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Palaeomagnetism of the Foyers and Strontian granites, Scotland

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Palaeomagnetic data from the "newer granites" of Foyers and Strontian show similar directions of magnetization with southerly declinations and horizontal to intermediate, mostly downward dipping, inclinations. These palaeomagnetic directions which accord with previous data from the Helmsdale granite are thought to be of Siluro–Devonian age. The present results are not sufficiently precise to justify discussion of possible lateral displacements along the Great Glen Fault of the order of a few hundred kilometres, but it is clear that the recent idea of a c. 15–20° latitudinal offset along the Fault in the Carboniferous has to be disregarded.

1. Introduction

The present paper reports on palaeomagnetic properties of the Foyers and Strontian granites, Scotland. These intrusions are bounded by the Great Glen Fault (Fig. 1), and radiometric data from both complexes suggest typical Caledonian "newer granite" ages around 400–435 Ma (Miller and Brown, 1965; Pidgeon and Aftalion, 1978; Harmon and Halliday, 1980). Both complexes are built up of tonalite, granodiorite and adamellite, emplaced in that order into metasedimentary rocks of the Moine series (Mould, 1946; Sabine, 1963; Marston, 1971; Munro, 1973).

Kennedy (1946) suggested that the Foyers and Strontian complexes had originally been part of the same granitic body, indicating ~100 km sinistral post-emplacement movement along the Great Glen Fault (GGF). Several authors have dealt with various geological and geophysical aspects of this model (i.e., Flinn, 1969, 1975; Holgate, 1969; Garson and Plant, 1972; Winchester, 1973; Storetvedt, 1974a; Storetvedt et al., 1978; Pankhurst, 1979; Speight and Mitchell, 1979; Van der Voo and Scotese, 1981; Smith and Watson, 1983). Storetvedt (1974a), based on a certain discrepancy in the Devonian palaeomagnetic data between Norway and the Northern Highlands, argued for a minimum of 200–300 km sinistral movement along the Fault, the suggested displacement being in fair agreement with the matching of metamorphic zones across the Fault (Winchester, 1973; Storetvedt, 1974b). More recently Van der Voo and Scotese (1981) have suggested that the GGF transcurrence may have been of the order of 2000 km. On the other hand, Torsvik et al. (1983) and Storetvedt and Torsvik (1983) concluded that a movement as suggested by Van der Voo and Scotese is not supported by the existing palaeomagnetic evidence from Upper Silurian and Devonian formations adjacent to the Fault.

The Foyers granite has been investigated previously by Kneen (1974) using alternating field demagnetization. This method, however, did not produce a well-defined grouping of stable magnetization directions, and various authors (Morris, 1976; Piper, 1979) have subsequently re-interpreted the data which are based on samples from the granite and surrounding Moine series as well as the overlying Middle Devonian sandstone. The Foyers granite and other plutonic rocks of the Central and Northern Highlands may be of great potential

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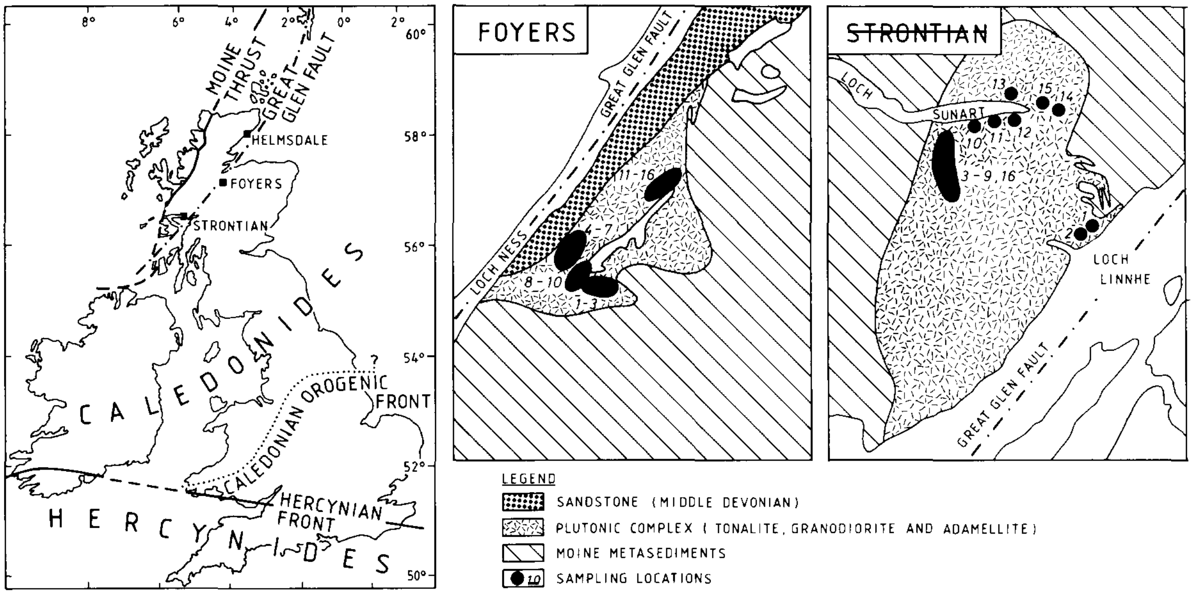

Fig. 1. Geological sketch map of the Foyers and Strontian granites and their geographical locations. Simplified after Kennedy (1946) and Watson (1978).

significance for clarifying palaeotectonic problems in the region, provided that well-defined palaeomagnetic results can be established.

A total of 86 drill cores have been collected from 16 sites in the Foyers granite. Sites 1–10 represent the granodioritic member of the complex, while sites 11–16 are from the tonalitic part (Fig. 1, Table I). Field sampling in the Strontian granite included 93 drill cores from 16 sites: site 1 from the adamellite, sites 3–13 and site 16 from the granodiorite and sites 14–15 from the tonalite. Site 2 represents a cross-cutting dyke and its adjacent country rock (adamellite). Radiometric ages from the dyke suggest a Permo–Carboniferous age (281 ± 5 Ma, Speight and Mitchell, 1979). For field orientation both magnetic and sun compasses were used.

TABLE I

Sampling details from the Foyers and Strontian granites

Site	Foyers sample	Rock type	Strontian sample	Rock type
1	Fo1 –Fo5	G	ST1 –ST6	A
2	Fo6 –Fo11	G	ST7 –ST16	A, D
3	Fo12–Fo14	G	ST17–ST24	G
4	Fo15–Fo19	G	ST25–ST29	G
5	Fo20–Fo24	G	ST30–ST35	G
6	Fo25–Fo29	G	ST36–ST39	G
7	Fo30–Fo32	G	ST40–ST44	G
8	Fo33–Fo39	G	ST45–ST48	G
9	Fo40–Fo45	G	ST49–ST54	G
10	Fo46–Fo52	G	ST55–ST59	G
11	Fo53–Fo57	T	ST60–ST64	G
12	Fo58–Fo63	T	ST65–ST72	G
13	Fo64–Fo68	T	ST73–ST77	G
14	Fo69–Fo74	T	ST78–ST84	T
15	Fo75–Fo80	T	ST85–ST88	T
16	Fo81–Fo86	T	ST89–ST93	G

G = Granodiorite; T = Tonalite; A = Adamellite; and D = Dyke (Dolerite).

2. Laboratory data

Measurement of the natural remanent magnetization (NRM) were carried out using a Squid magnetometer and a Digico spinner magnetometer. Thermal demagnetization was performed in a Schonstedt furnace with a residual field less than 15 nT in the cooling chamber. Stability of NRM was further investigated by means of alternating field (AF) demagnetization.

2.1. *Foyers granite*

Directional distribution of the NRM suggests that a present day field component (probably of viscous origin) contributes strongly to the total remanent magnetization (Fig. 2A), but a N–S directional smear suggests the presence of an underlying ancient field component. NRM intensities range between $5 \cdot 10^{-3}$ Am^{-1} and $3.5 \cdot 10^{-1}$ Am^{-1}, the average being around $1 \cdot 10^{-1}$ Am^{-1}.

