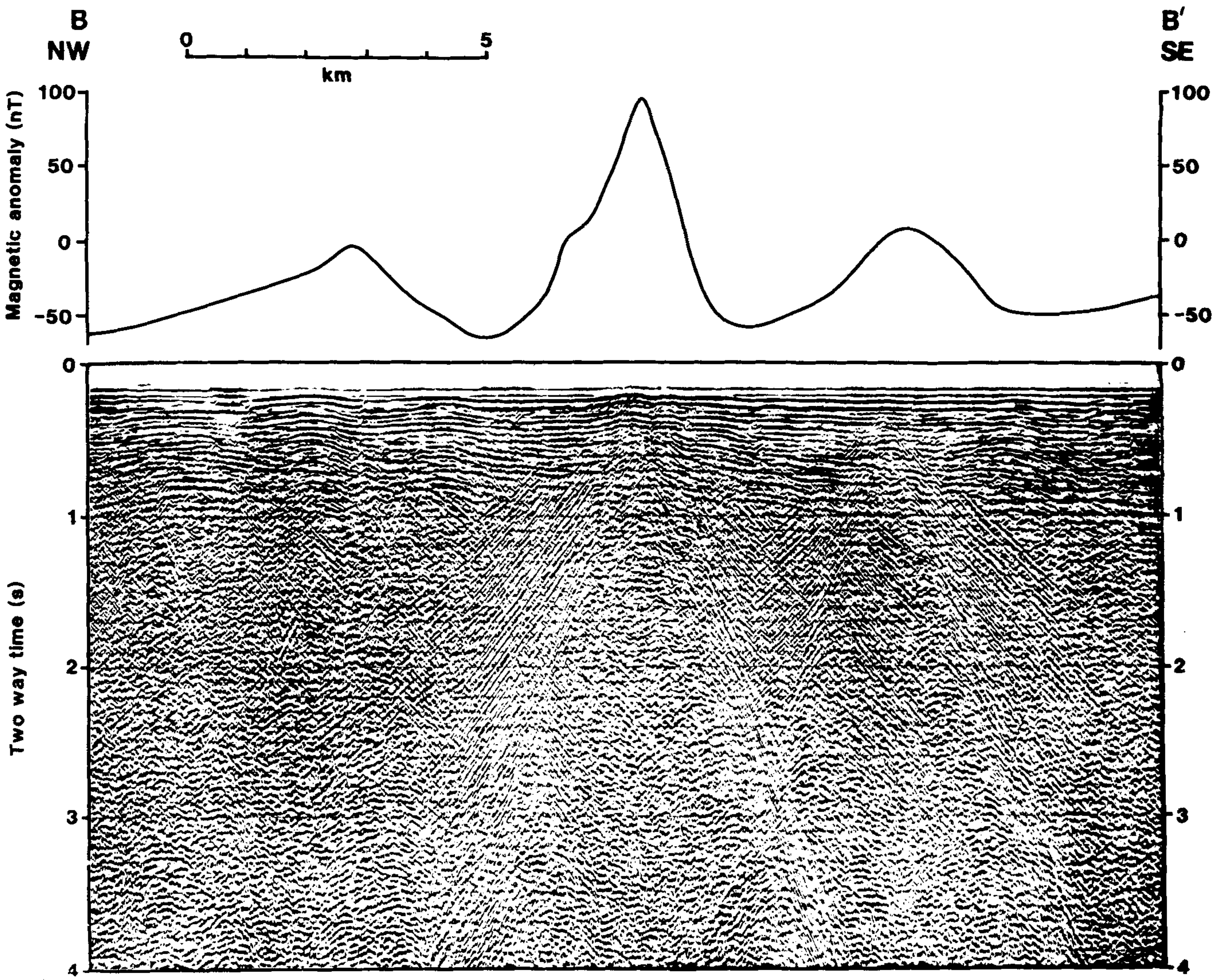

Figure 5. Part of a Western Geophysical 30-fold stacked seismic reflection line (BB′ in Fig. 6) showing prominent diffraction patterns from major ENE-trending tholeiitic dykes cutting Carboniferous limestone east of Dunbar. Total field aeromagnetic anomaly profile (flight height 300 m above sea-level; Institute of Geological Sciences 1972) is shown above, and is modelled in Fig. 7.

simple geometric explanation; the remanent component progressively decreases in amplitude eastwards, relative to the induced component. Profile DD′ can be modelled solely by an induced component, since the symmetrical character of the anomaly has completely disappeared.

