Physics of the Earth and Planetary Interiors, 54 (1989) 156–162
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

Palaeomagnetic data bearing on the age of the Ytterøy dyke, central Norway

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(Received November 20, 1987; revision accepted February 1, 1988)

Torsvik, T.H., Sturt, B.A., Grønlie, A., and Ramsay, D.M., 1989. Palaeomagnetic data bearing on the age of the Ytterøy dyke, central Norway. Phys. Earth Planet. Inter., 54: 156–162.

The Ytterøy dyke has a near-isotropic fabric and clearly post-dates Caledonian regional deformation. It has a two-component magnetization structure with a low-blocking temperature component ($D = 016°$, $I = +73°$, $\alpha_{95} = 9$) removed below 300 °C. The high-blocking temperature component ($D = 216°$, $I = -42°$, $\alpha_{95} = 8$) could be primary in origin. The palaeomagnetically obtained age accords well with an Rb–Sr biotite age of 256 ± 10 Ma, and it could be argued that intrusion of the Ytterøy dyke was related to extensive Permian rifting and faulting within the Møre Trøndelag Fault Zone. Tentatively we ascribe the previously claimed late Devonian age (K–Ar and $^{40}Ar-^{39}Ar$ biotite ages) for the Ytterøy dyke as resulting from the presence of excess Ar or alternatively, K loss induced by a later hydrothermal flux.

1. Introduction

The lamprophyre dyke on the Island of Ytterøy, central Norway (Fig. 1B, C), was first described by Carstens (1961) and argued to be of post-Caledonian (Permian) age. On the basis of palaeomagnetic data, however, Storetvedt (1967) concluded that the dyke was of late Caledonian (Devonian) age. Later, Priem et al. (1968) reported biotite ages of 256 Ma (Rb–Sr) and 363 Ma (K–Ar). They argued that the late Devonian age represented an initial cooling stage, whereas the apparently younger Permian age was ascribed to substitution of radiogenic Sr by common Sr in circulating fluids.

Råheim (1974) disputed the Devonian age for the Ytterøy lamprophyre and contended that the K–Ar age could be apparently high as the result of excess Ar, thereby supporting Carstens (1961) view of a Permian or late Carboniferous age.

Finally, in the course of the dating history of the Ytterøy dyke, Mitchell and Roberts (1986), by means of $^{40}Ar-^{39}Ar$ stepwise degassing obtained a 'total fusion' biotite age of ~ 370 Ma. This apparently confirmed the late Devonian age of the Ytterøy dyke, and agreed with the conclusions of Storetvedt (1967) and Priem et al. (1968).

As part of a regional investigation of fault-rocks within the Møre Trøndelag Fault Zone (Torsvik et al., 1989; Grønlie and Torsvik, 1989), this account reports new palaeomagnetic data from the Ytterøy dyke, and discusses our preference for a Permian age for the dyke.

2. Sampling and geology

The Ytterøy lamprophyre is located in a limestone quarry on the Island of Ytterøy, and was

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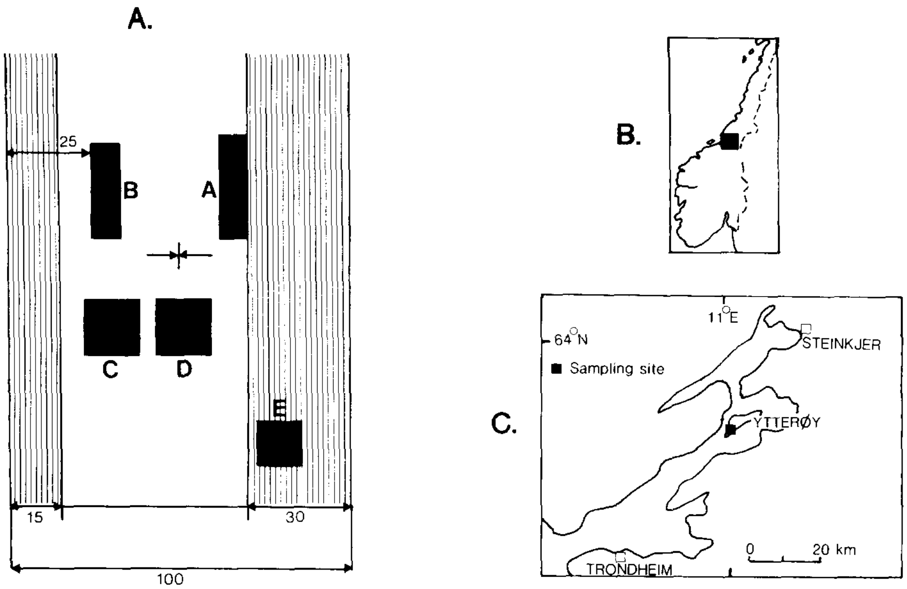