Figure 3 (specimen Fo18–A, Fo23–A and Fo31–A) gives typical examples of the behaviour of remanent magnetization versus stepwise thermal demagnetization for granodiorite specimens. Almost all investigated samples display southerly directional movements. Vector diagrams demonstrate that in the early stages of demagnetization a steeply inclined, downward pointing remanence vector is being removed. This latter component has a certain stability overlap with a shallow and southerly directed component that is isolated above 400–500 °C. Intensity patterns indicate distributed blocking-temperature spectra, but with a relatively sharp decay in the 550–580 °C range. In come cases a substantial proportion of the remanence intensity still remains after 580–600 °C treatment. However, owing to the unstable character of the NRM beyond these temperatures, demonstrated by irregular intensity patterns and non-repeatable directional measurements, suggests viscous components (VRM) induced during measurement. On the other hand, measurement of low-field susceptibility after each demagnetization step (cf. specimen Fo18–A) do not show major changes during thermal treatment.

A 3-component magnetization system is present in specimen Fo23–A; a steep downward pointing (positive) component is erased below 225 °C, a shallow northerly directed vector is demagnetized in the range 225–370 °C, and finally the high temperature component (shallow reversed) is left at $T > 400$ °C. Thus apart from a superimposed viscous magnetization aligned along the present Earth's field direction, this specimen contains the 2 antiparallel components of the practically flatlying remanence axis that constitutes the characteristic magnetization of the Foyers complex. Thermal treatment of some tonalite specimens give results

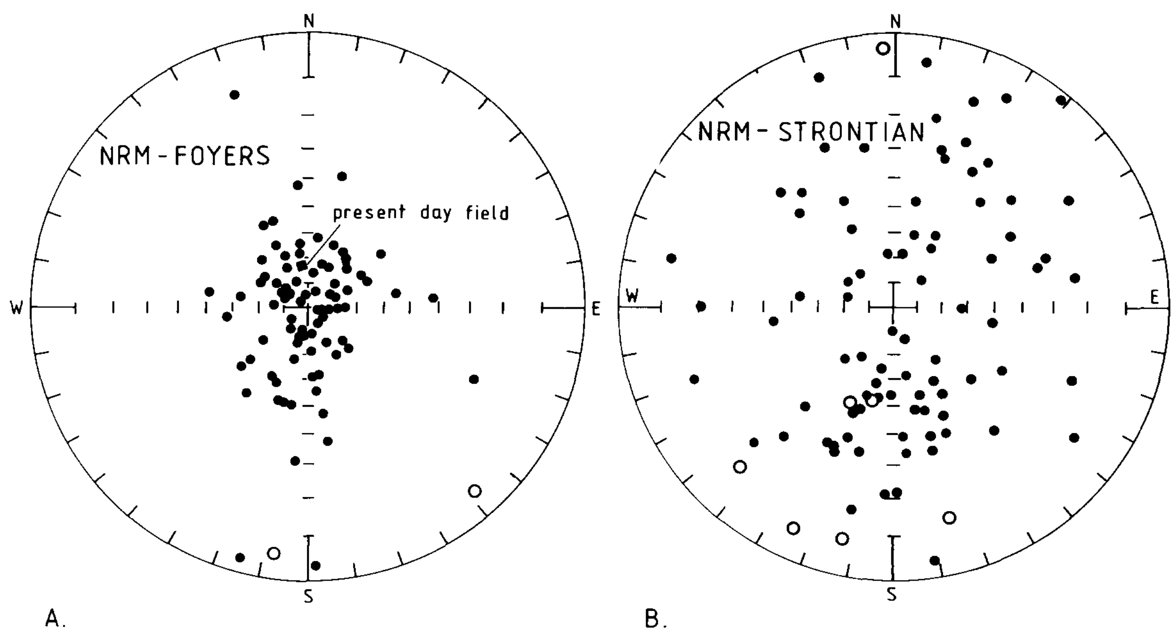

Fig. 2. Stereographic representation of total NRM directions from the Foyers (A) and Strontian (B) granites. Throughout this paper open symbols in the stereograms are upward pointing directions and closed symbols downward pointing directions.

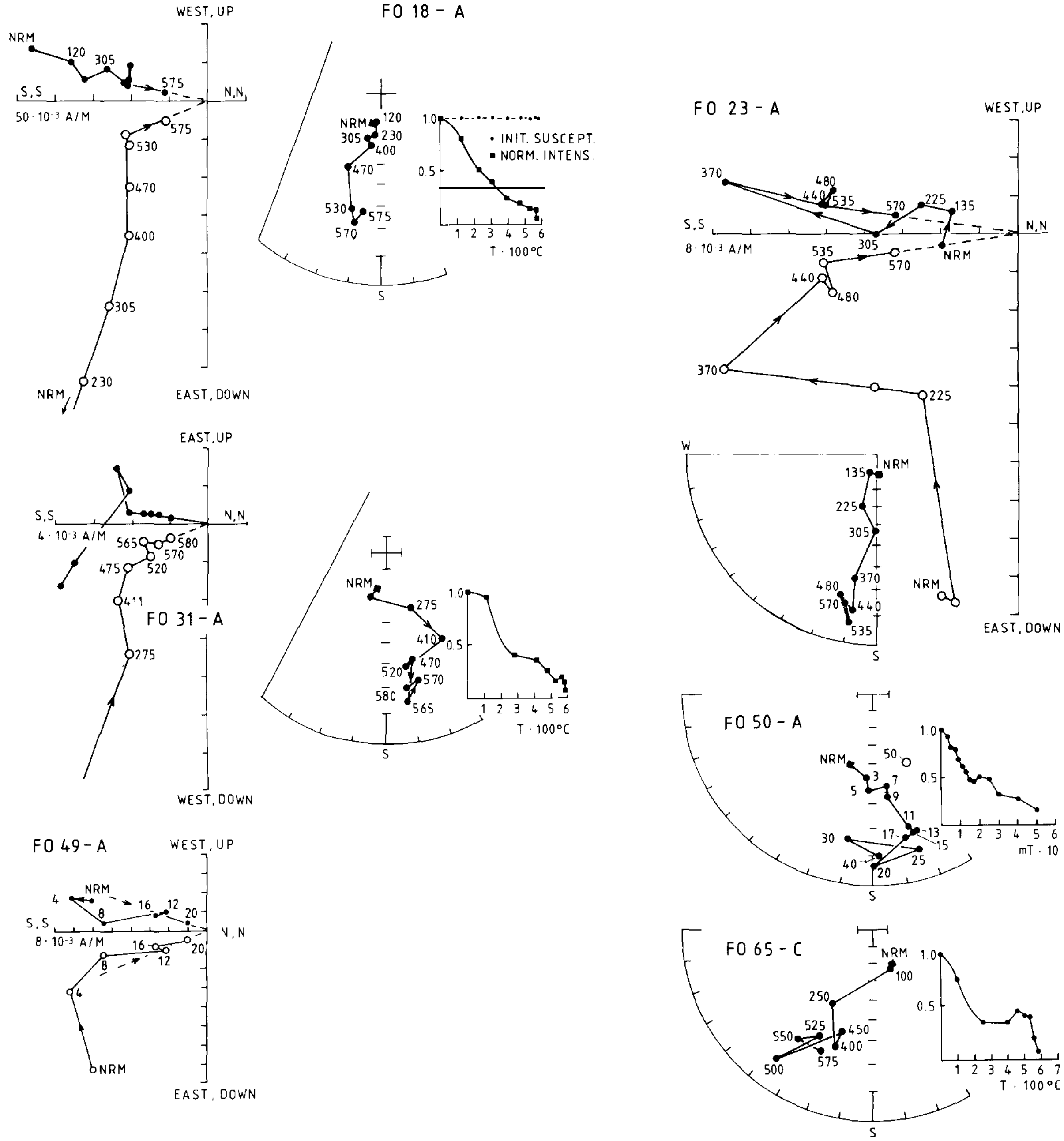

Fig. 3. Thermal and AF demagnetization behaviour from the Foyers granite. Specimens Fo18–A, Fo23–A, Fo31–A, Fo49–A and Fo50–A are from the granodiorite member and Fo65–C from the tonalite. In the orthogonal vector projections solid symbols represent points in the horizontal plane and open symbols points in the vertical plane.