The other anomalies mapped in Figs 1 and 6(a) have similar wavelengths and amplitudes to the Dunbar anomaly, but there are few or no other constraints to enable useful modelling to be done. Presumably they represent dykes with widths on the same order of magnitude as the Dunbar group, and thus the cumulative width of the swarm offshore east of Scotland is at least 10 km.

3 DISCUSSION

3.1 Can alternative models account for the anomalies?

If the anomaly has an overall skewness, as have profiles CC′ and DD′ (Figs 6 and 8), it can be modelled in two basic ways; first, by varying the inclination of the total vector, or secondly, by removing an *ad hoc* sloping linear regional. The latter method is hardly justified without additional constraints, so the former method only is used. Constant, or ‘dc’ shifts to fit the observed to the modelled anomalies are, however, justifiable on the grounds that they represent very deep regional effects, and/or departures of the IGRF from the actual ‘regional’ field.

In the modelling discussed above, all the polygonal models have been kept as simple as possible, for example by restricting the faces to be vertical or horizontal, and by finding the polygon with the fewest number of vertices that will satisfy the anomaly. Are we inadvertently exaggerating the real width of the dykes by these restrictions? As a test of this possible source of error, an alternative model for dyke no. 2 of the onshore profile AA′ (Fig. 4) was developed. Rather than assuming one fat dyke, we start with five identical thin dykes with their tops 10 m below ground level (Fig. 9 initial model). Their cumulative width is 60 m, and

