UNIVERSITY OF KEELE

Keele Science & Technology Centre

Association for Science Education
Staffordshire Section

KSTTC GEOLOGY SECTION Joint Excursion with the

North Staffs Group of the Geologists Association of London

Geology in the Field - Fieldwork near the Potteries XVIII:

THE NORTH STAFFORDSHIRE DYKE SWARM - DARWIN'S DYKES

Tuesday evening September 8th 1987 meeting at 5.30 pm at SJ 842400 at the bends in the Trentham-Stableford Road in the Hanchurch Hills.

Locality 1a,b,c The Hanchurch Hills c.SJ 841400 near the road between Hanchurch and Stableford. The Darwin locality according to Garner 1844. However, the dykes were discovered here independently by an amateur, J. Kirkby, in the early 1840s. The dykes are exposed both to the north and south of the lane according to geological 1:10,000 maps. To the south (1a) a dyke may be located in the roadbank and traced by fragments southwards (1b). To the north of the lane (1c) sites of Kirkby's trenches may possibly be located. Darwin's locality is likely to be beneath or alongside the carriageway at 1(a). The rocks were described as olivine diabase (Hampton in Kirkby 1874), nepheline basanite (Scott 1920, Scott 1925)

Locality 2 The quarry in Church Wood Butterton SJ 834419. The first recorded exposure of a dyke here was c.1851 when W. Warington Smyth and E.W. Binney surveyed the area. The quarry is described by Gibson (1905), Scott in Gibson (1925), Cope (1966) who reports two olivine dolerite dykes with an isotopic age date of 52.4 ± 1.4 my (from J.A. Miller). Thompson (1975) provides worksheets for school and college parties. Permission to visit must be obtained from Mr C.F. Matthews, Lymes Farm, Butterton, 0782-617489. Flett (1910) described nepheline basanite from this quarry.

Locality 3 The fields for 325m SSE of Church Wood Quarry. The geological survey map showed a single outcrop of dyke rock but the area has been resurveyed most successfully by vertical magnetic gradiometer by Sowerbutts (1987). This technique, allied to an isometric computer plotting of the results, shows up the nature of the dykes most clearly and leads to much discussion of their mode of emplacement.

Locality 4 An outcrop of dyke rock on the Trentham-Whitmore road reported in Kirkby (1984) at SJ 833415.

Locality 5 Former outcrops to the southwest of Butterton Lodge on both sides of the lane at SJ 831427. This is where Darwin found the dykes according to Gibson (1905) and Cope (1966) (but neither citing documentary evidence). The use of Gibson's field sketches (1898) may allow us to relocate the outcrops. Olivine dolerite (Flett in Gibson 1905) and nepheline basanite (Flett 1910) are described from here.

Locality 6 Lymes Farm SJ 828431. Former outcrops in the foundations of one of Mr Matthew's barns.

Locality 7 A former outcrop 60 yds WNW of the bridge carrying the A53 over the M6 motorway at SJ 826435.

Locality 8 the Lymes Road borehole, formerly referred to as the Seabridge borehole (see the original borehole log with 8 dykes, the chemical analyses in Scott in Gibson 1925 and Scott 1926). See also the interpretations of Cope (1966 figs. 2 and 4) compared with Exley (1970), and the Coal Board mapping of the Great Row Seam underground (Hodgkinson 1986). Scott recognised the following rocks under the microscope: augitite, limburgite, nepheline basanite, crinanite.

Locality 9 Former outcrops at the former Keele University Sewage Farm bacterial bed at SJ 824441 (see Cope 1966 pp 26-27). Compare the nature and disposition of the dykes across the Seabridge Fault according to the interpretations of Cope (1949, 1966) and Exley (1970). Cope described olivine dolerite with no nepheline.

Dyke N-S trend Loc 1a
5 metres up from telegraph pole on bend of road
Stableford - Trentham -
Affects the sandstone - bleaches them - Post Trias
? - Tertiary
52 Ma ± 1.4 Ma

? same dyke in path straight from road
under tree - sketch in gibson

~~South~~ North side of bend along path - supposed tholei
in podsolised pebble beds
200 m north

Butterton Church Wood Quarry
Keele S/S - fluvial beds - Equatorial Savanna + overbank dep - Dip west

original notes + maps lost.
Rock worked for paths at Butterton Hall
Reversed paleomag.
52 Ma ± 1.4 Ma Eocene. from this Q

Pyroxene, olivine, nepheline in groundmass + analcite
(Feldspathoids)

Similar to Scottish Crinanites

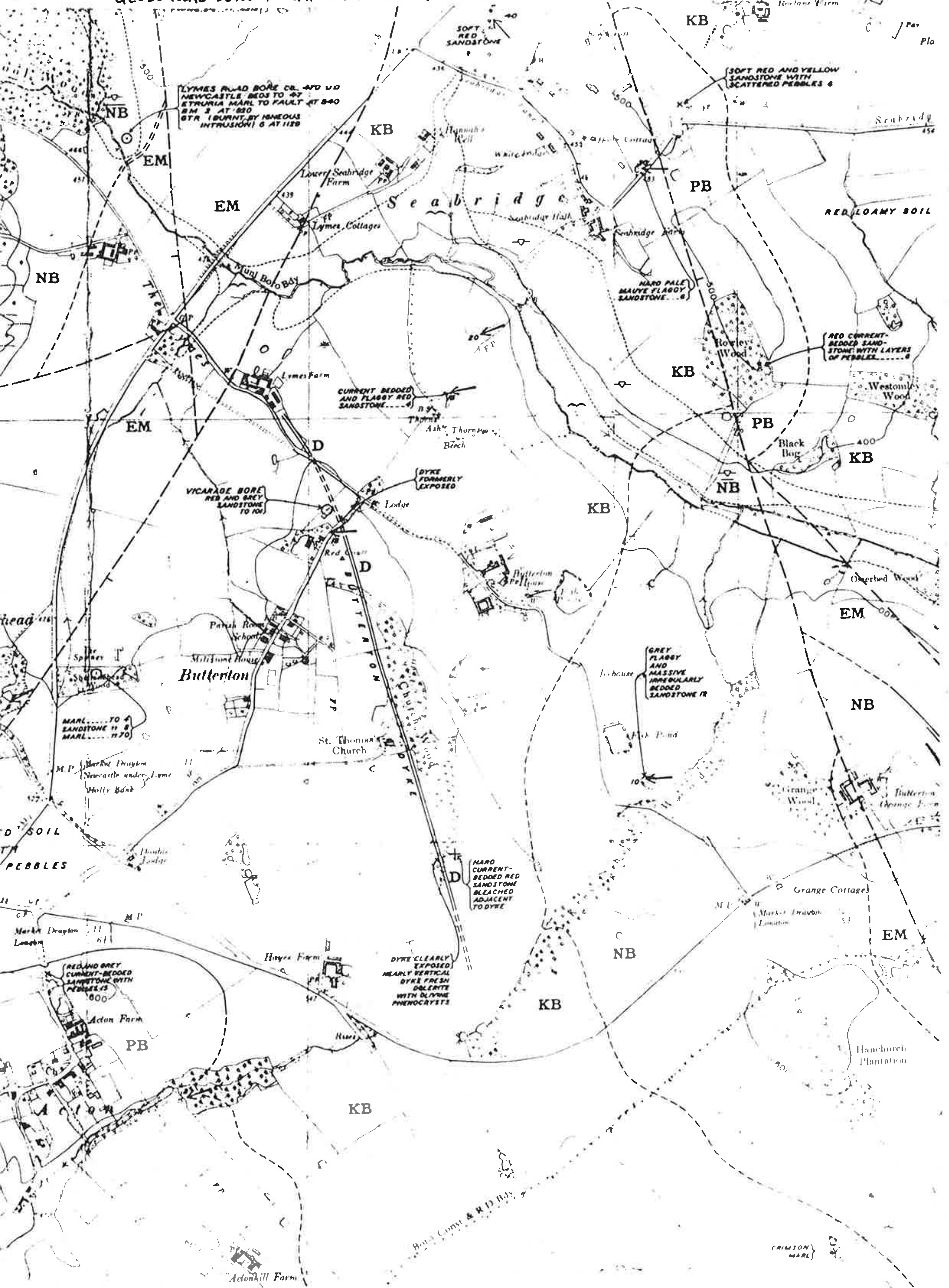
Joints + Faults - up which magma came.
+ parallel to normal Apedale fault

Calcite in vesicles !!

Butterton Village - Lodge Gate on corner
walcot Gibson's field diagram.
other accounts. 55 + (90) yards from corner
South - opposite house entrance
? 'new' wall over entrance to ? ary

Lymes Farm -
M6 bridge 60 yards WNW dyke + fault.
Lymes Farm Bridge.
Sewage farm to N.

GEOLOGICAL SURVEY MAP 1 : 10 560 (MAPPED BY F.W. COPE 1944-5)