Fig. 1. (A) Sampling details and (B, C) geographic location of the Ytterøy dyke. Sampling of the dyke was confined to five sub-sampling areas (A–E). Along the margins of the dyke, the rocks are highly fractured (dashed lines); dimensions are in cm.

previously described by Carstens (1961), Priem et al. (1967) and Mitchell and Roberts (1986). The dyke is characterized by abundant phlogopitic biotite and carbonate–chlorite pseudomorphs after olivine, with a fine-grained groundmass dominated by biotite, clinopyroxene, calcite, analcite and magnesite (Mitchell and Roberts, 1986). The dyke is oriented 054/71 SE. With a maximum width of 1 m, and exposure over a distance of ~2 m, palaeomagnetic sampling of the dyke clearly must be limited. The contact limestone was considered to be unsuitable for palaeomagnetic study. The central part of the dyke is fairly massive, although weathered, and along its margins the dyke is strongly fractured (Fig. 1A). Both the central and marginal parts of the dyke appeared to be fragile, and so a battery-powered drill was employed in the field to minimize vibration. Palaeomagnetic sampling of the dyke was carried out in five separate areas, denoted A–E, and a total of 30 cores were drilled in the field. A–D were confined to the relatively massive central part of the dyke, whereas area E was drilled directly into the fractured marginal part of the dyke.

3. Laboratory experiments

The anisotropy of magnetic susceptibility was measured on a low-field induction bridge (KLY-1).

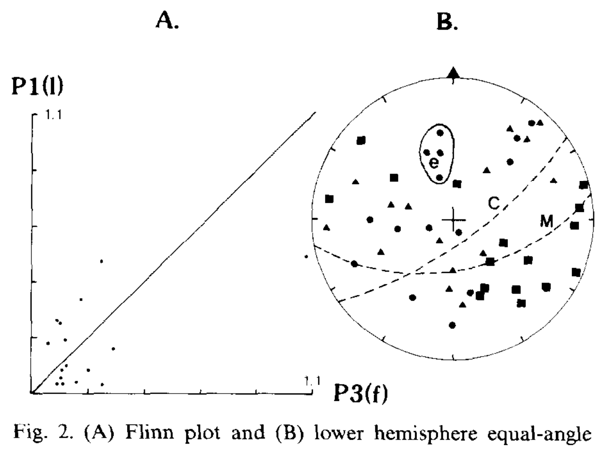

Fig. 2. (A) Flinn plot and (B) lower hemisphere equal-angle stereographic projection of the principal axes in the magnetic susceptibility ellipsoid. K_{max}, K_{int} and K_{min} are shown as ■, ▲ and ●, respectively. Dashed great-circles denoted C and M represent the dyke contact (/plane of fracturing) and mean magnetic foliation plane for area E (downward dipping planes).

The natural remanent magnetization (NRM) was measured on a two-axis cryogenic magnetometer, and the stability of the NRM was tested by means of stepwise thermal demagnetization. Remanence components were estimated by means of least-square line fitting.