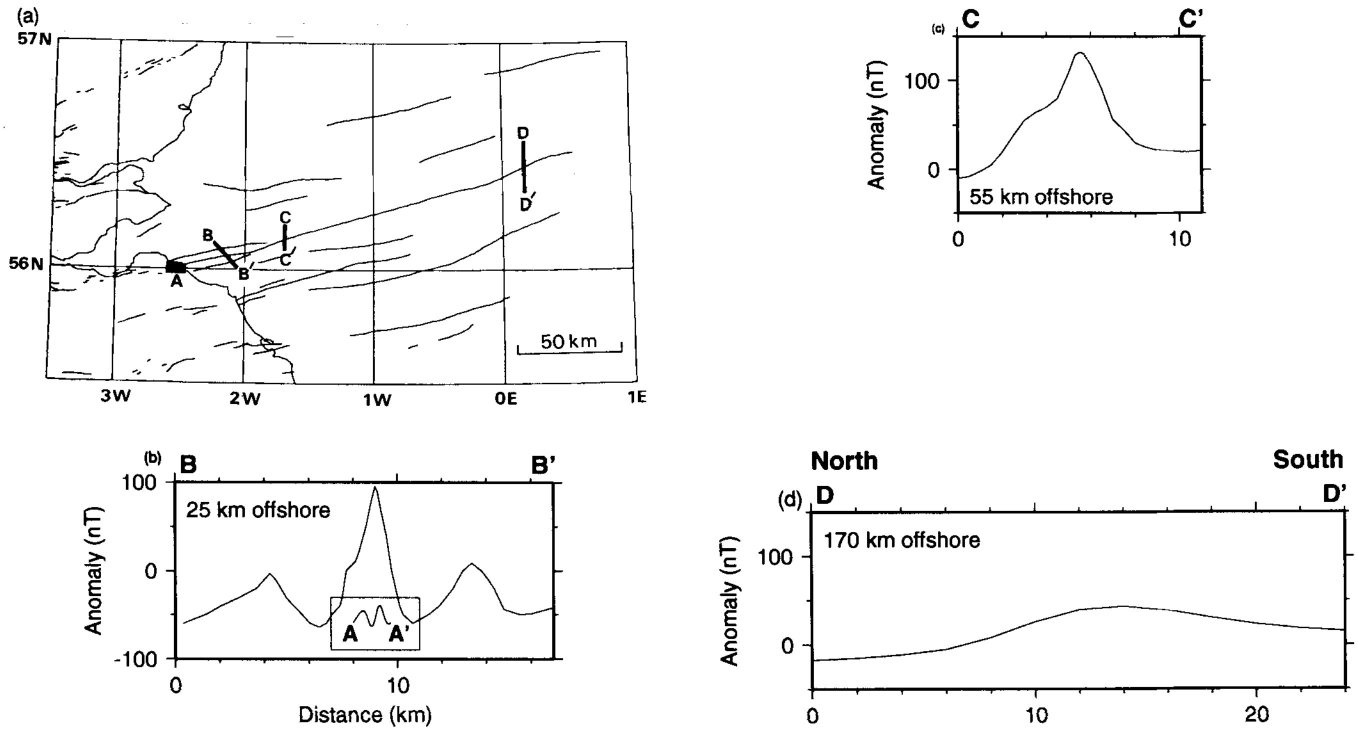

Figure 6. Magnetic profiles along the Dunbar dyke anomaly, drawn to the same scale. (a) Map of dyke anomalies in the western North Sea, showing location of profiles BB′, CC′ and DD′ over the Dunbar dyke group. The area of profile AA′ (Figs 3 and 4) is shown by solid rectangle A. UTM projection, central meridian 1°W. (b) Profile BB′, flight height 300 m. Inset shows ground-level profile AA′ (Figs 3 and 4) upward continued to 300 m and at the same scale. (c) Profile CC′, flight height 300 m. (d) Profile DD′, flight height 300 m.