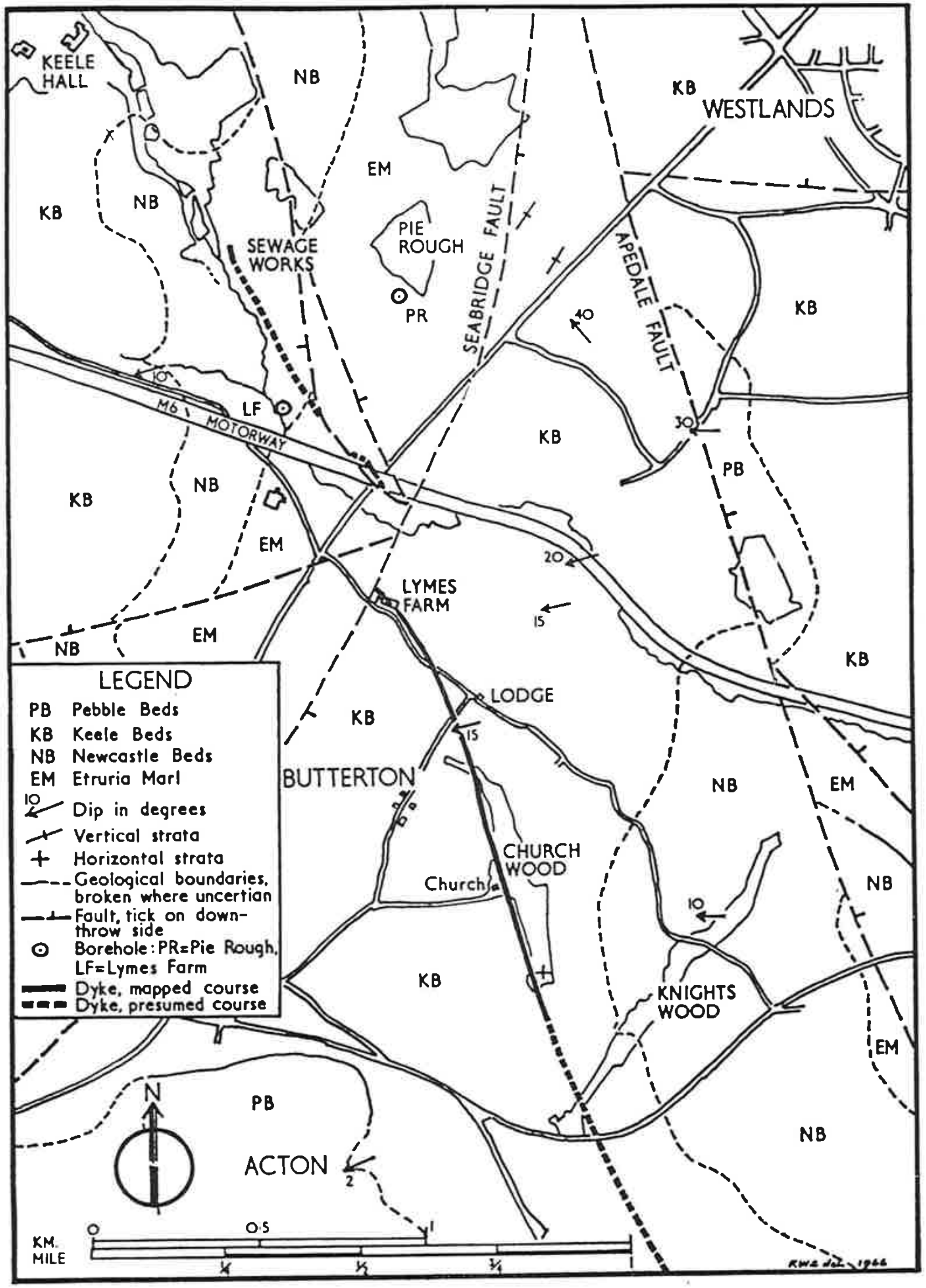


FIGURE 1 - Geological sketch-map of the area between Keele, Newcastle, and Butterton, Staffordshire, to show the course pursued by the Butterton Dyke.

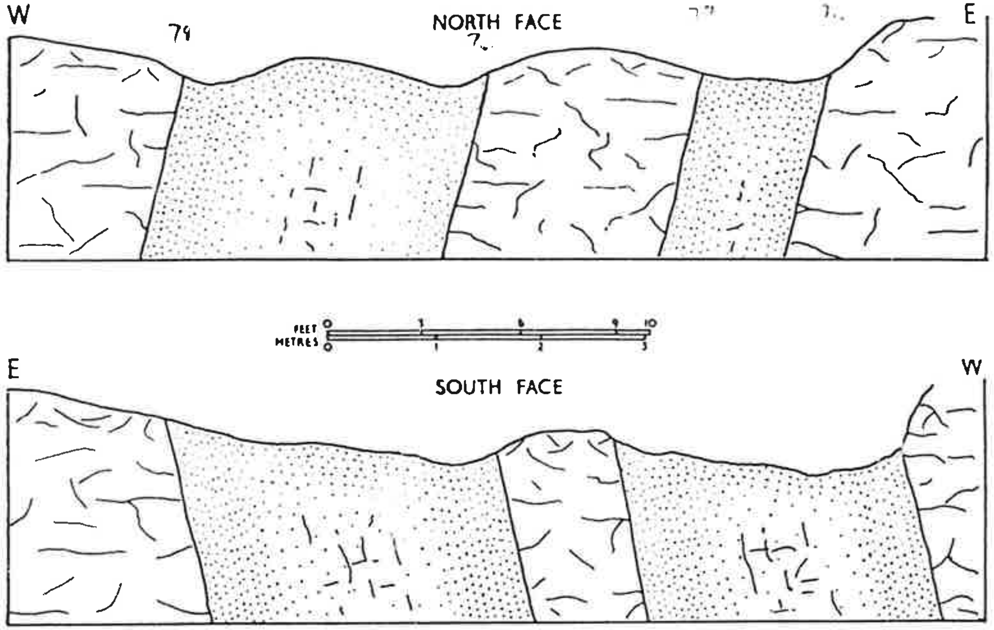


FIGURE 3 - Diagrammatic representations of the Butterton Dyke as exposed in the faces of the disused quarry at the south end of Church Wood, Butterton. Sandstone is indicated by unshaded areas with markings of strong irregular jointing. Decomposed dolerite is represented by the dotted areas; fresher dolerite appears as cores marked with sub-parallel joints.

GIBSON 1905

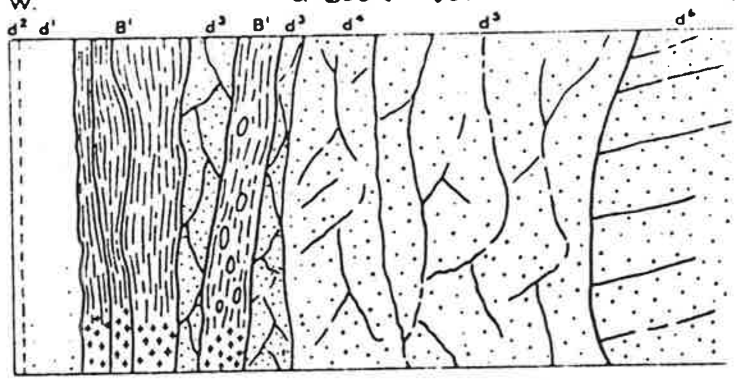
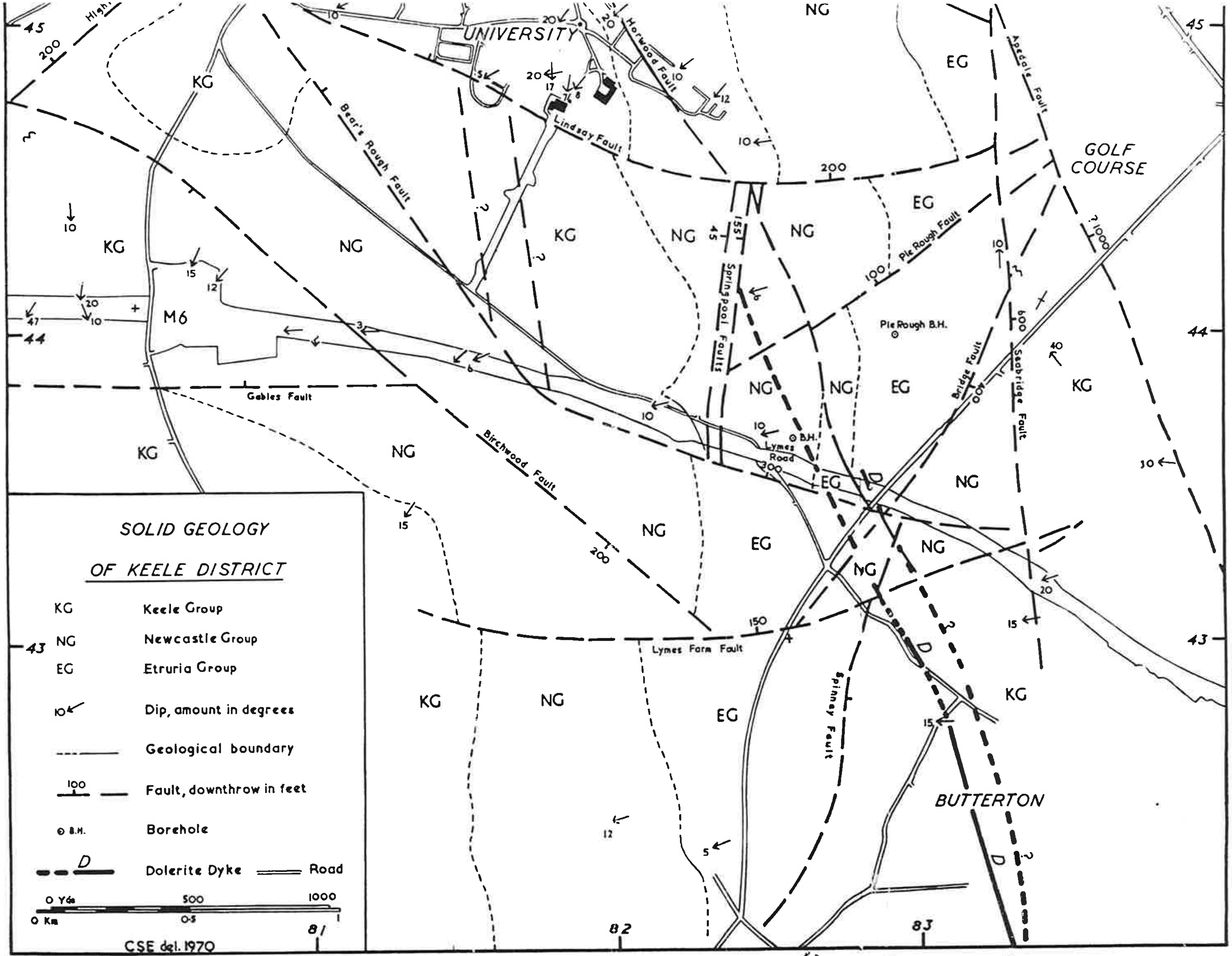


FIG. 15.—*Igneous Dyke in the Keele Group, Butterton Park.*

d² Unaltered sandstone.	d³ Altered grit, 3 to 4 ft. wide.
d¹ Altered do., 3 ft. wide.	d⁴ Soft white sandstone, 10 ft. wide.
B¹ Dyke, 8 ft. and 3 ft. wide.	d⁵ Olive coloured sandstone.
	d⁶ Red sandstone.



GEOLOGICAL MAP OF THE AREA OF THE BUTTERTON DYKE (R C S EXLEY 1970)

Scott, A 1926 Trans. North Staffs Field Club 60, 143-146.