Individual samples can show an anisotropy of ~ 4%. A near-random distribution pattern of the principal axes (Fig. 2) is obtained, however, and so the dyke must be regarded as possessing an isotropic fabric and thus clearly post-dates regional deformation in the area. Only area E, from the strongly fractured marginal part of the dyke, shows a well-defined magnetic foliation (K_{max}–K_{int}) which almost coincides with the dyke margins and plane of fracturing. This magnetic fabric is attributed to the effect of marginal shearing.

Thermal demagnetization experiments reveal the presence of two characteristic remanence components. A low-blocking component (LB) is characterized by a steeply inclined, downward-dipping inclination with declination near north. This LB component is always removed near 300 °C (Figs. 3, 4). The high-blocking (HB) component is confined to blocking temperatures between 300 and 580 °C. Declination is near southeast, with steeply to intermediate, upward-pointing inclinations (Fig.

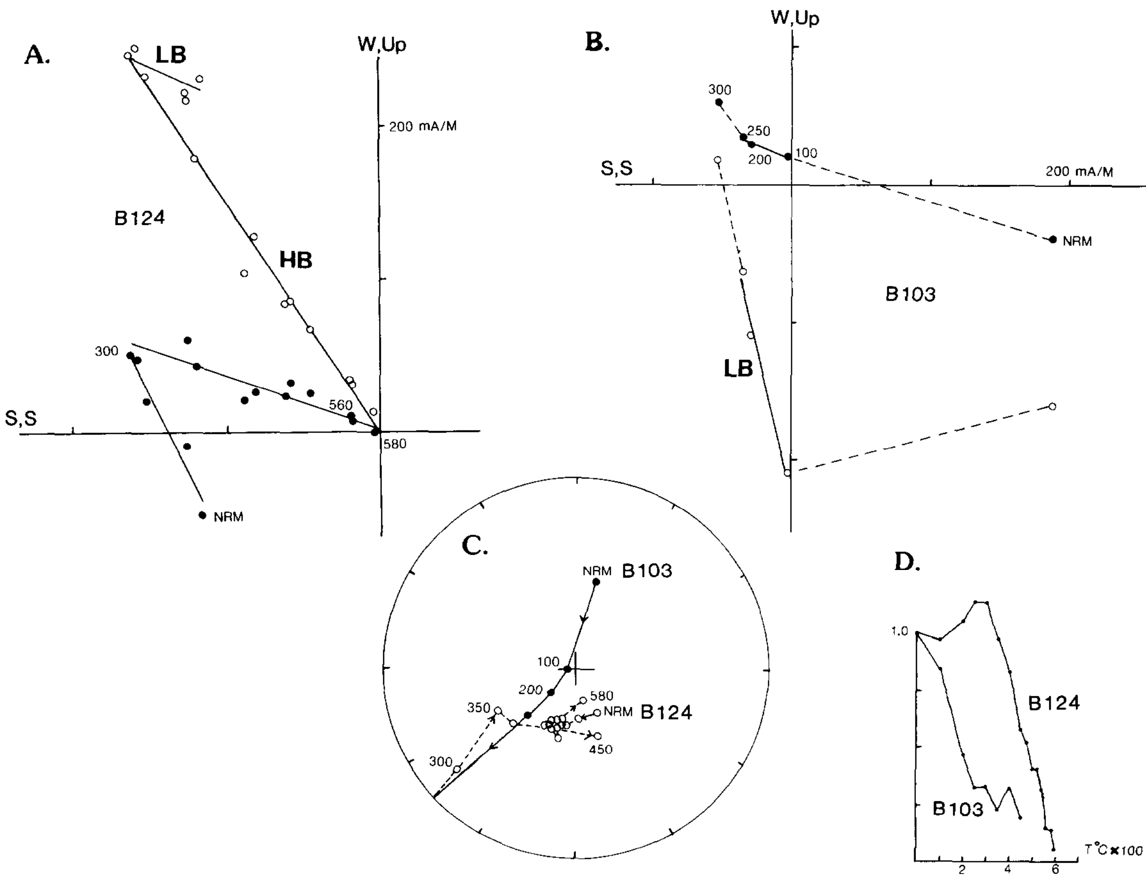

Fig. 3. Typical examples of thermal demagnetization. Most specimens are characterized by a two-component magnetization structure, with a LB component removed at around 300 °C (A). In some cases (B) only the LB components were identified owing to viscous behaviour at high temperature. (C) and (D) show the corresponding equal-angle stereographic projection and normalized decay curves. In orthogonal vector-plots (A, B), closed and open symbols represent points in the horizontal and vertical plane, respectively. In stereographic projections, open and closed symbols denote negative and positive inclinations, respectively.