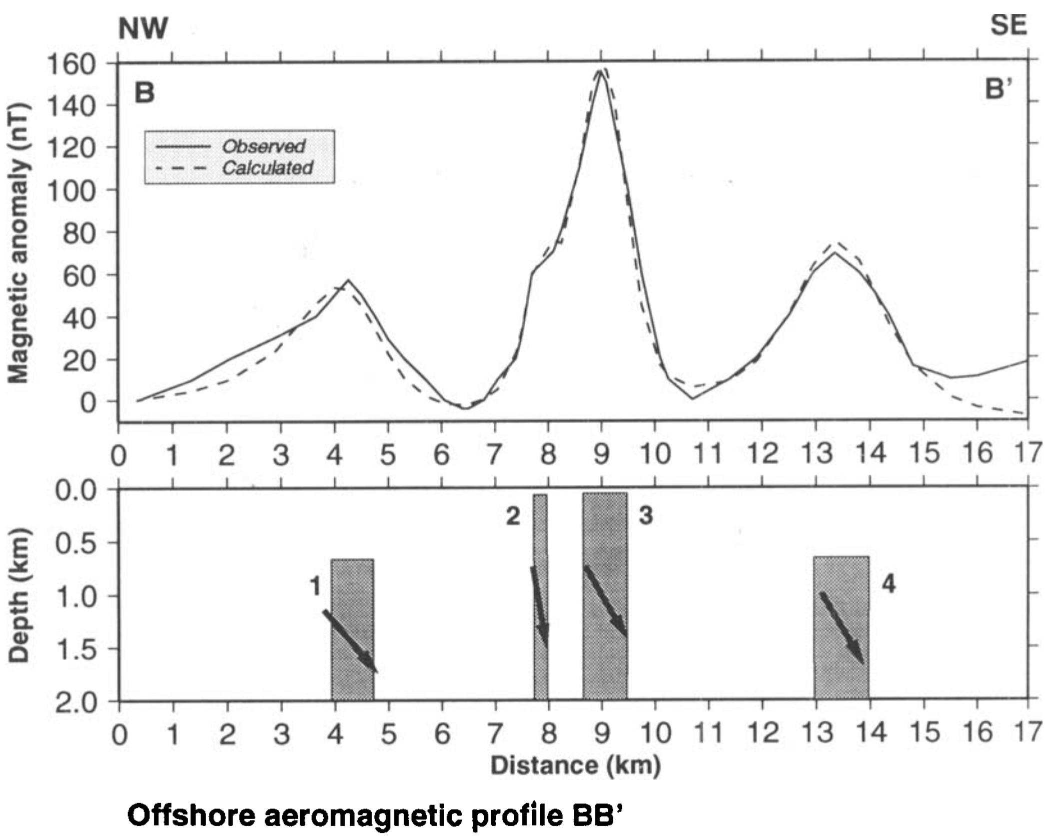

Figure 7. Modelling of the triple-peaked total field magnetic anomaly BB (Figs 5 and 6b) by three main dykes and one subsidiary dyke. Flight height 300 m above sea-level. The model anomaly is due to four 2-D prisms with a total (induced plus remanent) magnetization vector **T** in the directions shown by the vectors. Model space has a vertical exaggeration of ×2. Datum is sea-level. Model prisms extend to 'infinity' downwards and normal to the model plane.

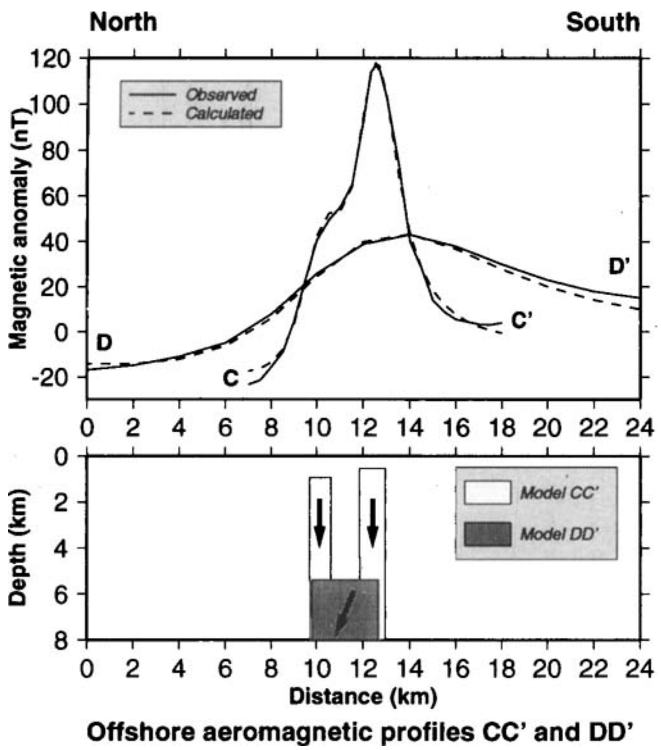

Figure 8. Observed and calculated total-field aeromagnetic anomalies for profiles CC′ and DD′, respectively. Locations shown in Fig. 6; flight height 300 m above sea-level. Total (induced plus remanent) magnetization vectors **T** for each prism are in the directions shown by the vectors. Datum is sea-level. Model prisms extend to 'infinity' downwards and normal to the model plane.

