PALAEOMAGNETISM AND THE AGE OF THE YOUNGER DIABASES IN THE NY-HELLESUND AREA, S. NORWAY

ERIK HALVORSEN

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Palaeomagnetic measurements on the younger diabases of the Ny-Hellesund area, S. Norway, suggest a magmatic emplacement in late Carboniferous or Permian times. This conclusion is in agreement with that of a previous palaeomagnetic study and with some recent whole-rock potassium-argon analyses.

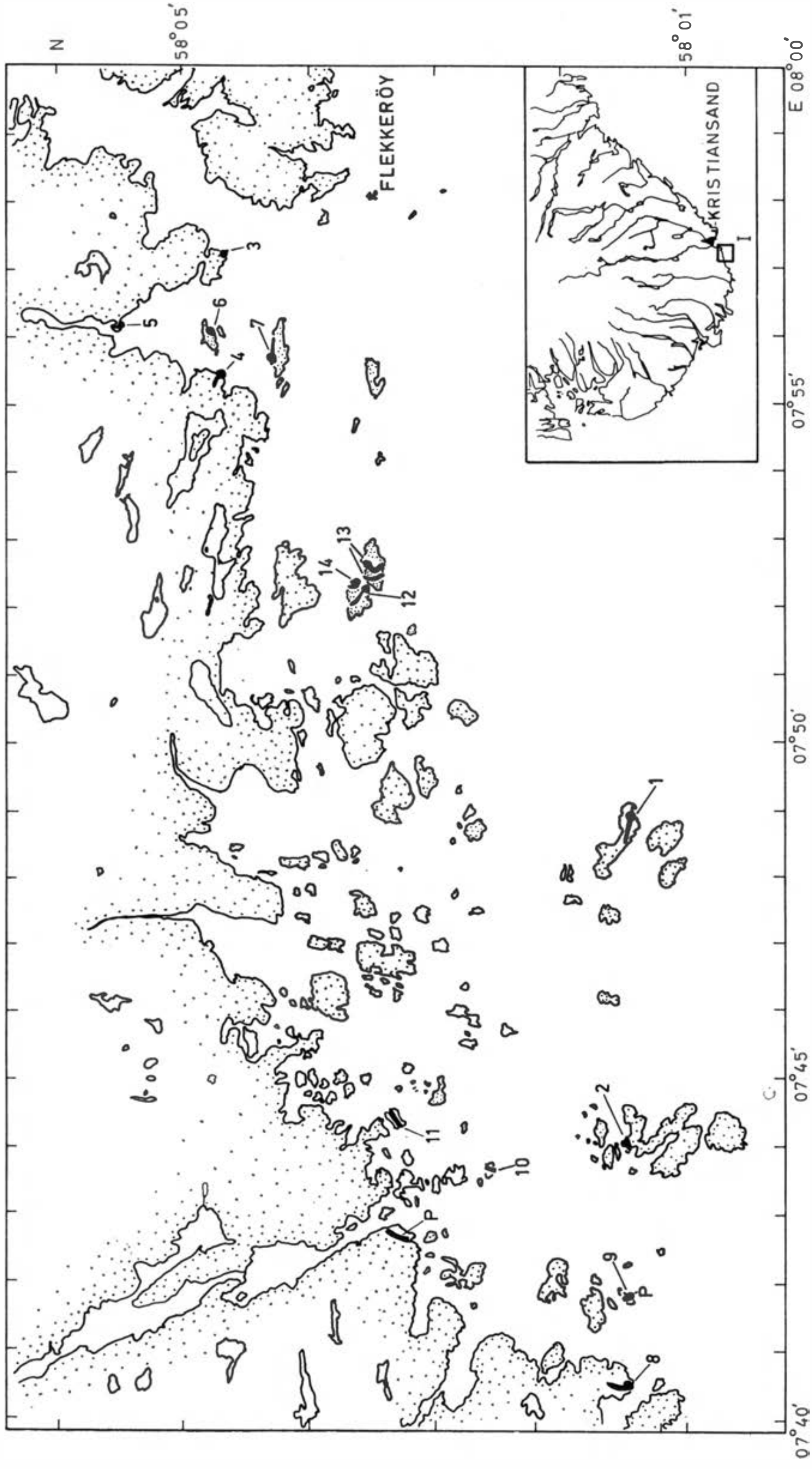
E. Halvorsen, Department of Geophysics, University of Bergen, 5000 Bergen, Norway.