TABLE I. CHEMICAL COMPOSITION OF THE BUTTERTON AND OTHER ROCKS.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	44.15	45.09	39.40	43.94	44.69	44.47	44.37
TiO_2	1.56	2.59	2.28	2.45	.46	2.73	2.37
Al_2O_3	14.60	9.90	8.65	14.03	14.17	7.59	14.19
Fe_2O_3	2.29	5.73	10.36	1.95	3.35	6.25	3.12
FeO	9.19	13.51	8.09	11.65	10.86	9.57	7.28
MnO	0.21	0.20	0.28	0.32	0.31	0.49	0.24
MgO	12.03	10.91	9.53	10.46	6.41	11.93	7.84
CaO	9.42	6.55	10.49	8.99	10.28	10.24	12.68
K_2O	1.55	1.55	1.53	0.33	2.01	1.46	1.92
Na_2O	3.11	1.37	1.73	2.68	3.64	4.27	3.86
H_2O +	1.12	1.50	2.86	2.31	2.53	0.73	1.23
H_2O −	0.30	0.38	0.29	0.85	1.05	0.48	0.24
P_2O_5	0.18	0.20	0.16	0.20	.45	0.54	0.83
CO_2	0.19	0.95	4.80	0.16	nt. fd.	tr.	nt. fd.
	99.90	100.43	100.45	100.32	100.21	100.75	100.17

TABLE II. THE NORMS OF THE ROCKS THE ANALYSES OF WHICH ARE GIVEN IN TABLE I.

	1.	2.	3.	4.	5.	6.	7.
Orthoclase	9.63	9.43	9.60	1.72	11.83	8.90	11.24
Albite	6.41	12.02	10.75	20.52	8.50	5.76	3.71
Anorthite	21.56	16.64	12.26	25.78	16.63	—	16.03
Nepheline	11.00	—	2.76	1.75	12.38	13.63	15.80
Diopside	20.28	12.82	34.05	15.86	27.07	37.84	34.30
Hypersthene	—	26.70	—	—	—	—	—
Acmite	—	—	—	—	—	4.62	—
Olivine	24.33	8.72	9.19	26.09	16.85	15.69	7.79
Magnetite	3.31	8.33	16.27	3.11	4.94	6.73	4.46
Ilmenite	3.10	5.01	4.76	4.85	.77	5.17	4.61
Apatite	.35	.33	.36	.35	[illegible]	1.34	[illegible]

1. Nepheline basanite (crinanite)[1], Hanchurch Woods, Staffs. III, 6. 3. 4. Locality ①
2. Limburgite,[1] Seabridge, Staffs. III (IV), 5. 3. (4). 3.
3. Limburgite (vesicular),[1] Seabridge, Staffs. IV, 2. 2. 2. 2. } Seabridge Borehole Locality ⑧
4. Crinanite,[2] Slac nan Sgarth, Inver Cottage, Jura, III, 5. 4. 5.
5. Crinanite,[3] Howford Bridge, Mauchline, Ayrshire, III, 6. 3. 4.
6. Picrite-theralite,[4] Lugar, Ayrshire. IV. 2. 2. 2. 2.
7. Essexite,[5] Craighead, Lanarkshire. III. 6. 3. 4.

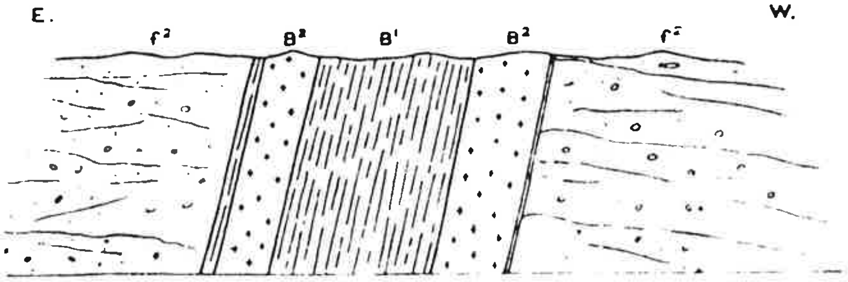


Fig. 14. Igneous Dyke in the Bunter Sandstone, Hanchurch Hills.
f² Bunter conglomerate. B² Nepheline basanite. B¹ Decomposed Dyke.

Kirkby 1894
Gibson 1905.

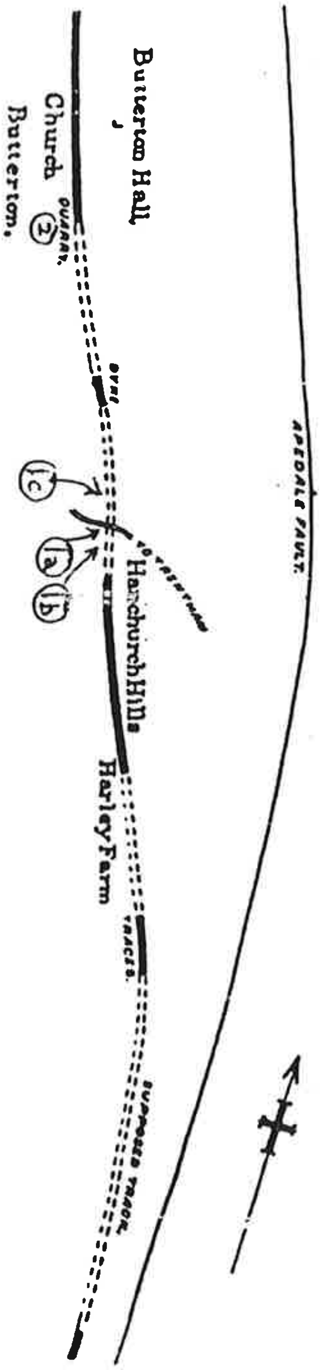
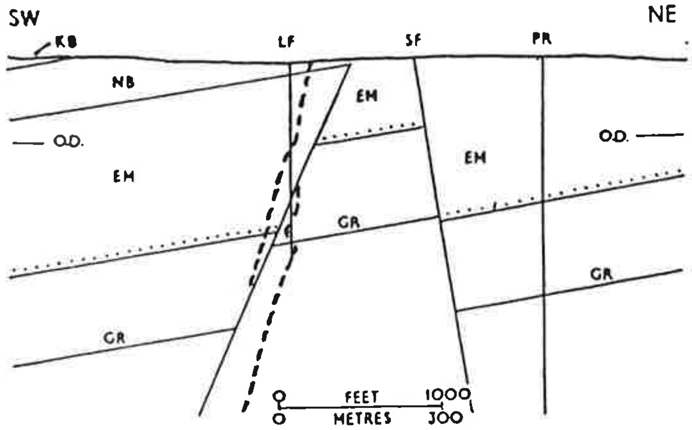


Fig. 14.
Plan of the Butterton and Swynnerton Dyke. (After J. Kirkby, N. Staffs. Field Club. Vol. xxviii. 1894.)
One inch = about one mile.



Locality 8

FIGURE 4 - Section along a line through the Lymes Farm borehole (LF) and Pie Rough borehole (PR), showing a possible interpretation of the structure, and behaviour of the Butterton Dyke (thick broken line).

Key to lettering: KB, Keele Beds; NB, Newcastle Beds; EM, Etruria Marl; GR, Great Row; SF, Seabridge Fault.

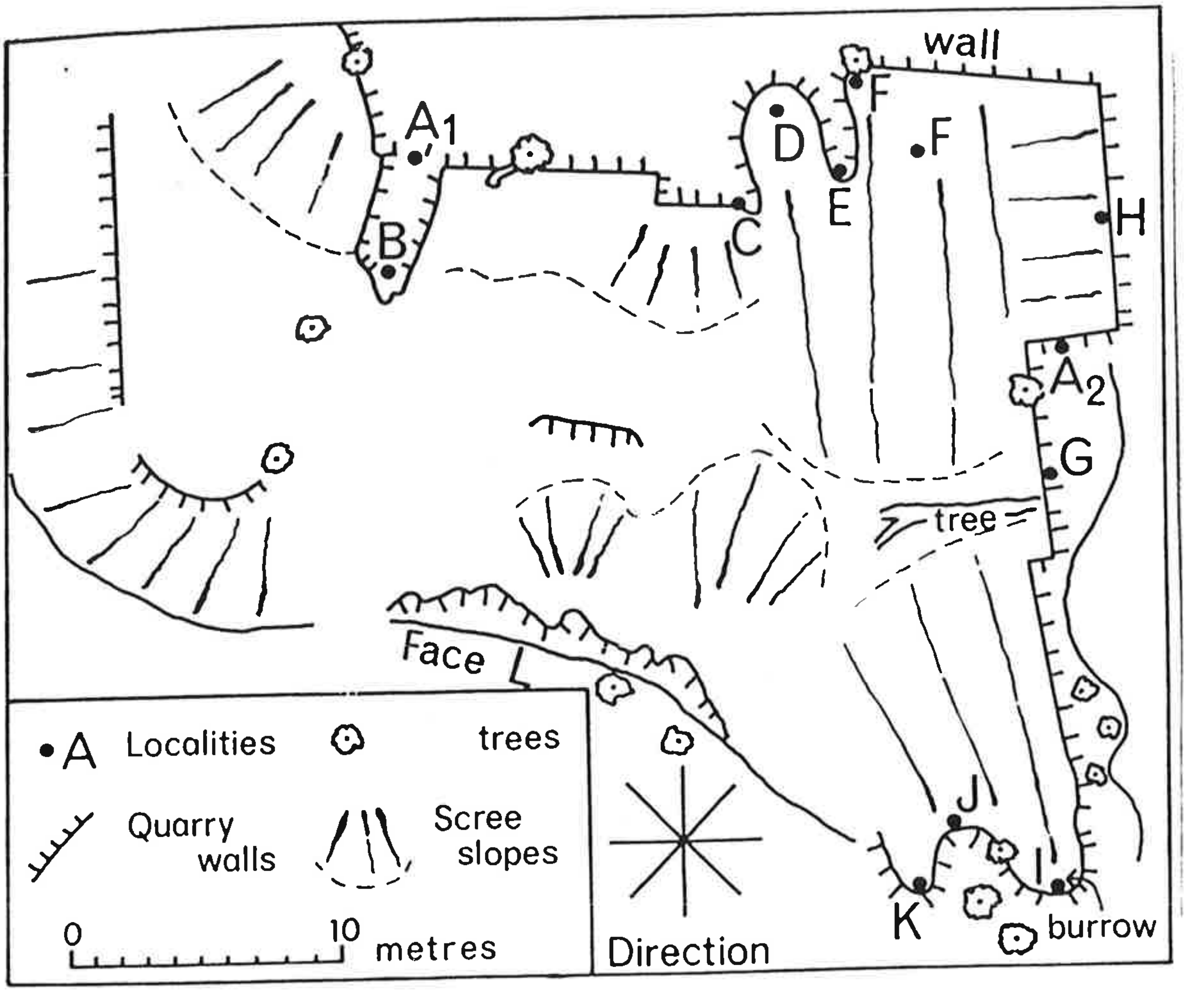


Fig. 2. Plan of Butterton Church Quarry.