TABLE II

Bulk magnetic properties of AF demagnetised specimens from Foyers

Site	Specimen	J_n	$M_{1/2}$	RCF	k	SIRM	Q'
1	1B	126	5.0	13.0	10.4	18.9	0.15
	2A	150	4.0	13.0	12.6	21.4	0.15
	3B	131	4.0	13.0	27.8	30.9	0.06
	4A	84	10.0	13.5	8.3	16.1	0.13
	5B	115	4.0	10.5	13.0	21.3	0.11
2	6A	81	4.0	22.0	6.1	28.4	0.17
	7B	77	5.0	20.0	5.3	21.1	0.18
	9A	100	2.0	9.0	8.2	11.7	0.15
	11A	84	4.0	12.0	6.4	17.9	0.17
3	13A	19	11.0	30.0	2.3	18.4	0.11
4	15A	138	3.0	10.0	17.1	31.7	0.10
	17A	115	2.0	13.0	17.8	27.4	0.08
9	41A	69	4.0	12.0	11.1	15.8	0.08
	42A	66	2.5	14.0	13.7	27.7	0.06
	45A	76	2.5	8.0	13.8	18.7	0.07
10	47B	340	2.5	6.0	48.8	103.8	0.14
	48A	279	1.0	6.0	52.5	100.4	0.07
	49A	9	10.0	24.0	1.6	6.8	0.07
	50A	6	15.0	26.0	0.8	5.6	0.09
11	53B	112	1.5	8.0	26.1	37.7	0.05
	54C	80	5.0	8.0	21.9	33.2	0.04
	55A	78	3.0	14.0	15.6	29.6	0.06
15	76A	151	1.0	10.0	18.4	34.6	0.10
	77A	200	2.5	9.0	26.0	48.9	0.10
	80A	73	5.0	14.0	15.1	35.2	0.06

J_n = Natural remanent magnetization (10^{-3} Am^{-1}); $M_{1/2}$ = Median destructive field (mT); RCF = Remanence coercive force (mT); k = Bulk susceptibility (10^{-3}SI); SIRM = Saturation isothermal remanent magnetization (Am^{-1}); and $Q' = 4\pi \cdot J_n/k$.

that are in general agreement with those from the granodiorite (cf. specimen Fo65–C). However, a major part of tested tonalite specimens exhibit irregular behaviour upon demagnetization. Thus, it was not possible to determine characteristic remanence directions apart from a strong contribution of a present day VRM.

Directional changes upon AF treatment are similar to those from thermal demagnetization (cf. Fo49–A and Fo50–A), but the AF method shows more scattered results as well as demonstrating poorer resolution of components than the thermal technique. Therefore, the palaeomagnetic results from the Foyers complex, Table III, include more thermally tested specimens than AF tested specimens. Median destructive fields ($M_{1/2}$) are usually below 5 mT (cf. Table II) and for most specimens their bulk magnetization is randomized in the 15–30 mT range.

Typical examples of isothermal remanent magnetization (IRM) versus increasing field (H) for the granodiorite and the tonalite rocks are shown in Fig. 4a, b. Almost all specimens are saturated in fields of 150–200 mT. Table II summarizes measurements of remanence coercive forces (RCF), i.e., the field value oppositely directed to that being applied for saturation (IRM/H) and which makes the net magnetization equal to zero. The RCF values are in the range of 5–35 mT, typically around 10–15 mT.

Specimens that are unstable during AF demagnetization are usually those with high NRM intensity and low $M_{1/2}$ and RCF values. Large within-site variations in bulk magnetic properties may occur (cf. Table II). For site 10 the NRM intensity varies from $6–340 \cdot 10^{-3}$ Am^{-1} and the saturation IRM from 5.6–103.8 Am^{-1}, indicating a high degree of magnetic inhomogeneity. Note that the 2

TABLE III

Palaeomagnetic results from the Foyers granite

Site	Specimen	Method	D(°)	I(°)	Range (°C, mT)	Site	Specimen	Method	D(°)	I(°)	Range (°C,mT)
1	FO 2–B	T	180	+4.6	370–575	7	FO30–A	T	185	+13	570–580
	FO 3–B	AF	028	+4	10–20		FO31–A	T	171	+18	565–580
	FO 4–A	AF	175	+15	10–30		FO32–A	T	200	+35	565–580
	FO 4–B	T	160	−3	440–570						
	FO 5–A	T	195	−6	370–575	9	FO40–A	T	351	+2	450–580
2	FO 8–A	T	185	+15	530–570	10	FO49–A	AF	195	+17	12–20
	FO 9–A	AF	183	+30	20–35		FO50–A	AF	180	+11	11–40
3	FO12–A	T	186	−25	370–580	11	FO53–B	AF	205	+10	9–20
	FO13–A	AF	185	−18	9–40		FO56–A	AF	218	+5	9–25
	FO14–A	T	178	−12	300–500						
	FO14–B	T	187	−25	175–575	13	FO64–A	T	195	+13	200–400
							FO65–B	T	205	+3	300–580
4	FO16–A	T	176	+22	480–535		FO65–C	T	172	+33	400–550
	FO18–A	T	192	+27	530–575		FO66–B	T	210	+10	200–500
							FO66–C	T	206	+27	450–550
5	FO20–A	T	203	−5	470–575		FO68–B	T	235	+35	250–575
	FO21–A	T	183	+12	400–575						
	FO22–A	T	181	+7	370–580	14	FO70–C	T	188	+9	400–575
	FO23–A	T	188	+12	440–570		FO71–A	AF	190	−7	7–35
	FO24–A	T	167	+29	440–535						
						15	FO78–B	T	170	+5	500–575
6	FO26–A	T	180	+17	570–575		FO80–A	AF	180	+18	10–20
	FO28–A	T	186	+35	565–580						
	FO29–A	T	178	−6	520–570	16	FO82–A	T	195	−5	450–580
							FO84–A	T	188	+5	400–580

specimens from this site having the lowest NRM intensity were the only ones which revealed the shallow southerly magnetization that characterizes the formation (cf. Table III).

Saturation magnetization versus temperature (J_s–T) curves were obtained by means of a Curie balance. Almost reversible heating and cooling curves (Fig. 4c, d) define Curie-temperatures (Tc) around 580 °C. This, in accordance with thermal decay curves of the NRM and weak-field susceptibility versus increasing thermal treatment, indicates that the bulk-magnetic properties are dominated by magnetite, and that chemical changes are minimal during heating. The instability/reproducibility problem at higher temperatures is therefore assigned to the acquisition of viscous components in small residual magnetic fields.