Introduction

Diabase dikes are very frequent along the southern coast of Norway. This paper deals with the younger diabases dissecting the Precambrian in the Ny-Hellesund area (Fig. 1). Some of the dikes have been the subject of an earlier investigation (Storetvedt 1966) suggesting an intrusive age of Late Carboniferous-Permian. His results show, however, a linear rather than a circular distribution of tested site mean directions. The reason for this may be that the time of intrusion covers periods of relative polar shifts, or alternatively that stable secondary magnetizations upset the original component.

Table 1. Sampling details

Site no.	Rock type		N	Sample nos.
1	Vertical	diabase	6	41– 46
2	–	–	5	51– 55
3	Labradorite	–	5	56– 60
4	Vertical	–	2	61– 62
5	Labradorite	–	3	63– 65
6	–	–	2	66– 67
7	–	–	3	68– 70
8	–	–	5	93– 97
9	Porphyritic	–	5	98–102
10	Oligoclase	–	7	103–109
11	–	–	5	110–114
12	Labradorite	–	3	125–127
13	–	–	4	128–131
14	–	–	5	132–136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These possibilities were the main reasons for further investigations. The renewed investigation is based on 60 samples of diabases collected by K. M. Storetvedt from altogether 14 different sites. Sampling details are given in Table 1. (A collection of lamprophyre samples in the same area, which according to Storetvedt (1966) exhibit a rather complex magnetic behaviour, is not considered in this paper. However, a separate treatment of this collection is planned.)

Geology and sampling

Normally the dikes along the southern coast of Norway have a vertical dip trending approximately parallel to the coast line. In the Ny-Hellesund area, however, they are mainly injected as nearly horizontal sheets. Here the direction of strike changes from WNW-ESE to WSW-ENE (Carstens 1959). The country rocks are granitic gneisses and migmatites (Barth 1945).

According to Carstens the horizontal dikes are of two main types: a rather fresh labradorite diabase and a more altered oligoclase diabase. The labradorite diabases occur mainly in the eastern part of the area while the oligoclase diabases are found in the western part. Furthermore, an inclined porphyritic plagioclase diabase occurs. Of vertical dikes 3 different outcrops are present. The thickness of the dikes nowhere exceeds three metres.

It is difficult to determine the exact number of independent dikes because the continuation of the outcrops is interrupted by the sea. Tectonic movements of any importance for the present study have not been revealed.

The age of these dikes has been discussed by Hjelmquist (1939), Barth (1943) and McGregor (1948). A Permian age is considered most likely. McGregor suggests a connection with Scottish diabases and lamprophyres.

K-Ar age determinations

Altogether five samples from five sites were selected for age determination (Fitch & Miller 1968). Initially 15 samples were examined megascopically and in thin section, after which the more promising samples for whole-rock K-Ar determination were chosen.

Fifteen results from 5 selected samples are listed in Table 2. Argon extractions and purifications were carried out as described by Miller & Brown (1964), isotopic ratios were measured using an omegatron type mass spectrograph (Grasty & Miller 1965). Enriched argon-38 was employed

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Fig. 1. Geological sketch map of dike rocks in the Ny-Hellesund area (after Carstens 1959). Sampling sites are indicated by full circles. Map area shown on key map of southernmost Norway.

Table 2. Results of conventional total degassing potassium-argon age determinations (after Fitch and Miller 1968)

Site no.	Sample no.	K_2O	Atmos. Contam. %	v/m	Athmos. in m.y.	Average Age & error
			Kristiansand rocks			
		2.90	13.7	3.27×10^{-2}	314 ± 9	
1	42	2.90	13.0	3.26×10^{-2}	312 ± 9	313 ± 6
		2.90	13.1	3.26×10^{-2}	312 ± 9	
		0.669	44.6	6.55×10^{-3}	275 ± 8	
4	61	0.669	44.7	6.53×10^{-3}	274 ± 8	273 ± 6
		0.669	44.2	6.45×10^{-3}	271 ± 8	
		0.847	43.4	1.155×10^{-2}	373 ± 11	
8	93	0.847	39.0	1.199×10^{-2}	388 ± 11	380 ± 8
		0.847	40.2	1.171×10^{-2}	378 ± 11	
		1.08	26.7	9.87×10^{-3}	258 ± 8	
9	98	1.08	31.0	9.57×10^{-3}	250 ± 8	255 ± 6
		1.08	27.6	9.90×10^{-3}	258 ± 8	
		0.640	44.5	6.18×10^{-3}	271 ± 8	
14	135	0.640	50.8	5.92×10^{-3}	261 ± 8	266 ± 6
		0.640	50.1	6.03×10^{-3}	265 ± 8	

as an internal standard. The error associated with each separate age determination is calculated according to the method set out by Miller & Fitch (1964). In Table 2, v/m stands for volume of radiogenic ^{40}Ar or weight of sample. The decay constants used are $\lambda_e = 0.584 \times 10^{-10}$ year^{-1} and $\lambda\beta = 4.72 \times 10^{-10}$ year^{-1}.