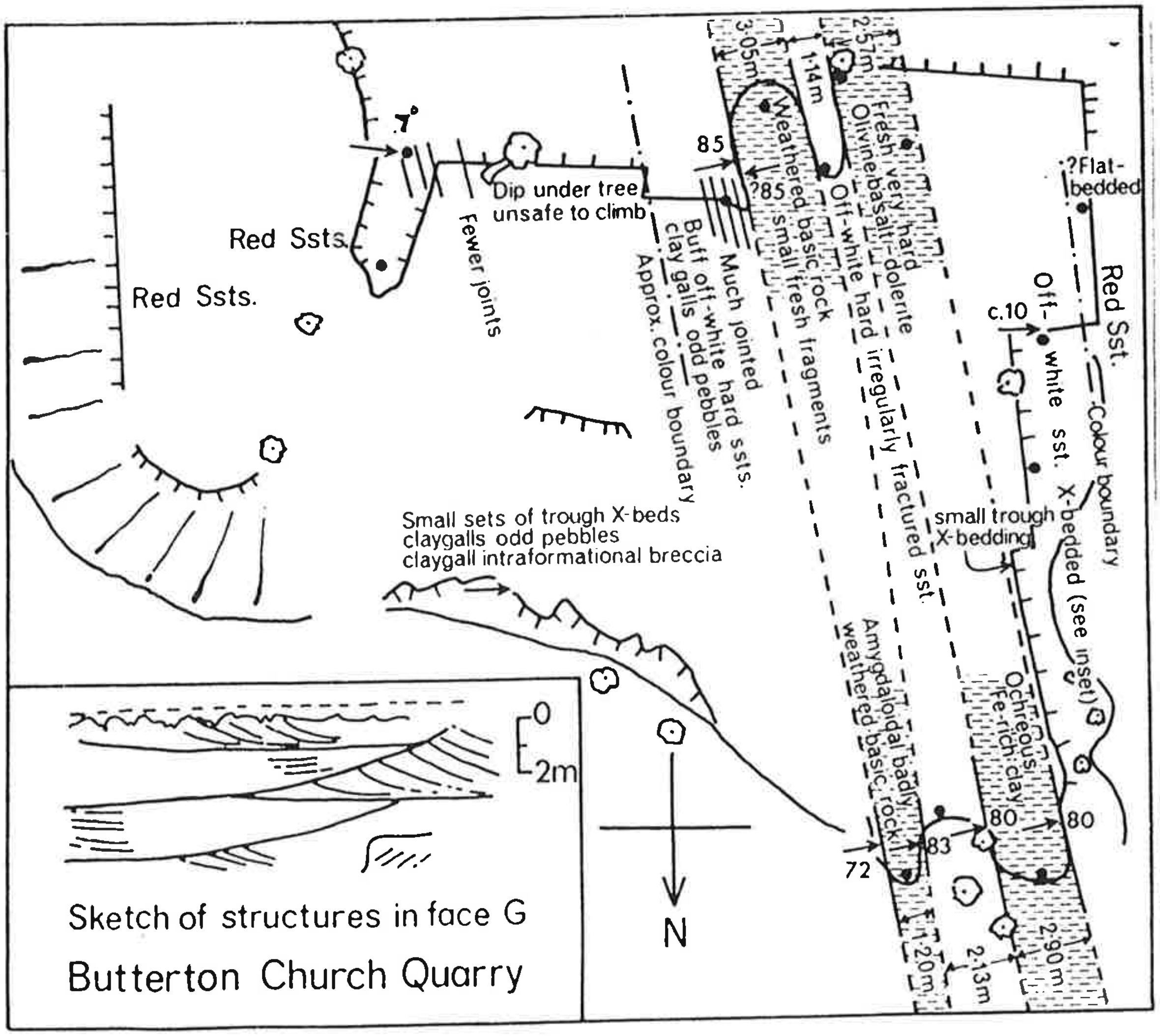


Fig. 3. Outline geological map of Butterton Church Quarry.

MAGNETIC MAPPING OF THE BUTTERTON DYKE – W.T.C. SOWERBUTTS
(Jl. geol. Soc. Lond. 144 1987 pp29–33.)

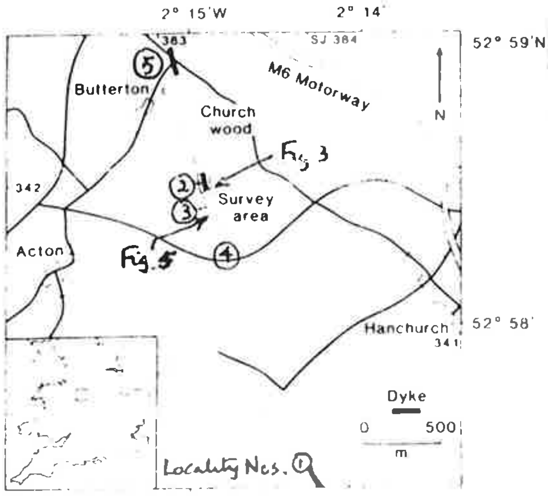


Fig. 1. Location map showing known exposures of the Butterton Dyke and the area where the magnetic survey was made.

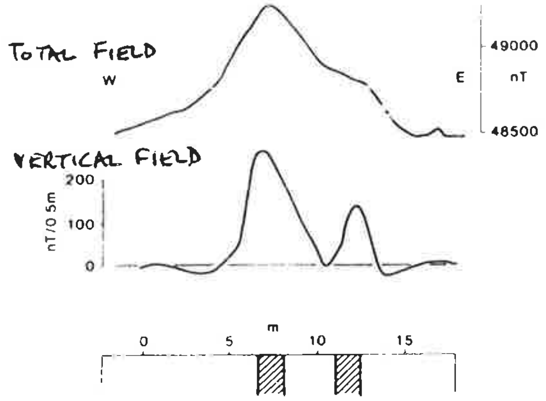


Fig. 3. Magnetic profiles obtained above the northern end of Church Wood Quarry (Grid Ref. SJ84; 834420) and section showing the position of two dykes (hatched) observed in the quarry face. The total magnetic field measurements show one broad anomaly whereas the profile of vertical magnetic gradient shows separate anomalies over each dyke.

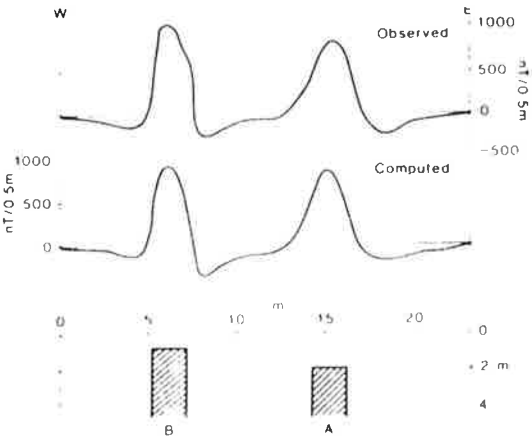
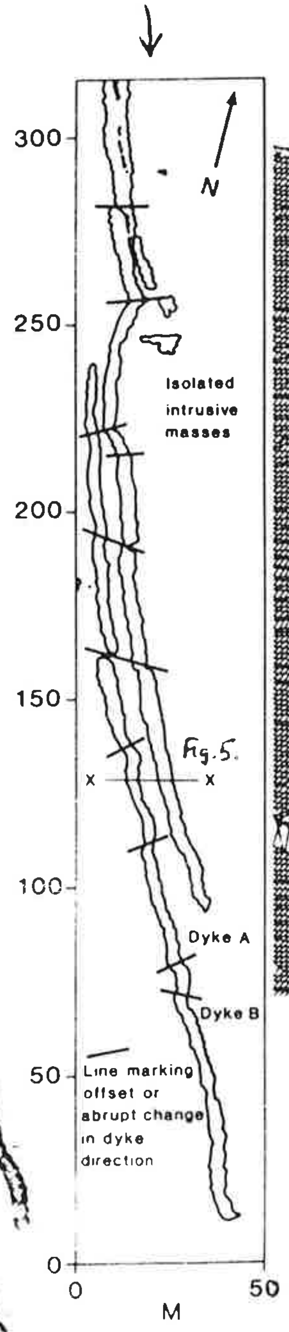
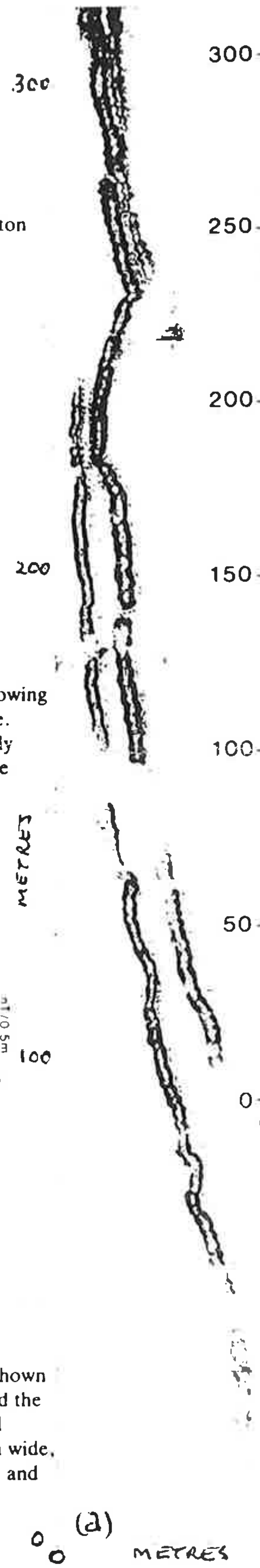


Fig. 5. Vertical magnetic gradient profiles for the line X–X shown in Fig. 4. The top profile is the measured vertical gradient and the bottom profile gives values computed for the two-dyke model shown in section below. In the model Dykes A and B are 2 m wide, 2 and 1 m below the surface, with magnetizations of 20 Am^{-1} and 8 Am^{-1} respectively.

Fig. 4. Map showing the +10 nT/0.5 m (+20 nT m^{-1}) magnetic contour to illustrate the detailed nature of the igneous intrusions. Places are marked where the orientation of the dykes appears to change. X–X marks the line of the magnetic profile shown in Fig. 5.