2.2. *Strontian granite*

The NRM directions of the Strontian granite (Fig. 2B) are considerably more scattered than corresponding results from the Foyers granite. The NRM intensities range between 5 and $200 \cdot 10^{-3}$ Am^{-1}. Altogether 92 specimens were thermally demagnetized. Site 1 (adamellite) revealed nearly horizontal magnetizations with southerly declinations. Figure 5(ST 2) shows a vector diagram for a specimen from this site, defining a single high temperature component above 525 °C. Almost all specimens from site 1 show the presence of a superimposed remanence of recent origin, and the thermal decay patterns reveal distributed blocking temperatures well below 600 °C. On the other hand, site 6 is characterized by single component magnetizations with blocking temperatures exceed-

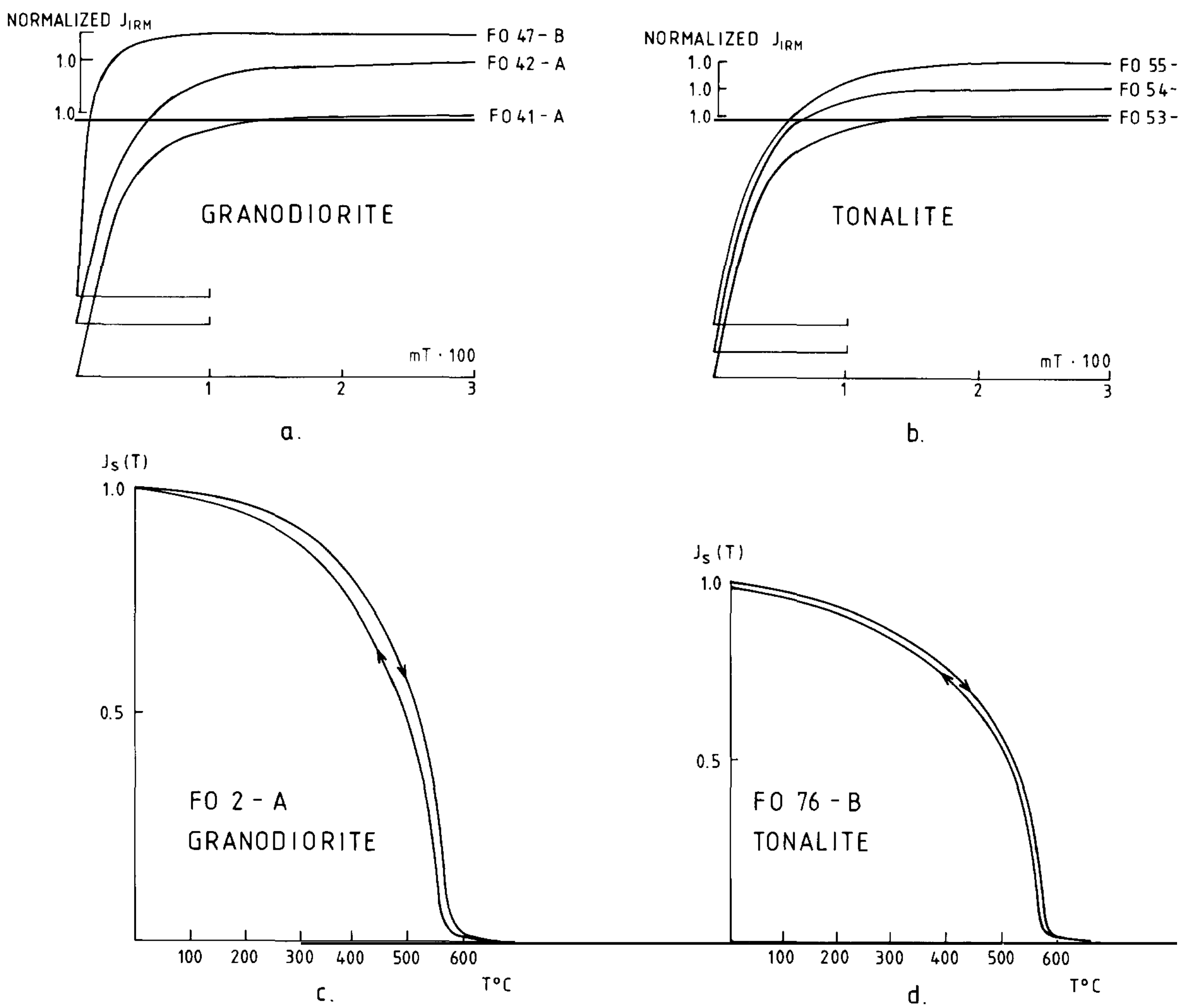

Fig. 4. Diagrams a, b demonstrate typical IRM aquisition curves (normalized intensity) from granodiorites and tonalite specimens along with examples of characteristic thermomagnetic behaviour (c,d) carried out in air.

ing 600 °C (cf. ST36, Fig. 5). Below 575 °C there are only minor directional and intensity changes, but above this temperature there is a marked linear trend towards the centre of the vector projections. Site 6 reveals characteristic remanence directions striking approximately due south and dipping 30° below the horizontal.

The majority of thermally tested specimens show shallow reversed magnetizations, but some specimens reveal the presence of shallow normal magnetizations. Specimen ST 51 (site 9) displays minor directional and intensity changes below 655 °C, indicating a composite northerly horizontal direction. Above this temperature the vector diagrams indicate the existence of a NE upward pointing magnetization. ST52 demonstrates a combination of at least 2 or 3 components; below 500 °C the vector diagrams demonstrate a southerly directional movement due to removal of a northerly, nearly horizontal component. In the range 500–655 °C a shallow SSW magnetization is being erased, and above 655 °C there are indications of

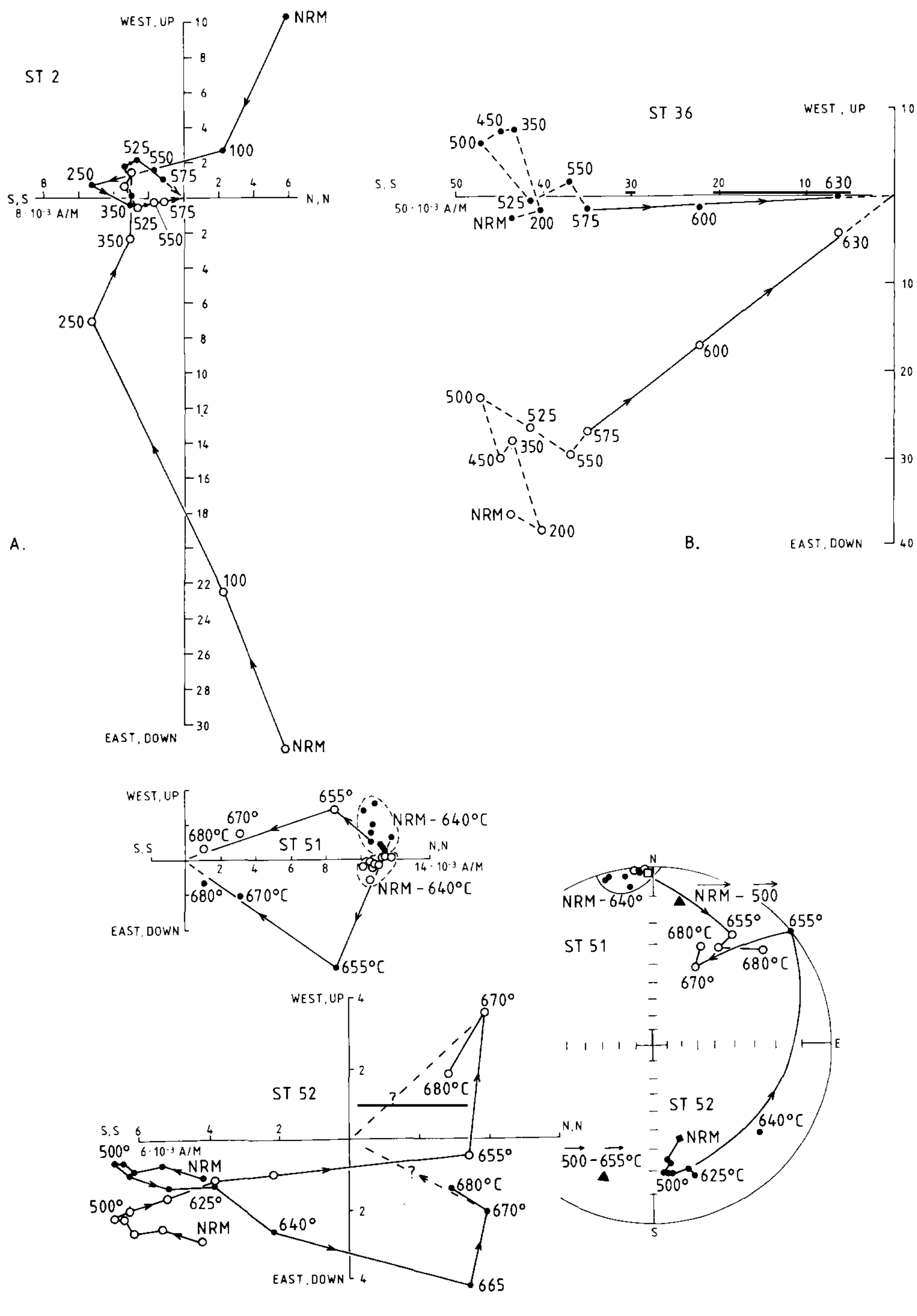

Fig. 5. Orthogonal vector-projections giving examples of thermal demagnetization from the Strontian granite; specimen ST36, ST51 and ST52 are from the granodiorite and ST2 from the adamellite (site 1). The corresponding stereograms are shown for ST51 and ST52. Vector-subtracted directions (triangular symbols) in the stereonet refer to specimen ST52.

the high temperature component, directed NNE and with shallow inclination, remaining.