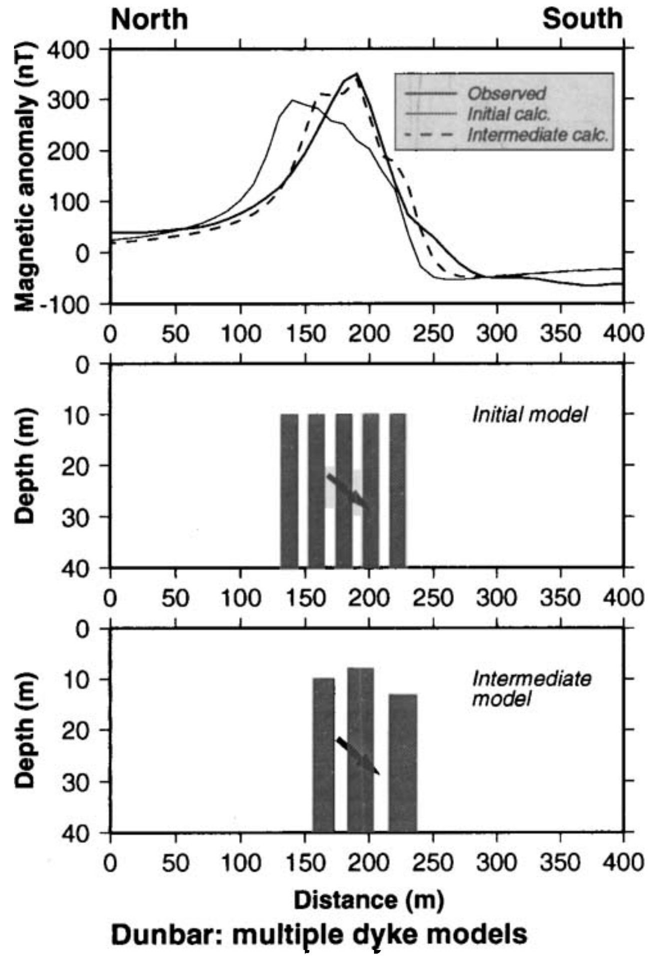

Figure 9. Alternative models for dyke no. 2 of profile AA′ (Fig. 4) using multiple dykes. Model and graph details are as in Fig. 4. See text for discussion. The initial model assumes five dykes of 12 m width with 9 m gaps between and tops at 10 m depth. The intermediate model is an attempt to retain a multiple dyke model after iteration. The cumulative width of the three remaining dykes is 57 m.

the separation between them is 9 m. A south-pointing vector inclined at 40° satisfies the overall skewness of the anomaly. Clearly the fit of this initial model is rather poor. Development of the model by trial-and-error iteration leads inevitably along the following lines.

(1) The two outermost dykes are seen to be irrelevant and are discarded.
(2) The three remaining dykes have to be thickened up.
(3) They have to be merged together to remove 'lumpiness' on the flanks of the modelled anomaly.

The intermediate model (Fig. 9) shows the second of these stages. Deeper than 20 m or so, the two pairs of facing walls of the dykes have no appreciable effect on the anomaly, as they practically cancel each other out. The crucial vertices in the model are the six marking the top surfaces of the three dykes. The unacceptably 'lumpy' intermediate modelled anomaly results from the gaps between the dykes. The only way to smooth this out is to merge the dykes, first so that two remain, and finally so that there is only one. Similarly, the only way to model satisfactorily the very pronounced point in the observed anomaly is to introduce the thin dyke intruded upwards almost to the surface. In conclusion, the model progresses back towards one like that shown in Fig. 4.

The width of dyke no. 2 on profile AA′ (Fig. 4) at depth is about 65 m. The initial model using multiple dykes started with a cumulative width of 60 m, and evolved to fewer dykes, but with a similar cumulative width. It may be, therefore, that instead of one single body at depth (the simplest dyke model) there are, in fact, multiple closely spaced bodies. Big dykes are likely to be composite, in any case, with varying magnetization through the component parts. It is clear that we cannot resolve these details, but what we can achieve by the modelling are good constraints on

(1) the *cumulative* width of the body or bodies, and
(2) the depth to the tops of the bodies.

3.2 How common are ultrawide dykes?

Seismic reflection observations have also been made of some of the Tertiary (Palaeocene) dykes of NW Britain inferred from geophysical methods. The Loch Ewe dyke in the North Minch west of Scotland is the best-documented example (McQuillin, Bacon & Barclay 1979, Fig. 7/22; Chesher, Smythe & Bishop 1983). It is about 500 m wide, with its top about 1 km below sea-level, and shows up prominently on all the seismic reflection sections that cross it. It dies out to the SE at the mainland coastline, and does not reach the surface anywhere. Its structural setting is therefore similar to that of the quartz-dolerites of the North Sea, in that it is big offshore, but diminishes or dies out at the coast. This curious observation remains unexplained.