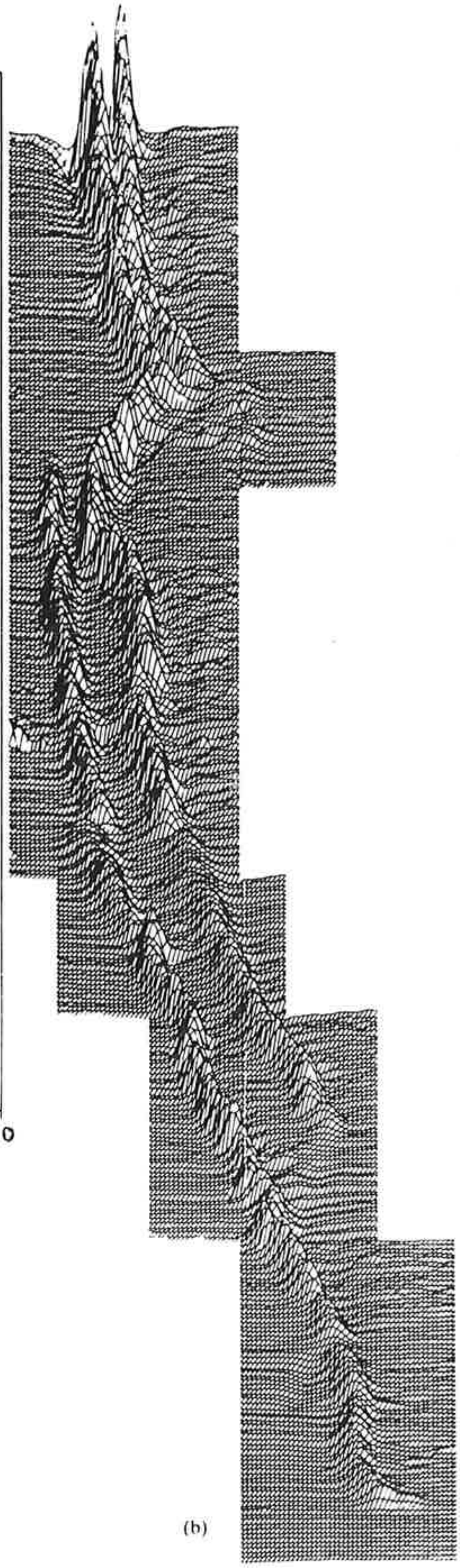


Fig. 2. Contour map and isometric plot showing the results of a vertical magnetic gradient survey made over part of the Butterton Dyke. The contour interval used is 10 nT/0.5 m (20 nT m^{-1}), positive values are contoured as solid lines and negative values as dashed lines.

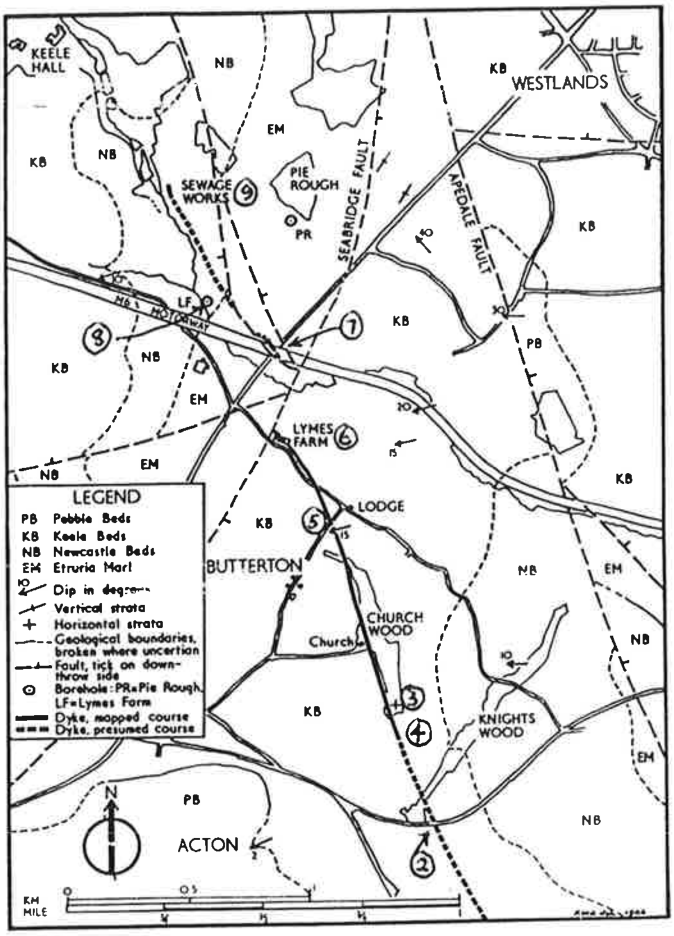
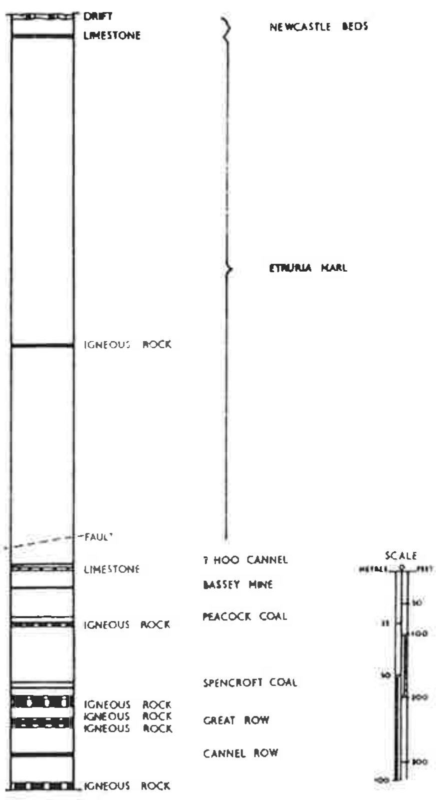


FIGURE 1 - Geological sketch-map of the area between Keele, Newcastle, and Butterton, Staffordshire, to show the course pursued by the Butterton Dyke.



LOCALITY 8

FIGURE 2 - Section of the Lymes Farm borehole, Lymes Road near Keele, Staffordshire, showing the main coals and igneous intrusions intercepted.

LOCALITY 6

a. Lymes Farm: In the 1945 Geological Survey revision the author mapped the dyke on surface features and occasional soil-fragments from near the Butterton Park Lodge gates almost to Lymes Farm on the north side of Lymes Road. Since the outcrop of the dyke, over this part of its length, was gradually departing from its usual north-north-westerly trend it was deemed inadvisable to extend the outcrop farther without positive evidence of the occurrence of igneous rock. Such evidence materialized in 1964, when a small temporary pit close to the farm buildings exposed a width of several feet of severely weathered dolerite, together with traces of the reddish-brown sandstones of the Keele Beds to the north and south. This exposure not only confirmed the course of the dyke as mapped, but extended the outcrop to a small extent in a north-westerly direction. It did not, however, afford any clear evidence of the width of the dyke or of its inclination.

LOCALITY 7.

b. Birmingham-Preston Motorway (M6): During the construction of the Hanford-Keele section of the Birmingham-Preston motorway in 1961, a width of just over 1 ft. of decomposed dolerite was exposed on the northern edge of the excavated area at a point 60 yds. west-north-west of the bridge now carrying the Newcastle-Market Drayton road over the motorway. The dyke, here cutting through soft mudstones of the Etruria Marl Group, showed an easterly contact which appeared to be striking approximately N 20° W. On the west side the dyke was terminated by a fault, cutting it at an oblique angle, which appeared to be a branch of a more powerful fault occurring immediately to the west. The exposure was not sufficiently good for determining the inclination of the dyke.

LOCALITY 9.

c. Sewage Works, University of Keele: In 1964, the dyke was clearly exposed, for a matter of days, on the north side of a circular excavation for a new bacterial bed, in Springpool Wood about 830 yds. south-south-east of Keele Hall, and almost a mile north-north-west of Darwin's locality.

The height of the exposure was 6 ft., of which the topmost foot consisted of disturbed soil and drift. The dyke, 3 ft. 6 ins. in width, and both contacts with brown and mottled mudstones of the Newcastle Beds were clearly displayed. The intrusion (Plate I) showed a broad middle zone of fresh blue-hearted dolerite with marked jointing parallel and perpendicular to the contacts. On each side of this a narrow contact-zone consisted of highly decomposed dolerite converted for the most part into a brown clay. The normally weathered yellowish-grey clay-mudstones of the Newcastle Beds assumed a brown and mottled coloration in proximity to the dyke.

As far as could be ascertained from this single vertical exposure (the floor of the excavation was covered with slumped clay and water), together with a small amount of excavation of the westerly contact for the purpose, the dyke is running in a direction N 10° W-N 20° W. Owing to an increasing thickness of drift in other shallow excavations immediately to the south, it was not possible to see the igneous rock again in that direction, nor was it exposed in the bed or banks of the stream to the west and south of this exposure.

The exposure is illustrated by Plate I, the direction of the face being W.S.W.-E.N.E. It will be noticed that in the higher part the dyke shows an easterly hade of about 20° but that within the few feet to the base of the exposure the intrusion has become nearly vertical. On a later page (p. 33) it will be shown that the dyke probably has a general westerly hade in this vicinity and the measured easterly inclination at the surface may be due to superficial movements.

THE PETROGRAPHY OF THE DYKE ROCK

SEWAGE WORKS LOCALITY 9

A blue-hearted block of rock extracted from the middle relatively unweathered zone of the dyke, temporarily exposed at the sewage works in the University grounds at Keele, yielded thin-sections which showed the rock to be surprisingly fresh, in view of the narrowness of the intrusion and the shallowness of cover.

The rock is a fine-grained olivine-dolerite. It shows numerous phenocrysts, up to 2.5 mm across, originally of olivine but almost all now entirely converted into serpentine. There is very little iron oxide within the serpentine pseudomorphs, but the original idiomorphic outlines of the olivine crystals have been markedly accentuated by the growth of peripheral magnetite.