Each specimen was crushed and the 30/50 mesh fraction was used for the analysis. Three repeated total degassing determinations were made on each sample.

The results from sites 1 and 8 are probably highly unreliable because thin section studies of the specimens concerned show that extensive secondary mineralogical changes have taken place.

Sample 61 from site 4 (vertical dike) appears to be remarkably fresh. The K-Ar age of 273 m.y. is regarded as a close estimate for the true age of intrusion. The age of 255 m.y. from site 9 is regarded as a minimum age for intrusion. Alteration is more intense in this specimen than in the samples from site 4 and site 14.

The results from the samples 61, 98, and 135 suggest that sites 4, 9, and 14 are closely related Early Permian intrusions, probably all intruded around 270 m.y. ago.

Fitch & Miller suggest that sites 1 and 8 may be of late Precambrian or Early Palaeozoic origin, their apparent ages being biased by argon losses both during the Caledonian orogeny and during the Permian activity in this area. As seen below, this latter conclusion is not compatible with the palaeomagnetic results.

Experiments

The intensity of the natural remanent magnetism ranges between 2.93×10^{-4} and 1.24×10^{-2} e.m.u. /cm^3. Both the intensity and the direction of permanent magnetism were determined using an astatic magnetometer following the method described by Collinson et al. (1957). At least one cylinder (19 × 19 mm) from each sample was studied.

The direction of the remanent magnetism was mostly found to be widely scattered with planar distributions through the direction of the present geomagnetic field. This indicates that the measured remanent directions are affected by viscous magnetism.

Alternating field demagnetization was used to remove the effect of the viscous components. The equipment used is similar to that described by Creer (1959). A variable electrolytic resistance is used to produce a linear decrease of current through the demagnetization coils. The tumbler ratio is 11 : 16.

Thermal demagnetization was applied in order to test the possibility of stable secondary components. The method used is mainly as described by Storetvedt et al. (1968). However, the application of two sets of Helmholtz coils connected in series with one set acting as a 'field control coil' has given much better field cancellation than previously obtained (Hummervoll 1969).

A stable component of magnetization is considered to be achieved when no further systematic directional change during demagnetization occurs. The stable direction of each specimen may at least constitute those of three successive demagnetization steps, their overall mean direction being provisionally considered as the remanence direction in question.

Results

Directions as defined above were detected in samples from all sites except site Nos. 3, 6, and 7. One sample from site 6 and all samples from site 7 moved away from the present field direction when demagnetized, approaching the stable directions found in the other sites. However, the intensity dropped below the measurable limit of the magnetometer used, before any stable direction could be detected. The second sample from site 6 revealed an anomalous direction and is excluded from further discussion. The intensity of this sample was nearly an order of magnitude greater than that of the first sample, indicating surface phenomena like lightning as a possible explanation.

Two samples from site 3, samples Nos. 59 and 60, show directions of magnetism not far from the present field. When alternating current demagnetization is applied on these samples, they exhibit quite 'hard' magnetization. They do not move against the stable direction found in samples from the other sites. On the other hand, thermal demagnetization results are in close agreement with the predominant stable direction data. Because most of the