A different group of directional results were obtained from sites 2 and 3 (Fig. 6). Site 2 was collected from the southeastern part of the complex where the granite (adamellite) has been cut by a basic dyke (dolerite). This rock structure was collected in a traverse perpendicular to the strike of the dyke, embracing both the dyke and the adjacent granite. Figure 6 shows there is a marked contrast in NRM intensity and Q'-factor between the granite and the dyke, particularly on the western contact. Dyke specimens show stable reverse magnetizations with intermediate steep negative inclinations, the blocking temperatures being dominantly confined to the range 450–540 °C (Fig. 7, specimen ST10). Owing to generally low magnetic stability, only 2 dyke specimens revealed successfully characteristic remanence components. The results from the 'baked' granite (cf. specimen ST7 and ST9) show similar directions. The magnetization of site 3 is roughly anti-parallel to that of site 2, the 2 sites defining a moderately steep palaeomagnetic direction with NNE–SSW declination (Fig. 6). This magnetization (as defined by sites 2 and 3), correspondings to the A-remanence which has been found previously in several rocks of Sutherland and Caithness (i.e., Storetvedt

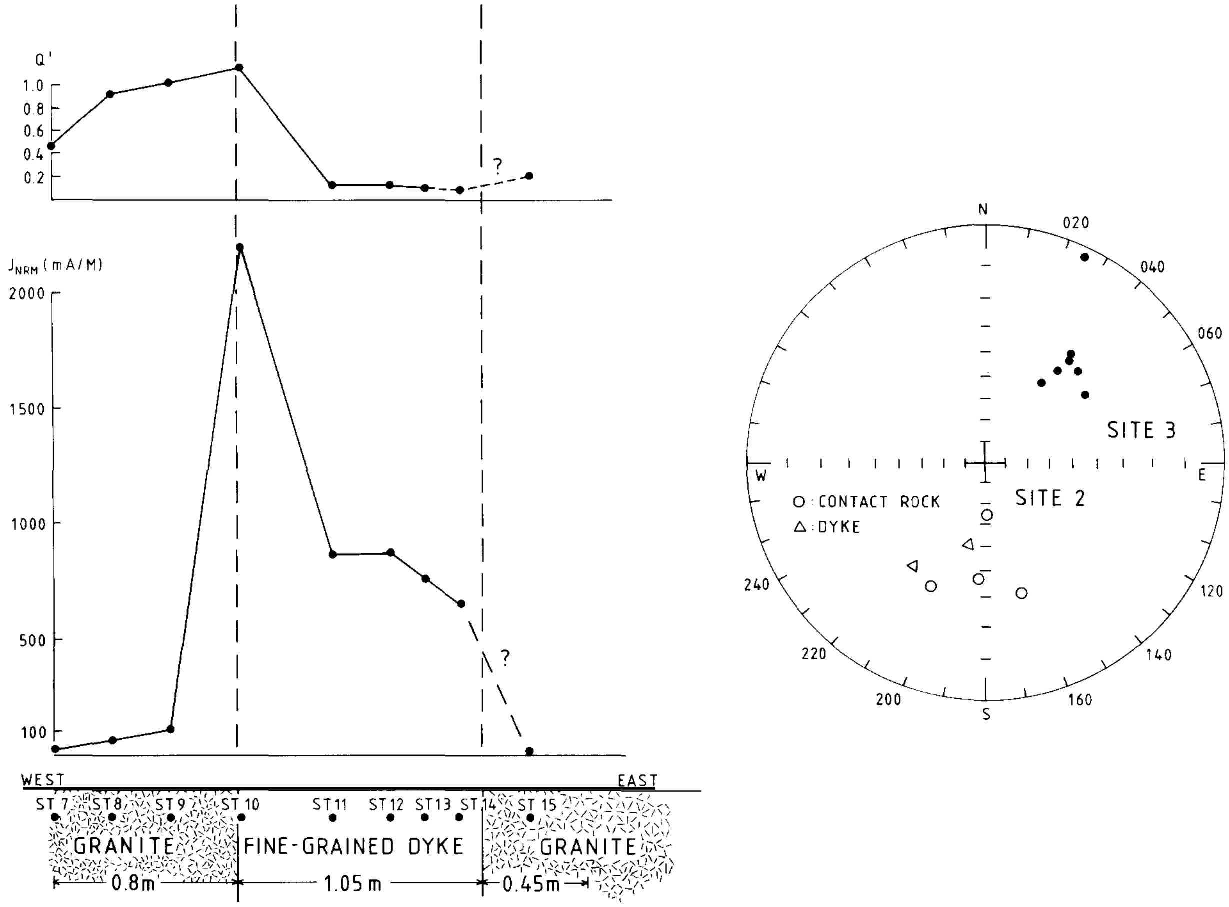

Fig. 6. Variations in magnetic properties ($Q' = J/k$ and J) along a dyke/contact rock traverse(Site 2; dolerite and adamellite). The asymmetry of the profile may be due to inadequate sampling in the eastern contact zone. The stereonet shows characteristic directions from dyke and contact rock specimens along with the directions of site 3 (normal). Sites 2 and 3 (except ST 20) constitute the A-axis magnetization.

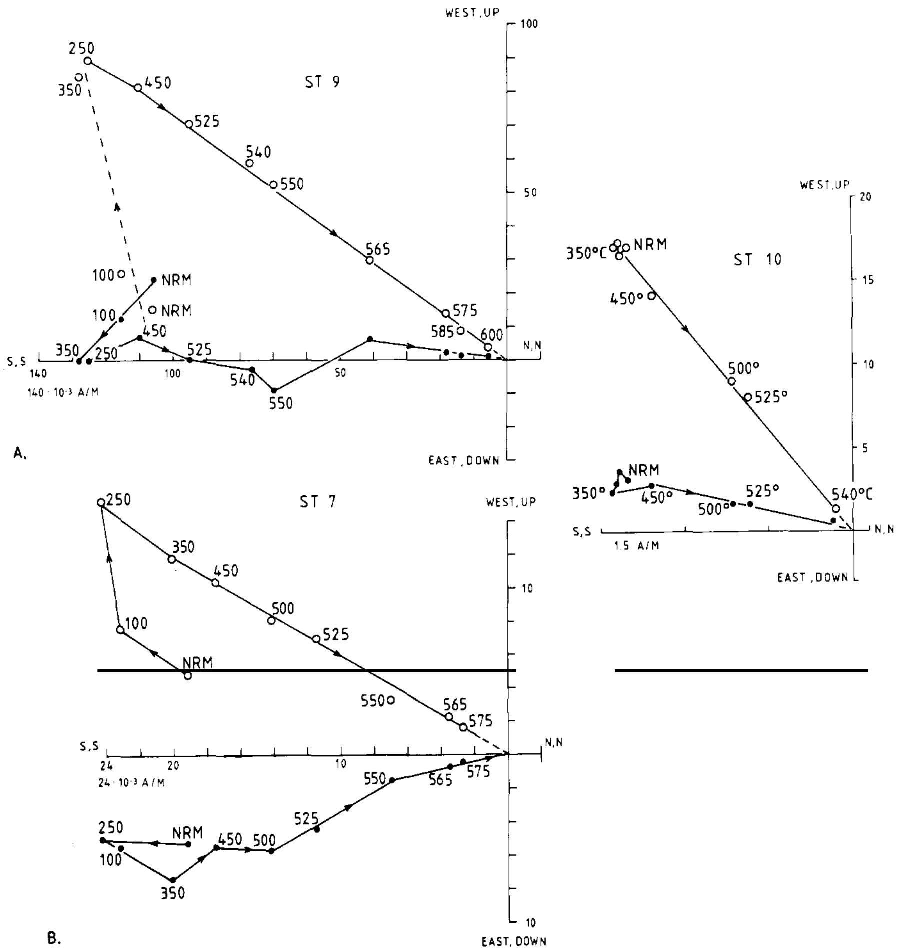

Fig. 7. Orthogonal vector projections of thermal demagnetization data of a dyke specimen (ST10) and of associated contact-granite (ST7 and ST9), site 2. See Fig. 6 for details on relative sampling positions.

et al., 1978; Storetvedt and Carmichael, 1979; Storetvedt and Torsvik, 1983; Torsvik et al., 1983).