The ground-mass of the rock consists of a felt of hypidiomorphic granular pinkish pale-brown augite, probably titanaugite, laths of plagioclase felspars of two distinctly different dimensions but none of it phenocrystic, and grains of magnetite and ilmenite; the last-named mineral also appears as small skeletal or sub-arborescent growths, the habit being similar to that of the ilmenite in a tholeiite described from a dyke in the Carboniferous Limestone of North Derbyshire.[4]

The bulk amounts of the minerals in the dolerite, in decreasing order, are augite, olivine (serpentine), palgioclase felspar, and iron oxides. There are minor amounts of a chlorophaeite, and very minor blebs of what may originally have been sparsely developed interstitial glass, but no evidence was found for nepheline which Flett suggested may be present in the dyke rock from the Church Wood quarry near Butterton.[5]

LYMES FARM BOREHOLE 1920
Scott in Gibson & Wedd 1925
Original record in BGS and NCB Chatterley Whitfield

SCOTTS DESCRIPTION & DEPTHS (IN FEET)

ORIGINAL BOREHOLE RECORD ① ②

DEPTH	TRUE THICKNESS
MINERALISATION at 525	
DYKE 1 2'6" 530 - 532'6	1'9"
DYKE 2 1'6" 533'6" - 535'	1.0"

600 FEET

p94 534' Three specimens described
(i) basic crinanite (basic subalkaline)
(ii) augitite (ultrabasic)
(iii) limburgite (ultrabasic)

700

ORIGINAL CORES EXAMINED BY T. A. ROBERTSON (OF BGS) AND ALSO BY J.T. STOBBS

800

DRILL 840' [illegible]

DYKE 3 1-0"
844-845

p 94 1093 = 5a basic crinanite sub alkaline basic
1097 = 5a similar rock; larger phenocrysts
1100 = 5b still coarsely porphyritic - same rock type
1107 = 5c same rock type olivine > augite
1112 = 5c same rock: small porphyritic crystals in fine matrix

900

1130 = 7 basic crinanite
porphyritic olivine scarce: replaced by calcite often

DYKE 4 4'0"
972-976

1000 FEET

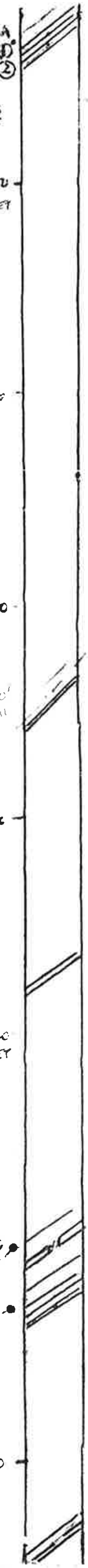
COMPOSITE DYKE 5
5a — 7'0" 1092-99
5b
5c 12'0" 1101-1113 } 1100 calcite

DYKE 6 4'0"
1020-1024

DYKE 7 1-0" calcite
1129-1130

DYKE 8 4'0"
1232 - 1236
black shale + igneous rock

1200



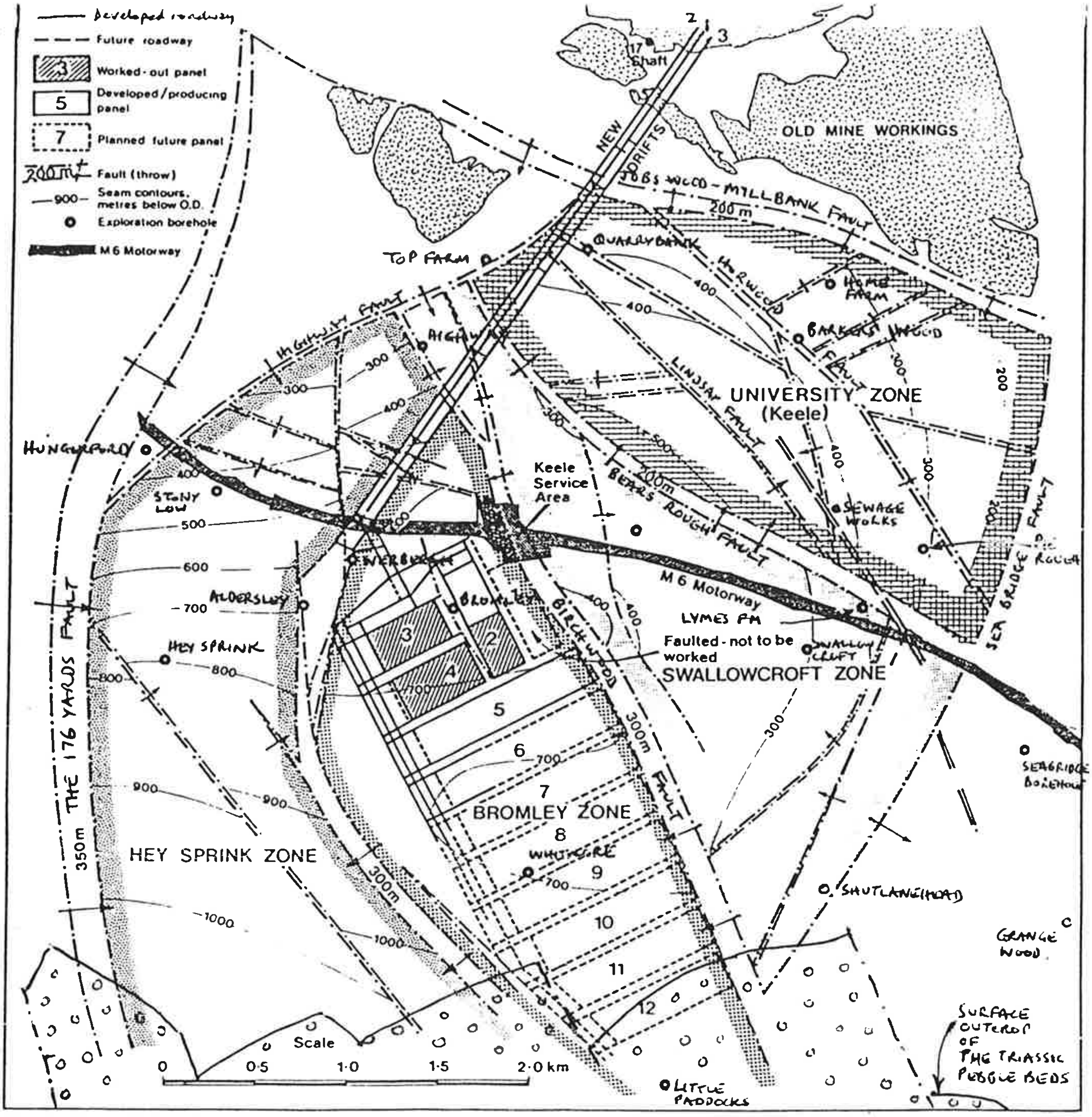


Fig. 3: Plan of Silverdale New Mine showing major faults, colliery workings and depths below O.D. in the Great Row seam.
(From Hodgkinson 1988 Mining Magazine, Sept issue)

Some buried Tertiary dykes of Britain and surrounding waters deduced by magnetic modelling and seismic reflection methods

SUMMARY: Dykes of Tertiary age have been identified by modelling offshore marine and aeromagnetic data and onshore aeromagnetic data. Dykes have been found in the North Sea off NE England, and in the Irish Sea. Published aeromagnetic maps have also been used to locate non-outcropping Tertiary dykes in the Scottish Borders. Many of the offshore anomalies are caused by multiple dykes that cannot be separately resolved. All dykes retain the dominant NW-SE trend of the known Tertiary dykes although this trend approaches E-W near the east coast of England. Under the North Sea the trend swings back and becomes increasingly southerly trending. The dykes may be the result of NW-SE compressional or NE-SW tensional stress with deep crustal weaknesses causing changes in trend.

J. geol. Soc. London, Vol. **142**, 1985, pp. 1047–1057, 12 figs.

S. R. Kirton & J. A. Donato 1985

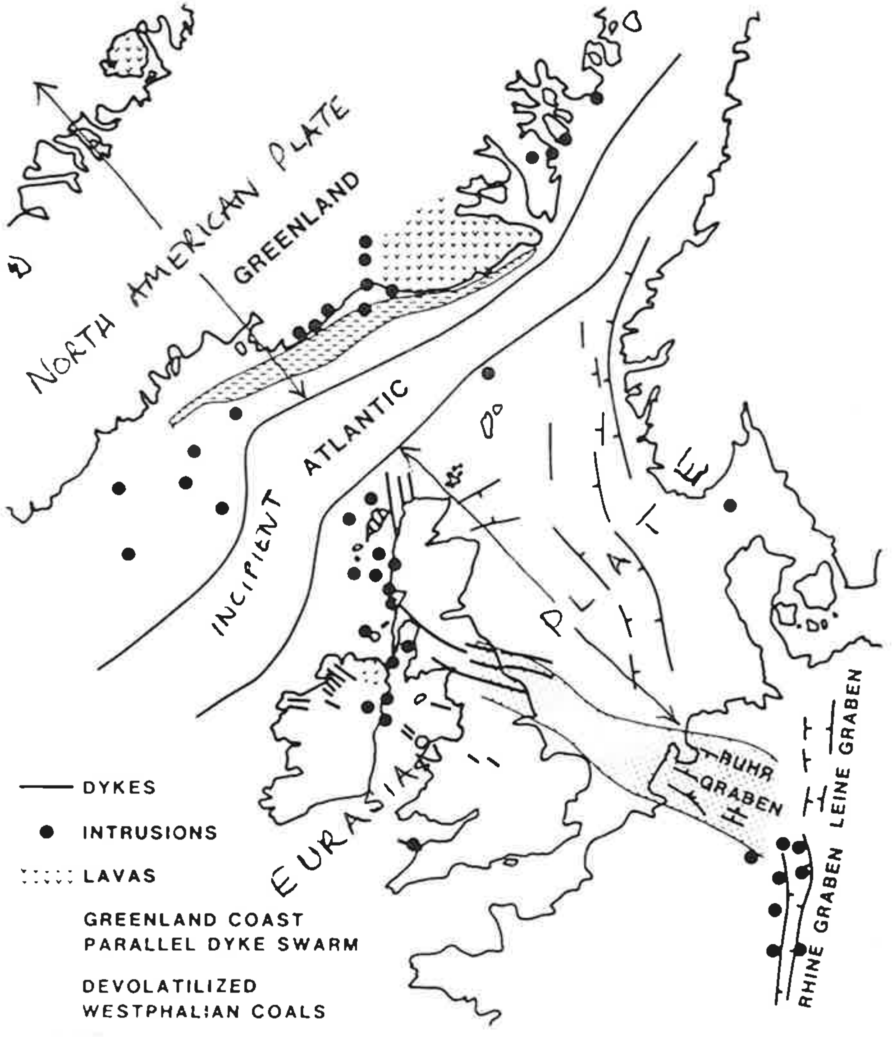


FIG. 12. Tertiary reconstruction of North Atlantic areas showing generalized Tertiary dyke pattern. diagram in Bell (1976).

