THE PALAEOMAGNETISM OF SOME TERTIARY IGNEOUS ROCKS FROM UBEKENDT EJLAND, WEST GREENLAND

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Paleocene intrusive rocks were found to be magnetically unstable, but six lavas, some 64 years old, yielded stable magnetic directions corresponding to a pole position at 54 N 152 W. The precision of the palaeomagnetic and radiometric determinations are inadequate to distinguish age differences between these rocks and those of the North Atlantic Tertiary Province but a small difference of some 5 million years is suspected.

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Rock samples collected on an expedition from the University of St. Andrews to Ubekendt Ejland, West Greenland, were examined in an attempt to determine a pole position for these Paleocene rocks. This pole position can be compared with pole positions determined for the North Atlantic Tertiary Province and can eventually be compared with Tertiary rocks in Baffin Island, Canada. Such studies should eventually reveal the presence or absence of age differences between these rocks and determine the magnitude of possible movements associated with continental drift between the areas subsequent to their volcanic activity.

Geology

The geology of the Cretaceous-Tertiary rocks of the West Greenland basin has been described recently by Rosenkrantz & Pulvertaft (1969) and summarised by Henderson (1969). The distribution of basaltic rocks in the basin is shown in fig. 1. A thick sequence of sediments of marine and non-marine origin was laid down in the area between the Lower Cretaceous and the Danian (Lower Paleocene). During the Danian the area became volcanically active, possibly under the influence of the Tertiary volcanism of the Brito-Arctic province. Tuff layers are found intercalated in Danian sediments and the sediments are overlain by volcanic rocks, the lowest of which are submarine pillow breccias which are overlain by a thick pile of subaerial basalts. The basin is fault bounded and, on Nûgssuaq and on Svartenhuk, basalts overlap the fault and lie unconformably on the Precambrian rocks to the east. A certain amount of tilting has been reported in north-west Nûgssuaq in addition to block faulting. This area is in contrast to Ubekendt Ejland where Drever (1958) considers that the tilting of the basalts is not accompanied by major faulting or block displacement.

In parts of Nûgssuaq, south of the collecting sites on Ubekendt Ejland, the total thickness of marine sediments is at least 1500 m and possibly 2000 m in some places. A considerable part of the area between Svartenhuk and Nugssuaq and western Disko is covered by Tertiary basalts, including almost all of Ubekendt Ejland. In some of the areas the basalts are very thick; Rosenkrantz & Pulvertaft estimated the total thickness of subaerial basalt to be between 5 and 8 km in areas like south Svartenhuk, Ubekendt Ejland, north western Nugssuaq and western Disko. Dykes and sills occur in the sediments and lavas but their distribution varies very much from one area to another.

Two samples of basaltic lava were selected for radio-active dating by the K/Ar method. Unfortunately one of these, L1, had a very low K content, 0.1 %, and could not be dated precisely and the other, L16, although of higher K content, 0.19 %, contained some 90 % atmospheric argon and yielded ages of 57 and 70 million years on this sample (Mitchell & Evans, personal communication). These age determinations only substantiate, in general terms, the stratigraphical Paleocene age for these lavas and therefore their approximate contemporaneity with basalts in Baffin Island (dated as 58 ± 2 million years—Farrar quoted by Clarke 1968) and basalts of East Greenland and Scotland-Faeroes which are mostly 60–65 million years in age.

Field and Laboratory Procedure

Twenty-nine sites along the western coast (mean location 71.1 °N 54.0°W) of Ubekendt Ejland, West Greenland, were sampled by D. T. Meldrum on an expedition from the University of St. Andrews. At least six to eight hand samples were collected at each of 26 sites and drilled cores were obtained at three sites. At nineteen sites the samples were oriented with a sun compass, while topographic sightings were used at the remaining sites. In