Thermomagnetic curves from the granodiorite and adamellite rocks define almost reversible heating and cooling curves with Curie temperatures at ~ 580 °C (Fig. 8a). Even though several sites had

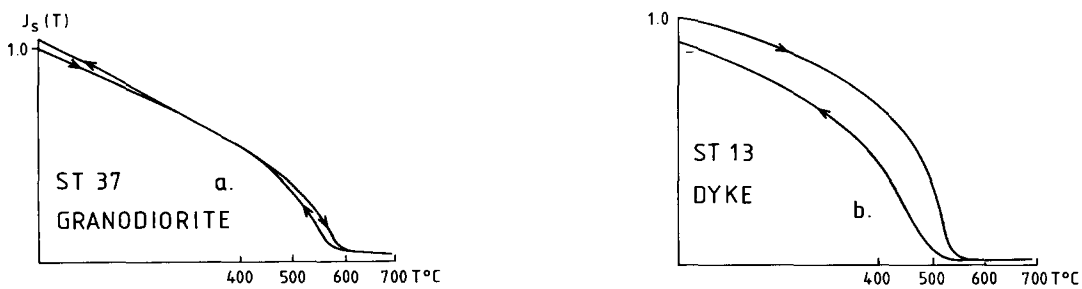

Fig.8. Thermomagnetic curves from the granodiorite (a) and dyke specimens from site 2 (b).

blocking temperatures exceeding 600 °C, the presence of haematite was not detected. This is probably due to the low spontaneous magnetization of this mineral compared to that of magnetite.

Thermomagnetic curves from the dyke material suggest the presence of titano-magnetite with Curie temperatures at around 530–540 °C (Fig. 8b), in accordance with the observed blocking temperature range. The heating and cooling curves are not reversible. This irreversibility associated with a lowering of the Curie point after heating to high temperatures (700 °C) is not attributed to thermal lag effects, but rather to alteration of the titano-magnetite upon heat treatment.

3. Palaeomagnetic interpretation

The present study has shown that the bulk magnetization of the Foyers complex most likely represents a recent field component (probably a VRM carried by multidomain magnetite). An underlying, more stable magnetization is uncovered only satisfactorily by thermal treatment above 450–500 °C, demonstrating the difficulty of removing the VRM.

The Strontian granite is also affected by an assumed recent VRM. Again, the dominant mineral is magnetite, but blocking temperatures well above 600 °C indicate that haematite may also carry a

TABLE IV

Palaeomagnetic results from the Strontian granite

Site	Specimen	D(°)	I(°)	Range (° C)	Site	Specimen	D(°)	I(°)	Range (° C)
1	ST 2	214	+5	525–575	7	ST40	193	+34	NRM–500
	ST 4	160	+11	200–560		ST41-A	190	+12	250–590
	ST 5	225	+8	450–575		ST41-B	181	+15	250–590
	ST 6	186	−13	400–575		ST42	198	+30	400–590
						ST43	191	+26	250–500
2	ST 7	165	−30	350–575					
	ST 8	180	−65	350–575	8	ST45-A	195	+23	150–625
	ST 9	184	−37	350–600		ST45-B	185	+25	250–625
	ST10	193	−50	NRM-525		ST47	173	+30	350–550
	ST12	215	−34	100–525		ST48	192	+20	150–625
	ST15	204	−30	250–550					
					9	ST49	039	−8	350–675
3	ST17-A	038	+30	450–575		ST51	029	−21	665–680
	ST17-B	045	+33	450–550		ST52	200	+13	500–665
	ST18	035	+45	350–500					
	ST19	038	+38	450–565	10	ST55	187	+26	NRM–650
	ST20	025	+2	450–565		ST56	199	+12	450–650
	ST21	055	+36	450–550		ST57	189	+25	NRM–650
	ST23	039	+32	450–575		ST58	195	+19	NRM–650
4	ST28	040	+15	350–560	12	ST65	185	+10	450–590
	ST29	010	−12	450–565		ST70	190	+25	250–450
						ST71	162	+46	250–540
5	ST30	175	+45	350–625					
	ST31	178	+30	350–630	13	ST76	025	−5	NRM–500
	ST32	175	+26	350–650					
	ST33	188	+20	450–675	16	ST89	188	+45	200–620
	ST34	188	+22	300–650		ST90	166	+19	450–590
	ST35	192	+30	450–650		ST91	185	+40	250–590
						ST92	202	+20	250–590
6	ST36	182	+32	525–630		ST93	190	+24	200–620
	ST37	185	+26	NRM–650					
	ST38	180	+45	350–625					
	ST39	165	+35	350–625					

substantial portion of the remanence (cf. specimen ST36, Fig. 5 and Table IV). Haematite could either date back to the original cooling or be of secondary origin. The existence of both low and high temperature blocking components with shallow inclination and northerly declination, partly overlapping with moderately steep reversed components, suggests that at least some of the remanence is of chemical (CRM) rather than of thermoremanent (TRM) origin. The palaeomagnetic data of the Strontian granite show 2 components of magnetization, A and B, forming a remanence build-up which is fairly similar to that encountered in the Helmsdale granite (cf. Fig. 1), as well as in Old Red Sandstone rocks of Sutherland and Caithness (Storetvedt et al., 1978; Storetvedt and Carmichael, 1979; Storetvedt and Torsvik, 1983; Torsvik et al., 1983). The A-remanence has been regarded as an overprinted magnetization of Late Palaeozoic–Early Mesozoic age. This conclusion fits with present evidence from the Strontian region in which both Permo–Carboniferous dykes (including site 2) as well as Upper Permian mineralization zones have been found (Ineson and Mitchell, 1974; Speight and Mitchell, 1979).

To test whether the observed Foyers directions (Fig. 9a), corresponding to the Strontian B-group, belong to a Fisherian distribution, Fig. 10 displays the data in a colatitude (a) and a longitude (b) plot (Lewis and Fisher, 1982). The linear trend through the origin of both plots, with a slope of 45° in the longitude plot, suggests that the Foyers data conform to a Fisherian distribution. In the colatitude plot, points near the origin represent observations close to the estimated mean direction, while observations furthest from the mean direction give points at the upper end of the plot. The slope of the colatitude plot define a precision parameter $K = 14.3$ which is in agreement with the K-value calculated in the standard way (Fisher, 1953).