In recent years the British Geological Survey (formerly Institute of Geological Sciences) has run extensive geophysical surveys over the UK mainland and surrounding continental shelf. For this paper marine and aeromagnetic surveys have been used in conjunction with commercial multichannel seismic surveys to define the extent of some proposed non-outcropping Tertiary dykes in Britain and surrounding waters. In particular, some examples with pronounced linear magnetic anomalies off the coasts of NE England, the Lake District and Anglesey have been investigated (Fig. 1). These have been modelled and compared to an anomaly of a known Tertiary dyke in the Scottish Borders.

Selection of interpreted anomalies

Data coverage is excellent for the entire area shown in Fig. 1. Marine traverses generally form a grid with a line spacing rarely greater than 6 km in any direction.

Tectonic significance of dykes

The areas of crustal weakness primarily utilized by the dykes are the igneous centres but, given a NW–SE oriented compressive stress as postulated by Vann (1978), it is unlikely that dykes could be intruded along the dominant NE–SW oriented Caledonian structures. It is far more likely that the dykes utilized a zone of devolatilized coals in the southern North Sea may be associated with Tertiary dykes extending, at depth, to the European mainland.

Although all the dykes retain a general NW–SE trend, the Scottish-centred dykes describe a sinusoidal curve. The most northerly are N–S trending but become increasingly easterly trending to the south. Near the North Sea coast they once more start to return to a more southerly trend.

The swarms are thought to be the result of NW–SE compressive (NE–SW tensional) stress, but underlying pre-existing or developing major crustal weaknesses approximately parallel to the compressive stress. Structural features of this trend are present in the North Sea as indicated by the anticlinal and synclinal axes shown on Figs 1 and 4; these features may have provided suitable zones for dyke intrusion in the North Sea. If Tertiary dykes are present at depth as indicated by the zone of devolatalized coals, the dykes may have been influenced by features as remote as the Ruhr Graben (Fig. 12). In S Scotland and N England, dykes initiated fractures uniting the pre-existing zones of weakness, i.e. those of the North Sea and of the igneous centres of Scotland, and did not utilize existing crustal weaknesses.

Conclusions

Modelling of magnetic anomalies suggests the existence of Tertiary dykes in the western part of the North Sea and the Irish Sea. Most of the latter are probably related to the centres of Ireland, while those in the North Sea are part of the swarm centred on Mull. The total length of the swarms radiating from the Scottish centres can be demonstrated to be at least 800 km and crustal weaknesses have determined local variations in the strike of dykes.

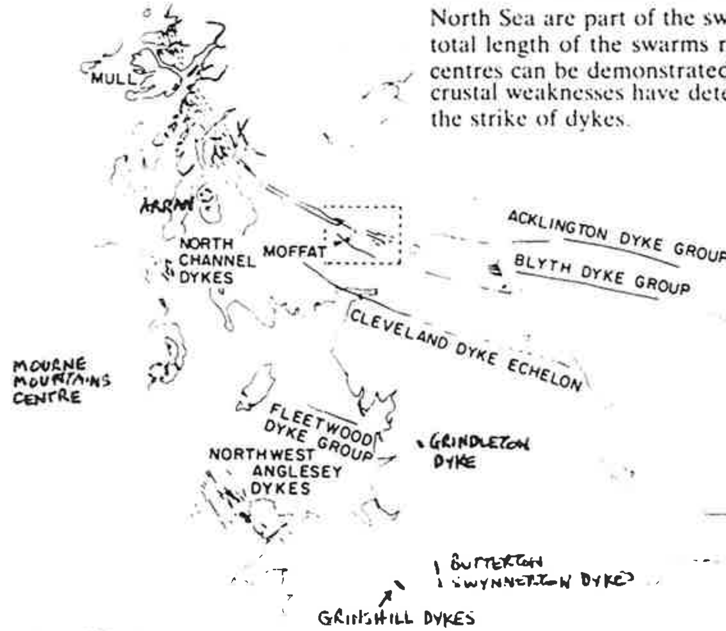
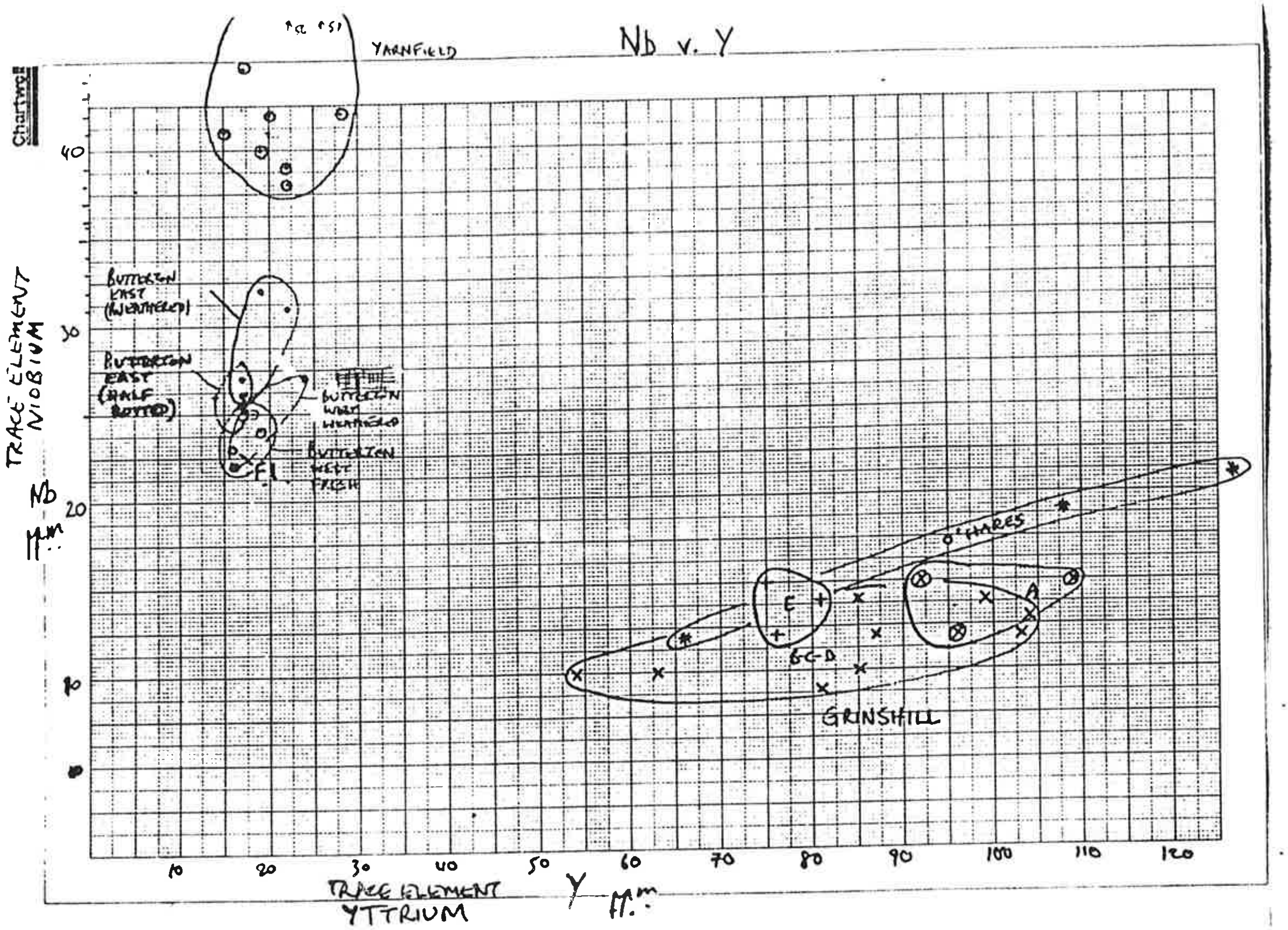
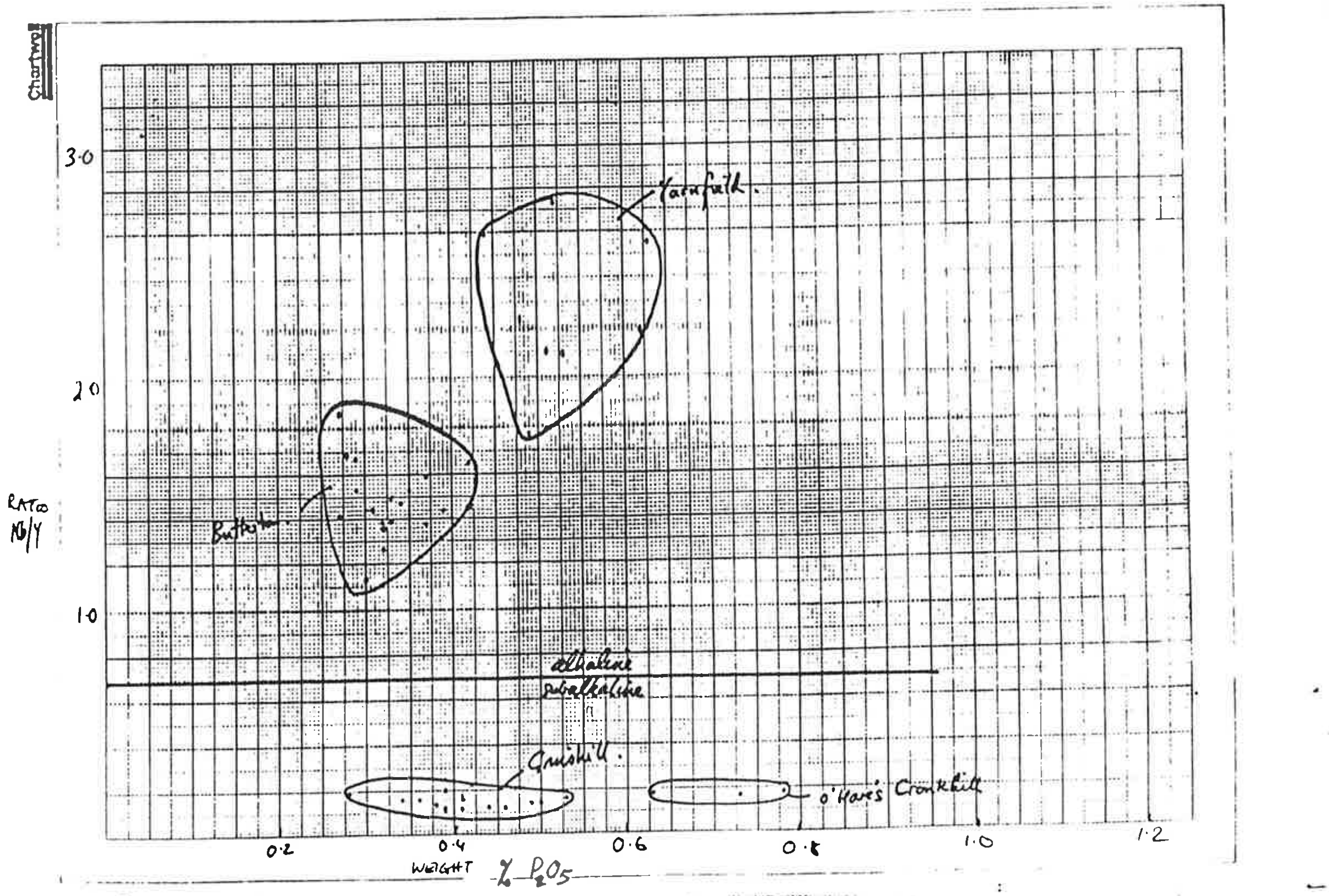