The Great Abitibi dyke on the Canadian Shield is 600 km long and 250 m wide (Ernst *et al.* 1987). The Great Dike of Nova Scotia (also known as the Shelburne Dike) is up to 200 km long and 60–180 m wide (Papezik & Barr 1981). Gravity modelling of the Great Dyke of Zimbabwe shows that it is bell-shaped, with the main feeder about 1 km wide (Podmore & Wilson 1987). This dyke is 550 km long. The Dunbar dykes have a cumulative width of 2–3 km over a length of 200 km (Table 1), which makes them (or it) as large, volumetrically, as any intracontinental dyke yet modelled.

4 CONCLUSIONS

Compilation of relevant geological and geophysical data from around Britain has been used to demonstrate that what was previously regarded as a relatively minor late Carboniferous dolerite dyke swarm is, in fact, one of the major dyke swarms of NW Europe. Individual dykes are inferred by geophysical modelling to be over 1 km wide; these may be the widest dykes discovered to date.

ACKNOWLEDGMENTS

This research was begun when the author was employed by the British Geological Survey (BGS). The work was inspired by Mike Russell (formerly at Strathclyde University), who perceived the likely regional importance of the swarm. I thank Mike also for assistance in carrying out the fieldwork at Dunbar, and both him and Andy Skuce for discussions on the regional implications of the dyke swarm. Mike's former student, Richard Pattrick collected the Tyndrum field data. I thank Western Geophysical for permission to reproduce the seismic section shown in Fig. 5. Bill Ashcroft (Aberdeen University) supplied unpublished maps of the Aberdeenshire dykes, based on his and his student's geophysical work, in advance of publication. Diagrams of dyke models were prepared using the GMT system (Wessel & Smith 1991) combined with a Gravmag-to-GMT set of subroutines written by the author.

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APPENDIX: SOURCES OF DYKE COMPILATION

The following aeromagnetic maps have anomalies interpreted as due to the dykes.

(1) Unpublished Canadian Aero Service aeromagnetic survey of the North Sea, 1:63 360 scale contour maps with flight lines, 1963. Sheets 10, 18, 19, 26, 27, 34.

(2) IGS Aeromagnetic anomaly: 1:625 000 Sheets 1 and 2; 1:250 000 Sheets 7–16; unpublished 1:63 360 scale contour maps and flight-line maps.

The complete archive of BGS geological maps was consulted. Compilations of NE Scotland dykes are also given by Munro (1986) and Trewin, Kneller & Gillen (1987). The following maps show quartz-dolerite dykes interpreted to be of late Carboniferous age:

(1) BGS 1 inch to 1 mile solid geology sheets 7, 10 (hand-coloured), 11, 15, 16, 21 (hand-coloured), 22–24, 25 (hand-coloured), 27–31, 36–38, 40, 41, 44, 45, 46 (hand-coloured), 47, 48, 53, 55, 56, 61, 66, 67, 76, 77 (hand-coloured), 86, 95 (hand-coloured), 97 (hand-coloured), 113, 114, West Shetland, North Shetland.

(2) BGS 1:50 000 solid geology sheets 9E, 14W, 14E, 32W, 32E, 33W, 39W, 39E, 48W, 48E, 49, 52W, 52E, 62W, 62E.

(3) BGS 1:100 000 solid geology sheet Uist and Barra (South).

(4) BGS 1:250 000 solid geology sheets Tyne-Tees 54N 2W, Lake District 54N 4W, Farne 55N 2W, Borders 55N 4W, Clyde 55N 6W, Tay–Forth 56N 4W, Argyll 56N 6W, Tiree 56N 8W, Peterhead 57N 2W, Moray–Buchan 57N 4W, Barra 57N 8W.

(5) BGS $\frac{1}{4}$ inch to 1 mile solid geology sheets 10, 13, 14, 16.