The colatitude and longitude plots for the Strontian group B (cf. Fig. 9b) show that this population conform less well to a Fisherian distribution (Fig. 10c,d) than the corresponding Foyers data. Reduced data-sets (removal of "discordant" observations) improve the population and the stat-

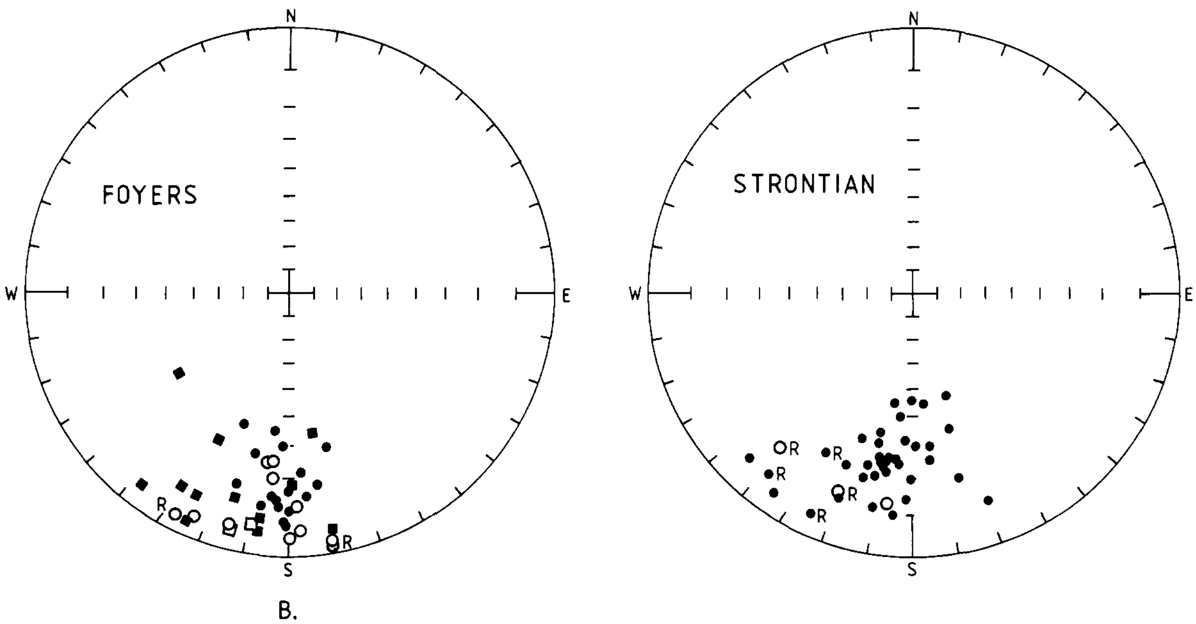

Fig. 9. Distribution of characteristic remanence directions from the Foyers and Strontian granite (Group B). Symbols denoted R are normal polarity data which have been reversed. For the Foyers data circles and squares denote granodioritic and tonalitic specimens, respectively.

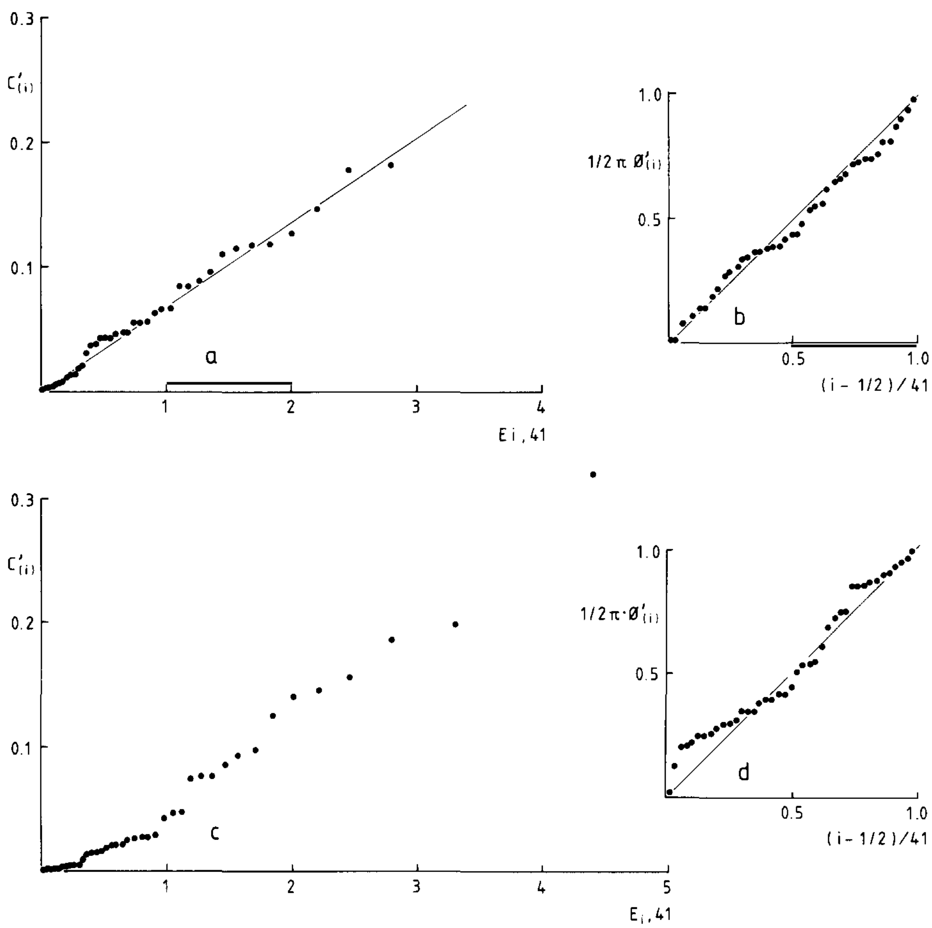

Fig. 10. Directional distribution test for the Foyers (a,b) and Strontian (c,d) data (cf. Fig. 9): colatitude plots (a,c) and longitude plots (b,d). This procedure has been adapted from Lewis and Fisher (1982), and may be used to test whether observed stable directions conform to a Fisherian distribution. Individual specimen directions have been rotated vis a vis the estimated mean direction, thus defining a new data set of polar co-ordinates, $R\mathrm{Dec}(n)$ and $R\mathrm{Inc}(n)$. In the colatitude plot the vertical axis represents calculated values of the distribution function $C'(i) = 1 - \cos R\mathrm{Inc}(i)$ (sorted values). These values have been plotted against the function Ei, $n = \ln(n/(n-1+1/2))$. Linearity through the origin indicates a Fisherian distribution, and we can get a graphical estimate of $1/K$, thus K. A better estimate of K is obtained by linear regression of $C'(i)$ and Ei, n, also giving a measure of the degree of linearity (correlation coefficient R; $R = 1$ for perfect linearity). The longitude plot tests the declination distribution. Rotated $R\mathrm{Dec}(n)$ is sorted in ascending order and normalized by $1/2\pi$. $R\mathrm{Dec}(i)$, $i = 1$, n. The observed normalized frequency of $R\mathrm{Dec}(i)$ (0,1) is plotted in the vertical axis. These values have been plotted against the expected distribution function $Ei,n = (i-0.5)/n$. A good Fisherian fit is recognized by a linear slope of 45° through the origin.

istical distribution parameters, but does not alter significantly the calculated mean direction based on all observations.

The palaeomagnetic data of the present study along with previous results from the Helmsdale granite (Torsvik et al., 1983) are summarized in Table V, and pole positions are plotted in Fig. 11. The 3 "newer granite" poles (the B-data) plot in the area of the majority of other "Mid"-Palaeozoic poles for N. Europe. The Foyers and the Strontian poles are not different statistically but the Strontian and Helmsdale poles which both come from west of the GGF differ at the 95% significance level. The latter polar discrepancy (ca. 15° of arc) could either be due to differences in magnetic age, or alternatively and perhaps most likely that the

TABLE V

Overall palaeomagnetic data for the Foyers and Strontian granites (present study) and for the Helmsdale granite (Torsvik et al., 1983)

Rock formation	N	K	a95	D(°)	I(°)	pole position		dp	dm
						Lat.	Long.		
Foyers granite	41	15	5.7	188.0	9.2	N27.2	E166.5	2.9	5.8
Strontian granite:									
Group A	12	19	9.3	206.3	−40.9	N51.6	E133.6	6.9	11.3
Group B	41	18	5.2	190.0	22.5	N21.1	E164.0	2.9	5.5
Helmsdale granite:									
Group A	21	29	6.0	183.1	−31.5	N48.9	E171.8	3.8	6.7
Group B	17	32	6.0	181.2	1.5	N31.1	E174.9	3.0	3.0
Strontian/Helmsdale B group combined: (east of GGF)						N26.2	E169.2		
All three "newer granites" combined:						N26.5	E168.3		

individual remanence grouping do not constitute single component magnetizations. In any case, the mean Helmsdale/Strontian B-pole (west of GGF) is indistinguishable from the Foyers pole (east of GGF). This poses further evidence against the idea of a larger scale (ca. 2000 km) Early Carboniferous horizontal displacement along the Great Glen Fault as proposed by Van der Voo and Scotese (1981). On the other hand, the data are not well defined sufficiently to enable one to make a reasonable assessment of the model involving a few hundred kilometres translation along the Fault.