FIG. 1. Location of Tertiary dykes. Includes dykes marked on published geological maps and dykes inferred from magnetic anomalies. The distribution is generalized in west of Scotland. The dashed line indicates central line of the zone of linear anticlinal and synclinal features of mid-Tertiary to Zechstein age referred to in the text. The dot-dash line indicates area of Fig. 2

Nb v. Y



YARNFIELD
BUTTERTON EAST (WEATHERED)
BUTTERTON EAST (HALF ROTTED)
BUTTERTON WEST WEATHERED
BUTTERTON WEST FRESH
O'HARES
GRINSHILL
TRACE ELEMENT NIOBIUM
Nb ppm
TRACE ELEMENT YTTRIUM
Y ppm
40
30
20
10
10
20
30
40
50
60
70
80
90
100
110
120



Yarnfield
Butterton
alkaline
subalkaline
Grinshill
o'Hare's Cronkhill
RATIO Nb/Y
3.0
2.0
1.0
0.2
0.4
0.6
0.8
1.0
1.2
WEIGHT % P_2O_5

GEOLOGICAL HISTORY OF THE BUTTERTON - SWYNNERTON DYKE SWARM

1. DEPOSITION OF THE BARREN RED COALMEASURES (Etruria Marl, Newcastle Sst, Keele Sst) AS CLIMATE CHANGES FROM EQUATORIAL TO SAVANNA, IN PART DUE TO DRIFT — c. 300 mya. SEDIMENTATION INFLUENCED BY FAULTING.
2. POST-CARBONIFEROUS FAULTING ?c.280 mya ALONG APEDALE - SWYNNERTON ZONES (ON INHERITED LINES OF WEAKNESS, MAJOR FRACTURES IN BASEMENT?) NNW - SSE FANNING NW IN KEELE AREA.
3. EROSION !280 - 248 my. DURING FURTHER PERIOD OF DRIFT NORTHWARDS.
4. DEPOSITION OF TRIASSIC (CANNOCK CHASE PEBBLE BEDS FM, WILDMOOR SST FM, BROMSGROVE (= HOLLINGTON = BEECH CLIFF) SST Fm c. 248-243 mya; MERCIA MUDSTONE GP inc. DENSTONE (WATERSTONES) Fm AT BASE 243 - 213 mya; L & M JURASSIC 213 - 163 mya. ; EROSION ?? 160 - 97 mya... ; DEPOSITION OF CRETACEOUS CHALK 97 - 65 mya. ; EROSION ... STEADY DRIFT NORTHWARDS THROUGHOUT. (AGES TAKEN FROM THE HARLAND et al SCALE (1982))
5. INTRUSION OF BASIC IGNEOUS DYKE SWARM (1-8 dykes) INTO EXTENSIONAL REACTIVATED FRACTURE SYSTEM (OR WRENCH FRACTURE SYSTEM?) PRIOR TO 52 mya EOCENE. SOME BRECCIATION, SOME XENOLITHS; NO MANTLE NODULES. RELATED TO NE-SW TENSION ASSOCIATED WITH OPENING OF NORTH ATLANTIC AND A POSITIVE HEAT FLOW ZONE RHINE - ICELAND. WATTS (1898) FIRST CONNECTED THE DYKES WITH BRITANO-ICELANDIC TERTIARY IGNEOUS EVENTS. BASIC MAGMA GENERATED IN UPPER MANTLE (? 30-60 km) BY EXCESS HEATING ... REACTIVATES CARBONIFEROUS MAGMA ZONES? POSSIBLE RELATIONSHIP TO "APEDALE" MAGNETIC (= VOLCANIC/PLUTONIC) HIGH OF CARBONIFEROUS AGE. INTRUSIONS 20 km LONG KEELE - NORTON BRIDGE.
   DYKES EITHER TAP ONE DIFFERENTIATING MAGMA CHAMBER OR SEVERAL SMALL, SLIGHTLY DIFFERENT ONES. ONE CHAMBER COULD BE TAPPED AT DIFFERENT DEPTHS TO GIVE ULTRABASIC PULSES (Augitite + Limburgite of LYMES Fm BOREHOLE), BASIC PULSES (Olivine Dolerite), SILICA DEFICIENT PULSES (Basic crinanites with felspathoids). SEE GEOCHEMICAL DATA FOR SUPPORT OF SECOND HYPOTHESIS — DATA FOR BUTTERTON PLOTS DIFFERENTLY TO YARNFIELD etc.
   MAGMA(S) CRYSTALLISE IN METASTABLE STATE AT DEPTH (Olivine + magnetite ; Ca feldspar plagioclase before Ti-augite -); PHENOCRYSTS DEVELOP. RATE OF COOLING INCREASES, COINCIDENT WITH INTRUSION. RESIDUAL LIQUID CRYSTALLISES; FeMg largely AUGITE AND Ca PLAGIOCLASE AS SMALL CRYSTALS IN LABILE STAGE.
   EARLY PHENOCRYSTS & GROUNDMASS ATTACKED BY RESIDUAL LIQUIDS WHICH CORRODE EARLY-FORMED CRYSTALS ESPECIALLY MAGNETITE (TO GIVE BIOTITE) OLIVINE + AUGITE (→ CHLORITE eg along CLEAVAGE PLANES) FELDSPARS ANALCITIZED. LATE-STAGE DEPOSITION OF FELDSPATHOIDS NEPHELINE generally before ANALCITE. AS MAGMA RISES TOWARDS UPPER PART OF CRUST (IF NOT NEAR THE SURFACE), LITHOSTATIC PRESSURE FALLS AND MAGMA GASES EXSOLVE CREATING GAS BUBBLES (VESICLES).
6. INTRUSIONS SET UP WATER CIRCULATIONS IN UPPER CRUST. CONNATE (INHERENT) AND JUVENILE (MAGMATIC) WATER (POSSIBLY METEORIC WATER) CIRCULATE, DISSOLVING $CaCO_3$ of FOSSIL SHELLS, CARBONATE CEMENTS, HEAVY METALS FROM SULPHIDES IN BLACK SHALES. GASES (eg METHANE) GENERATED FROM CARBONACEOUS SEDIMENTS. SOLUTIONS PRECIPITATE DOLOMITE, CALCITE, COPPER CARBONATES (MALACHITE, AZURITE), BARITE, OCCASIONAL SULPHIDES (eg CHALCOPYRITE) IN JOINTS, FAULT PLANES, FAULT BRECCIAS, VESICLES. THE ISOTOPIC AGE DATE ON THE ROCK OF CHURCH WOOD QUARRY MAY RELATE TO THESE LATE-STAGE ALTERATIONS ie 52 ± 1.4 MY (EOCENE) AS AT GRINSHILL SHROPSHIRE (A THOLEIITIC BASIC MAGMA) (51 my), GRINDLETON (CLITHEROE), ANGLESEY, AND MORECAMBE BAY (DYKES UNDERSEA).
7. FURTHER EARTH MOVEMENTS GIVE RISE TO SLICKENSIDED DYKE CONTACTS IN THE NORMAL, VERTICAL SENSE IN CHURCHWOOD QUARRY, IN A HORIZONTAL WRENCH-TEAR SENSE IN HIGHLOWS QUARRY (AND POSSIBLY IN THE FIELDS SOUTH OF CHURCH WOOD QUARRY ALSO).
   IT IS DEBATABLE WHETHER THE SEABRIDGE FAULT EXHIBITS TEAR FAULTING (SEE COPE'S 1966 MAP AND EXLEY'S 1970 ALTERNATIVE HYPOTHESIS) OR THE SWYNNERTON FAULT (SEE ROBERTSON'S FIELD MAPPING COMPARED WITH THE DISTRICT GEOLOGIST'S FINAL MAP - THE FORMER SHOWING NO DISPLACEMENT OF THE DYKES).
8. THE SWYNNERTON FAULT (? PART OF THE ASHBOURNE-DERBY MONOCLINAL LINE) MAY STILL BE "ACTIVE" cf THE STAFFORD EARTHQUAKE OF 1916. (see DAVIDSON 1924. BRITISH EARTHQUAKES, CUP).
9. PRESENT-DAY WEATHERING REDUCES THE DYKE ROCKS TO CLAY MINERALS WHICH STILL, HOWEVER, RETAIN CERTAIN TELL-TALE "FINGERPRINTS" OF THE ORIGINAL MAGMA TYPE IN THE FORM OF STABLE TRACE METALS eg. Yttrium, Niobium, Zirconium, Titanium etc. SUITABLE PLOTS OF RELEVANT TRACE ELEMENTS IN PPM and MAJOR ELEMENTS MAY HEL[P]

REDUNDANT HYPOTHESES

1. 1835-1844 MURCHISON'S, KIRKBY'S FAVOURING OF THE LINES OF ELEVATION THEORY (OF ÉLI DE BEAUMONT)
2. 1874 ALLPORT'S POST CARB - PRE PERMIAN DIFFERENTIALLY ERODED DYKE COVERED BY TRIAS
3. 1891 PoJ HEDDLE'S LAVA - VALLEY FILL IDEA (TRIASSIC AGE)
4. 1894 KIRKBY'S CONNECTION OF DYKES WITH S. STAFFS IGNEOUS CENTRES (BUSHBURY)
5. 1935 MARSHALL'S COMPARABLE HYPOTHESIS

DBT 6 9.1987

THE DARWIN LOCALITY IN THE HANCHURCH HILLS DISCOVERED c. 1842 BY CHARLES DARWIN AND POSSIBLY INDEPENDENTLY AT THE SAME TIME BY JAMES KIRBY, AN AMATEUR OF THE NORTH STAFFS FIELD AND NATURALISTS CLUB