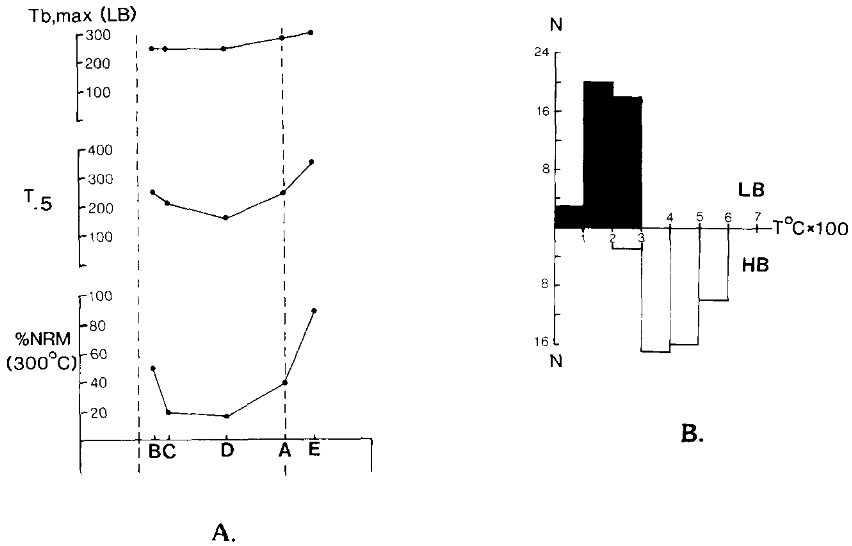

Fig. 4. (A) Variation in $T_{b,max}$ (maximum blocking temperature), $T_{0.5}$ (50% reduction of NRM during thermal treatment) and percentage of NRM left at 300 ° C for the LB component. (B) Unblocking spectra presented in a histogram. Note the almost-perfect blocking-temperature separation between the LB and HB components. (A) Position of areas across the dyke (see Fig. 1).

3A). Occasionally, this component was not identified owing to pronounced viscous and irregular directional behaviour above 400 ° C (cf. Fig. 3B).

Thermomagnetic analysis demonstrates Curie temperatures between 550 and 570 ° C, which along with thermal demagnetization experiments suggest a Ti-poor titanomagnetite as the principal carrier of remanence.

Barely any 'magnetomineralogical' changes can be observed through the dyke. The variations in NRM, bulk susceptibility and NRM/bulk susceptibility are minimal, the latter typically ranging between 0.06 and 0.14, indicative of multidomain titanomagnetite. The maximum blocking temperature for the LB component is almost constant throughout the dyke (Fig. 4A). Two parameters,

TABLE I

Overall palaeomagnetic data from the Ytterøy dyke (sample directions denoted *a* in Fig. 5(A) are excluded in the statistics)

Area	LB Component					HB Component				
	D	I	α_{95}	N	T_{max}	D	I	α_{95}	N	T_{max}
A	008	+73	8	10	[288]	234	−34	7	5	[465v]
B	329	+77	–	1	[250]	200	−41	15	3	[573]
C	046	+60	10	2	[250]	205	−30	14	3	[520v]
D	020	+80	5	3	[250]	197	−53	10	2	[540v]
E	020	+70	7	3	[300]	212	−53	8	4	[580]
A–E	019	+74	9	5	[268]	210	−43	12	5	[536]
	VGP: N80, E114: $dp/dm = 14/16$					VGP: N47, E150: $dp/dm = 9/15$				
Specimen level statistics (used in Fig. 5B):										
	016	+73	9	19	[285]	216	−42	8	17	[520]
	VGP: N81, E128: $dp/dm = 9/10$					VGP: N44, E143: $dp/dm = 6/10$				