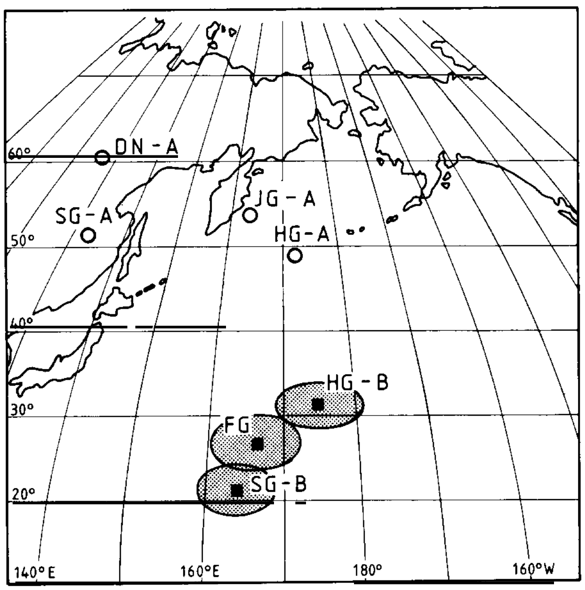

Fig. 11. Pole positions for the Foyers and the Strontian granites and Helmsdale granite. In addition, the A-poles, as obtained from Old Red Sandstone rocks of the Northern Highlands and interpreted as being of Late Palaeozoic/Mesozoic age, are also shown. The southern polar group consist of: The Foyers pole (FG), present study; the Strontian B-pole (SG–B), present study; the Helmsdale B-pole (HG–B), Torsvik et al., 1983. The northern polar group comprises: the Strontian A-pole (SG–A), present study; Duncansby Neck A-pole (DN–A), Storetvedt et al., 1978; John O'Groats A-pole (JG–A), Storetvedt and Carmichael, 1979; Helmsdale A-pole (HG–A), Torsvik et al., 1983.

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References

Fisher, R.A., 1953. Dispersion on a sphere. Proc. R. Soc. London, Ser. A: 217: 295–305.

Flinn, D., 1969. A geological interpretation of the aeromagnetic maps of the continental shelf around Orkney and Shetland. Geol. J., 6: 279–292.

Flinn, D., 1975. Evidence for post-Hercynian transcurrent movement on the Great Glen Fault in the Moray Firth. Scott. J. Geol., 11: 266–267.

Garson, M.S. and Plant, J., 1972. Possible dextral movement on the Great Glen Fault and the Minch Faults in Scotland. Nature (London), Phys. Sci., 240: 31–35.

Harmon, R.S. and Halliday, A.N., 1980. Oxygen and Strontian isotope relationship in the British late Caledonian granites. Nature, 283: 21–25.

Holgate, N., 1969. Palaeozoic and Tertiary transcurrent movements on the Great Glen Fault. Scott. J. Geol., 5: 97–139.

Ineson, P.R. and Mitchell, J.G., 1974. K/Ar isotropic age determinations from some Scottish mineral localities. Trans. Inst. Min. Metall., 83: 13-8.

Kennedy, W.Q., 1946. The Great Glen Fault. Q.J. Geol. Soc. London, 102: 41–72.

Lewis, T. and Fisher, N.I., 1982. Graphical methods for investigating the fit of a Fisher distribution to spherical data. Geophys. J.R. Astron. Soc., 69: 1–13.

Kneen, S.J., 1974. The palaeomagnetism of the Foyers Plutonic Complex Inverness-shire. Geophys. J.R. Astron. Soc., 32: 53–63.

Marston, R.J., 1971. The Foyers granite complex, Iverness-shire, Scotland. Q.J. Geol. Soc. London, 126: 331–368.

Miller, J.A. and Brown, P.E., 1965. Potassium argon studies in Scotland. Geol. Mag., 102: 106–134.

Morris, W.A., 1976. Transcurrent motion determined palaeomagnetically in the Northern Appalachians and Caledonides and the Arcadian Orogeny. Can. J. Earth Sci., 13: 1236–1243.

Mould, D.D.C.P., 1946. The geology of the Foyers granite and the surrounding country. Geol. Mag., 83: 249–265.

Munro, M., 1973. Structures in the south-eastern portion of the Strontian granitic complex, Argyllshire. Scott. J. Geol., 9: 99–108.

Pankhurst, R.J., 1979. Isotope and trace elements evidence for the origin and evolution of Caledonian granites in the Scottish Highlands. In: M.P. Atherton and J. Tarney (Editors), Origin of Granite Batholiths Shiva, Copenhagen, pp. 18–33.

Piper, J.D.A., 1979. Aspects of Caledonian palaeomagnetism and their tectonic implications. Earth Planet. Sci. Lett., 44: 176–192.

Pidgeon, R.T. and Aftalion, M., 1978. Cogenic and inherited zircon U–Pb systems in granites: Palaeozoic granites of Scotland and England. Geol. J., Spec. Issue, 10: 183–220.

Sabine, P.A., 1963. The Strontian granite complex, Argyllshire. Bull. Geol. Surv. G.B., 20: 6–41.

Smith, D.I. and Watson, J., 1983. Scale and timing of movements on the Great Glen Fault, Scotland. Geology, 11: 523–526.

Speight, J.M. and Mitchell, J.G., 1979. The Permo–Carboniferous dyke-swarm of northern Argyll and its bearing on dextral displacement on the Great Glen Fault. J. Geol. Soc. London, 136: 3–11.

Storetvedt, K.M., 1974a. A possible large-scale sinistral displacement along the Great Glen Fault in Scotland. Geol. Mag., 111: 23–30.

Storetvedt, K.M., 1974b. Great Glen Fault. Nature, 249: 777.

Storetvedt, K.M. and Carmichael, C.M., 1979. Resolution of superimposed magnetizations in the Devonian John O'Groats Sandstone, N. Scotland. Geophys. J.R. Astron. Soc., 58: 769–784.

Storetvedt, K.M. and Torsvik, T.H., 1983. Palaeomagnetic reexamination of the basal Caithness Old Red Sandstone; aspects of local and regional tectonics. Tectonophysics, 98: 151–164.

Storetvedt, K.M., Carmichael, C.M., Hayatsu, A. and Palmer, H.C., 1978. Palaeomagnetism and K/Ar results from the Duncansby volcanic neck, northeastern Scotland: superimposed magnetizations, age of igneous activity and tectonic implications. Phys. Earth Planet. Inter., 16: 379–392.

Torsvik, T.H., Løvlie, R. and Storetvedt, K.M., 1983. Multicomponent magnetization in the Helmsdale granite, North Scotland; Geotectonic implications. Tectonophysics, 98: 111–129.

Van der Voo, R. and Scotese, C., 1981. Palaeomagnetic evidence for a large (c. 2000 km) sinistral offset along the Great Glen Fault during Carboniferous time. Geology, 9: 583–589.

Watson, J., 1978. The basement of the Caledonide orogen in Britain. Geol. Surv. Can., Pap. 78–13. Project 27 Caledonide orogen, pp. 75–79.

Winchester, J.A., 1973. Pattern of regional metamorphism suggest a sinistral displacement of 160 km along the Great Glen Fault. Nature (London) Phys. Sci., 246: 81–84.