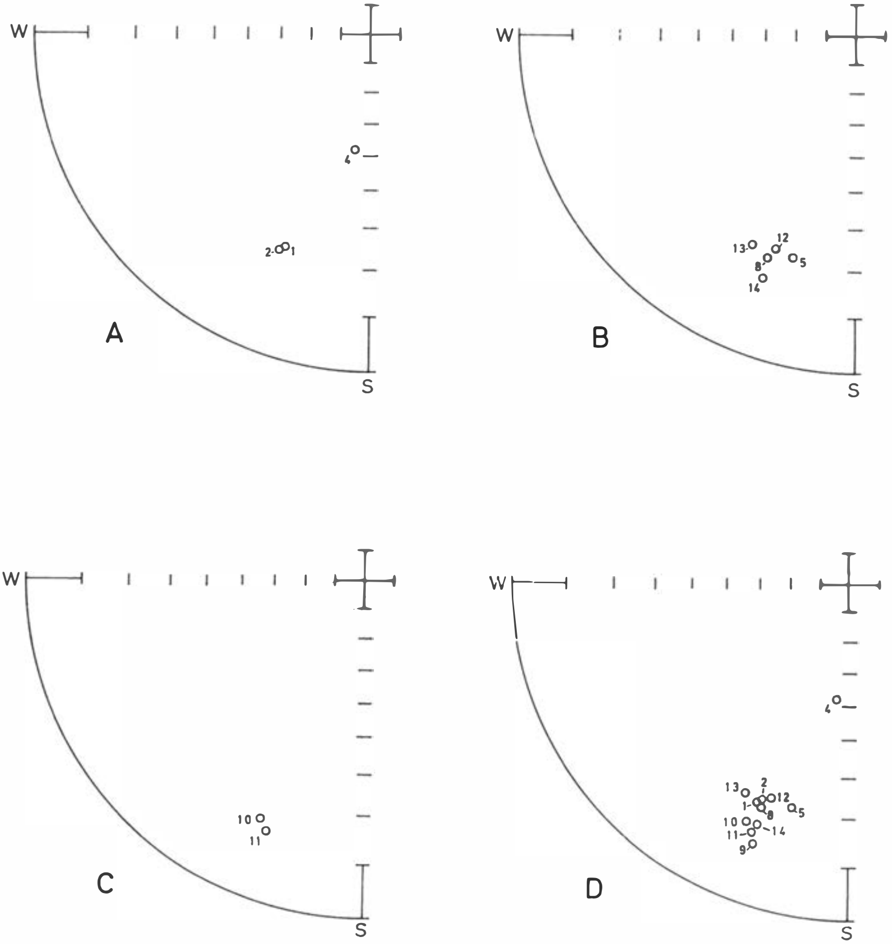

Fig. 2. Site mean directions from the vertical diabases (A), the labradorite diabases (B), the oligoclase diabases (C) and all diabases combined (D).

Table 3. Palaeomagnetic results

Site	D	I	N	k	α95	Pole	Remarks
1	202.4	–22.5	6	108.7	6.5		Weight on specimen directions
2	202.1	–21.3	5	181.9	5.7		– – – –
4	186.5	–51.9	2	–	–		– – – –
5	194.8	–21.3	2	–	–		– – – –
8	201.6	–20.0	5	115.1	7.2		– – – –
9	200.2	–11.1	2	–	–		– – – –
10	203.3	–15.3	5	338.2	4.2		– – – –
11	201.7	–14.1	2	–	–		– – – –
12	199.7	–21.4	2	–	–		– – – –
13	205.8	–21.4	4	651.3	3.6		– – – –
14	201.6	–15.3	4	105.4	9.0		– – – –
Mean I	202.0	–18.9	37	98.8	2.4	38.7 N 159.8 E	– – – –
Mean II	201.3	–18.4	10	283.9	2.9	38.6 N 160.7 E	Weight on site means

samples from this dike are very weakly magnetized, a determination of any stable direction was not successful.

Site mean directions and relevant statistics (Fisher 1953) are listed in Table 3. The overall mean direction is calculated with unit weight on specimen directions as well as on the site means. Fig. 2 shows site means plotted in stereonets.

The remanence directions obtained after thermal demagnetization to 600°C are mostly scattered, the intensity being reduced to 5–1 per cent of the original. Fig. 3 shows typical intensity decay curves against increasing temperature or a.c. fields for the different types of diabases. Decay curves for site 4 are also included. As seen in Fig. 2 A, the vertical diabases show two different directions when demagnetized. Both directions reveal stability against alternating current and thermal demagnetization.

The decay curves of samples from site 4 (Nos. 61 and 62) are not different from the other diabases in spite of their anomalous stable direction.

Conclusion

Apart from the results of site 4, the stable magnetization components of the dikes investigated constitute a well defined group of directions. This clustered group, comprising all the different types of chemical compositions present, suggests that the original remanence has not been significantly upset by deviating fields acting during any post-magmatic chemical activity. It must be concluded, therefore, that the majority of directions obtained represents the ambient geomagnetic field at the time the dikes were injected.

On present information (Storetvedt 1968) it appears that the pole relative to Europe remained fixed throughout most of the Palaeozoic era; the only change seems to have occurred at about the Middle Carboniferous.