LB, Low blocking; HB, high blocking; D, mean declination; I, mean inclination; α_{95} = 95% confidence circle (Fisher, 1953); N, number of specimens; T_{max}, mean maximum blocking temperature; v, viscous behaviour above the indicated temperature (HB), but with pronounced trajectory toward the origin in orthogonal vector-plots. VGP, Virtual geomagnetic pole; dp/dm, semi-axis of the oval of 95% confidence about the mean pole.
Mean sampling coordinates: N63.7, E11.1.

however, show minimum values from the central part of the dyke, i.e.,

(1) temperature required to reduce the NRM intensity by 50% ($T_{0.5}$), and (by implication)

(2) percentage of NRM left at 300 ° C.

This reflects the fact that the LB component in specimens from the central part of the dyke carries a higher proportion of the total NRM, and rules out the possibility that the LB component is owing to pure shear-heating by later fault-movement, as has been suggested for the Stabben Sill (Sturt and Torsvik, 1987), since this would affect the margins more strongly than the centre. In consequence, a 'regional' overprint is indicated, probably thermal (thermo-viscous) rather than chemical (thermo-chemical) in origin, owing to the well-defined blocking-temperature contrast (cf. Fig. 4B and sample B124 in Fig. 3).

4. Discussion

Apart from some clearly discordant sample directions (Fig. 5A), the LB and HB components define two statistically different directional groups of opposite polarity. Seen in relation to the original palaeomagnetic study of the Ytterøy Dyke (Storetvedt, 1967), only some HB directions from this study (marked *a* in Fig. 5A) correspond to the data presented by Storetvedt. These directions, however, are plainly directionally discordant and occupy a blocking-temperature spectrum similar to the remaining HB components.

Compared with a suggested apparent polar wander path for Fennoscandia (Personen et al., 1988), the HB component is most probably of Permian age, whereas the LB component was probably acquired in late Mesozoic/Cenozoic times (Fig. 5B). The latter component compares with a LB component obtained from the late Carboniferous (~ 300 Ma) Stabben Sill (Sturt and Torsvik, 1987). In the study of the Stabben Sill, however, the LB component was ascribed to the effect of later fault movements. It is interesting to note that the HB component from this ~ 300 Ma sill differs significantly from the Ytterøy dyke, and testifies to an older age (cf. Fig. 5B).

This account reports palaeomagnetic data from a single dyke with very limited sampling, and so the HB components could represent a short-time

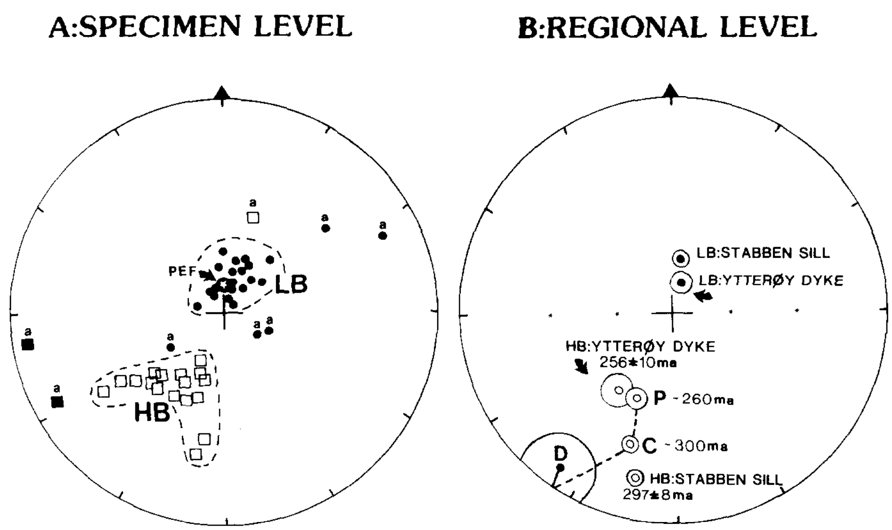

Fig. 5. (A) Distribution of characteristic remanence directions obtained from the dyke. 'Anomalous' remanence directions are denoted a. (B) LB and HB components plotted together with mean values for the late Devonian (D), late Carboniferous (C) and Permian (P) palaeofields (Pesonen et al., 1989). Some recent data from the Stabben Sill, Central Norway, are also included (Sturt and Torsvik, 1987). Declination and inclination have been re-calculated from the original poles to fit the present sampling position. Mean directions are plotted with A_{95}, whereas the Ytterøy and Stabben Sill data are plotted along with α_{95}.