In the present case this polar shift would imply a change in inclination of about 40 degrees. Therefore, palaeomagnetism should be able to provide a

Table 4. Palaeomagnetic data for Europe

Formation	Age	Treatment	Pole position	Ref.
Exeter lavas	Pl	AC + th.	46 N 165 E	Cornwell 1967
Nideck ign. rocks	P	th.	47 N 169 E	Roche et al. 1962
Nahe ign. rocks	P	AC	46 N 167 E	Nijenhuis 1961
Oslo ign. rocks	Pl	AC	47 N 157 E	Van Everdingen 1960
Whin Sill	Cu	AC + th.	44 N 160 E	Storetvedt and Gidskesaug 1969
Ny-Hellesund diabase	Cu–Pl	AC + th.	39 N 160 E	This paper
Kinghorn lavas	Cl	th.	17 N 161 E	Wilson and Everitt 1963
Kvamshesten	Dm	AC + th.	22 N 170 E	Lie et al. 1969
Røragen	Dl–m	th.	19 N 160 E	Storetvedt and Gjellestad 1966
Ringerike	Su	th.	21 N 159 E	Storetvedt et al. 1968
Volcanics of Great Britain	O	AC + th.	13 N 165 E	Nesbitt 1967

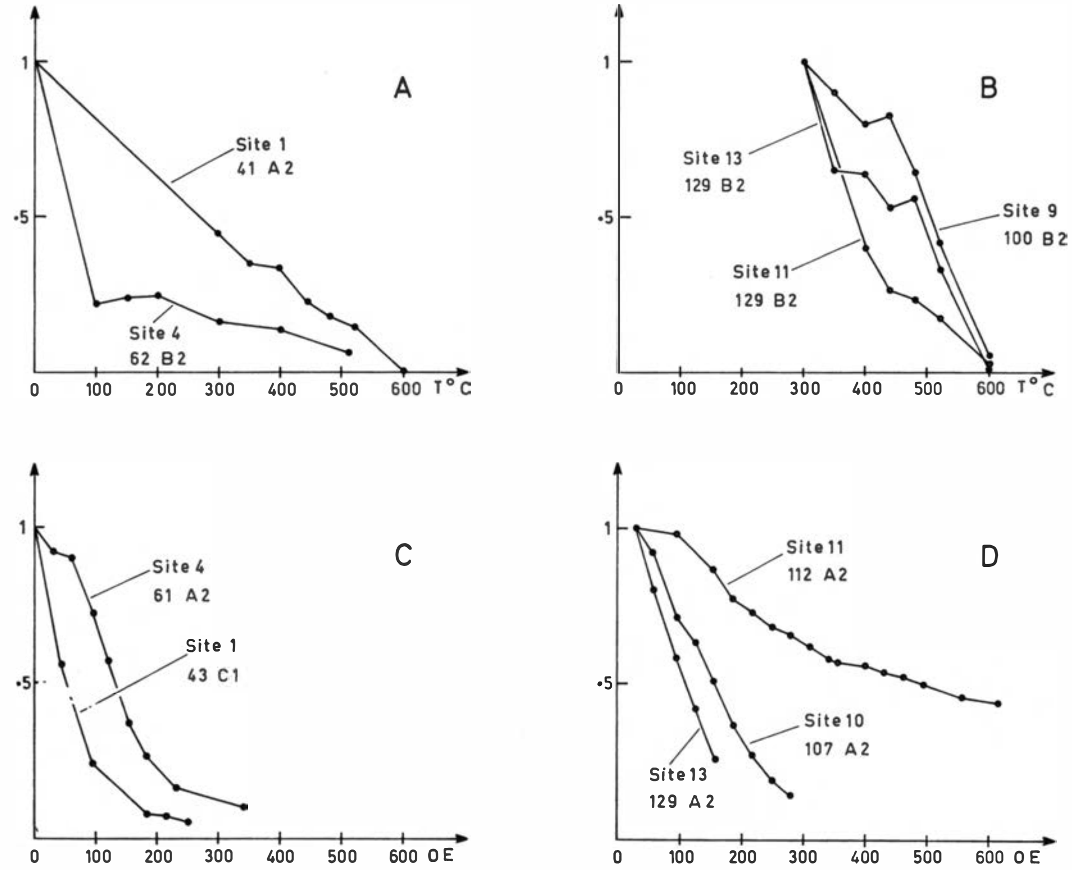

Fig. 3. Intensity decay curves for the different types of diabase, A and B for increasing temperature and C and D for increasing a.c. field.

fairly reliable age distinction between rocks younger and older than Middle Carboniferous.

The pole position of the Ny-Hellesund dikes (the choice of unit vector in the calculation has no importance) are, as shown in Table 4, in close agreement with European Late Carboniferous and Permian pole positions. This seems to imply that only one generation of dikes exists in this area; the age may well be Early Permian as inferred from the most reliable K/Ar determinations.

The conclusion of Fitch & Miller (1968) that some of the more altered dikes may be of an earlier origin is not confirmed by the palaeomagnetic data.

K/Ar measurements have also arrived at an Early Permian age of site 4, but the palaeomagnetic results are anomalous. As only two rock samples were collected from this latter dike a proper conclusion concerning its discrepant magnetization direction cannot be presented here.

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