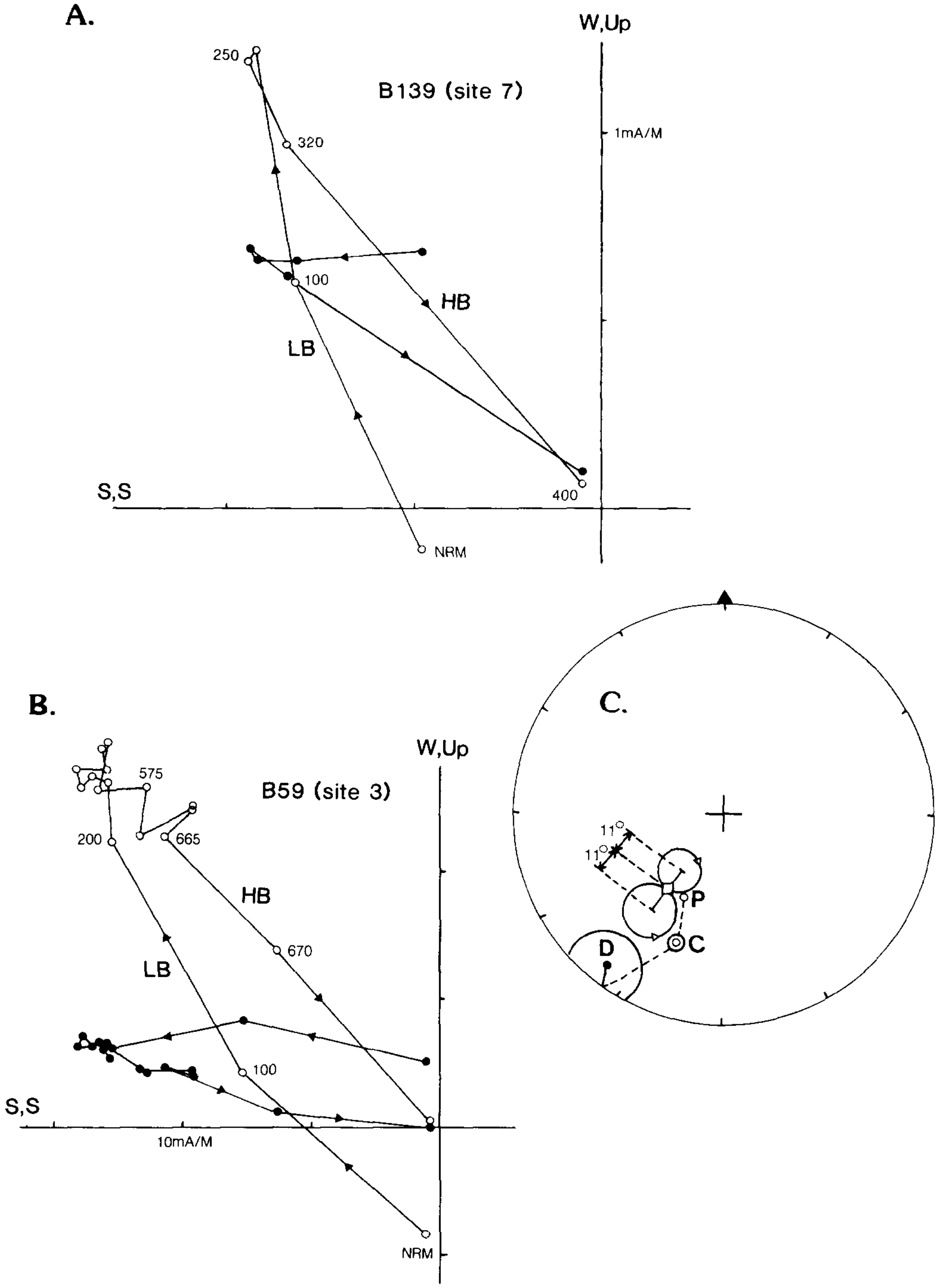

Fig. 6. (A, B), Typical results from fault-breccias within the Møre Trøndelag Fault Zone, showing an identical remanence build-up when compared with the Ytterøy dyke (compare Fig. 4). (C) Mean values of the Late Devonian to Permian palaeofield directions compared with two examples of treating the Ytterøy data as a spot-reading located on theoretical circles with a radius of 11°. If ~ 11° represents the maximum angle between the magnetic and rotational axis for the past 400 Ma, a Devonian spot-reading can be ruled out.

spot-reading, i.e. secular variation is not averaged out, rather than a genuine time-average of the geomagnetic field. A Devonian age, however, appears unlikely (Fig. 6C). This is based on the assumption of an angular difference of the order of 11° between the Earth's rotational axis and the geomagnetic axis and, unless it is a transitional spot-reading during a field-reversal, the HB Ytterøy component would not correspond to the late Devonian geomagnetic field for Fennoscandia. Thus, the palaeomagnetic age of the dyke is most probably bracketed within the late Carboniferous to early Triassic time range.

The Ytterøy dyke is located within the Møre Trøndelag Fault Zone, and palaeomagnetic data from fault-rocks (breccias) and hydrothermally altered rocks in this cone indicate a Permian age of extensional deformation and faulting. Indeed, fault-rocks display a similar two-component magnetization build-up, i.e. a LB and HB component (see Fig. 6A, B), closely similar to that encountered in the Ytterøy dyke (Grønlie and Torsvik 1989). This regional Permian and late Mesozoic fault-pattern is compatible with palaeomagnetic data from the Ytterøy dyke, and a combination of HB components from the Ytterøy dyke and the investigated fault-rocks reveals a mean pole-position near 45° N, 165° E, indicative of a late Permian age.

The Devonian $^{40}Ar-^{39}Ar$ biotite age of 370 Ma reported by Mitchell and Roberts (1986) represented a total fusion age, and yielded 'a complex age spectrum with no clear plateau at any true statistical significance'. It has been demonstrated in this account that titanomagnetites, with blocking-temperatures up to 550–580° C, crystallized/recrystallized in Permian times. If a Devonian age for the Ytterøy dyke is accepted, it is most surprising that 'Devonian' biotites with blocking-temperatures of say ~300° C were not reset, whereas titanomagnetites with substantially higher blocking-temperatures suffered complete overprinting. In conclusion, unless the HB component is exclusively secondary and thermo-chemical in origin, and this is most unlikely, we must consider that the Rb–Sr age of 256 ± 10 reflects the initial cooling system of the dyke, and is compatible with the Ytterøy HB component. The apparently high $^{40}Ar-^{39}Ar$ age may be ascribed to excess Ar, presumably related to late Mesozoic hydrothermal alteration. It is also possible that such later hydrothermal alteration may induce K-loss, which would have the effect of giving an anomalously high $^{40}Ar-^{39}Ar$ age (J.R. Mitchell, personal communication, 1987).

Acknowledgement

The Norwegian Research Council for the Humanities and Science (NAVF) and Statoil are acknowledged for financial support. Norwegian Lithosphere contribution no. 40.

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