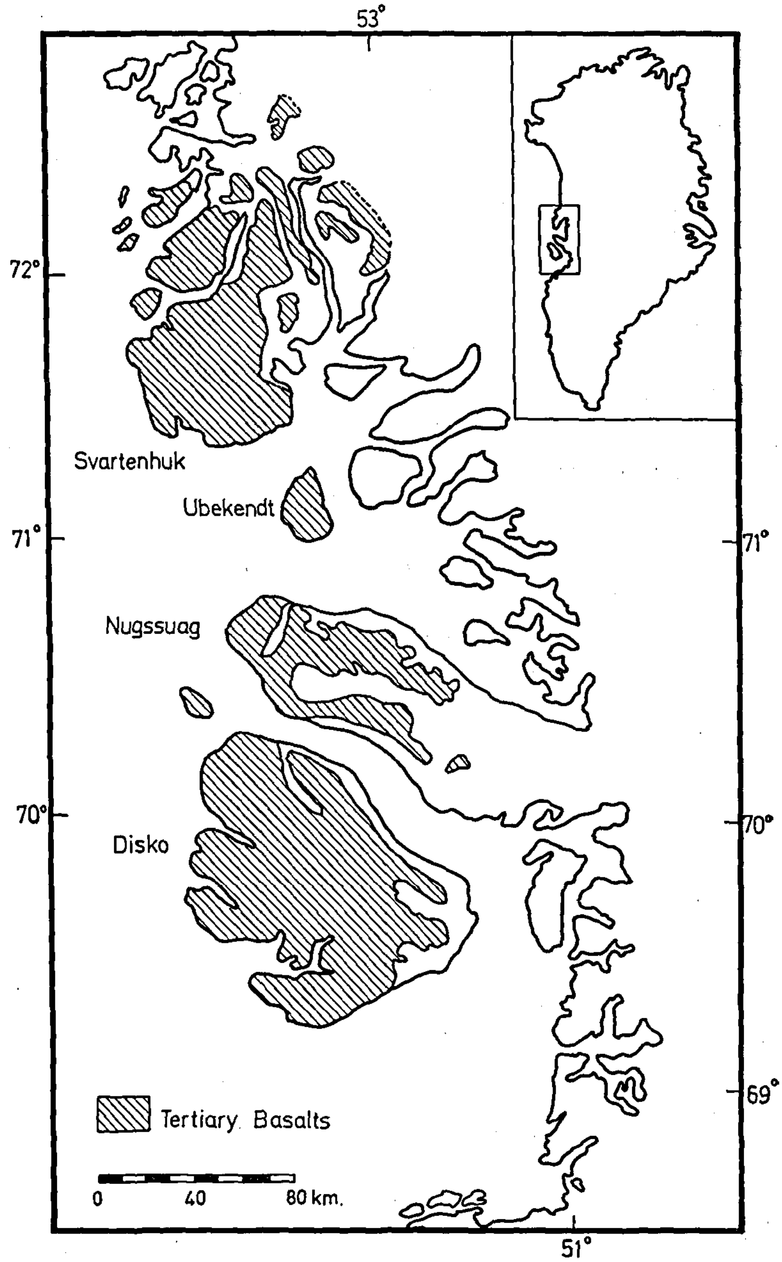

Fig. 1. Outcrops of Lower Tertiary bassalts in West Greenland. (after Henderson, 1969).

this way the samples are probably oriented to an accuracy of 2–3°. Two cylindrical cores 2.5 cm in diameter were drilled from each of some 200 hand samples using a non-magnetic drill in the laboratory; all cores were then sliced to provide one 2.5 cm high specimen per core.

The direction and intensity of magnetization of each of these specimens were measured using an astatic magnetometer beneath which the specimen was rotated to reduce effects of possible inhomogeneities (Collinson, 1970). The susceptibility was determined using a bridge (modified from Collinson et al. 1963). At least three pilot specimens were chosen at random from each site for stepwise demagnetization in alternating magnetic fields (Creer, 1959) using peak values of 85, 170, 255, 338, 507, 675 and 845 Oersted ($x10^3/4\pi Am^{-1}$), the direction and intensity for magnetization being measured after each successive treatment. In general, the result of the alternating field demagnetization showed that the within site scatter decreased until the 170 Oersted ($x10^3/4\pi Am^{-1}$) demagnetization level was reached, after which it began to increase; hence all the remaining specimens were treated in alternating magnetic fields of 85 and then 170 Oersted ($x10^3/4\pi Am^{-1}$) peak value in order to reduce the effect of low coercivity components. The directions of remanence were averaged (Fisher, 1953) giving unit weight to specimens to obtain sample mean directions, and combining sample directions to obtain site mean directions. The mean intensities and susceptibilities for each site were determined assuming a log-normal distribution (Tarling, 1966a). Thermomagnetic analysis of one to three specimens per site were later carried out on either a manual or automatic translation balance (Creer & de Sa, 1970).

Results

Intensity and Susceptibility

The average initial intensity of remanent magnetism was high, geometric site mean 12.19 gauss ($4\pi x10^{-4}Wbm^{-2}$), with somewhat higher intensities occurring within the lavas than the intrusives (table 2). The susceptibilities were of similar magnitude to the intensity, geometric site mean 11.92 gauss oersted $^{-1}$, but were lower in the lavas than in the intrusive. The lavas were therefore characterised by much higher Q ratios, being well in excess of 1.5 while most intrusive sites had Q values below 1.0; the geometric mean of the intrusive sites being 0.66.

On demagnetization, the intensities of remanence of the intrusive samples dropped by almost half in 85 Oersted ($x10^3/4\pi Am^{-1}$) peak alternating field and to slightly over one third of their initial intensity in 170 oersted

Table 1. Average stable directions and stability indices for each site.

Site	No. of Pilot Specimens	Decl.	Incl.	c. s. d.	Stability Index
Lavas					
L1	3	97	− 53	5	35.7
L2	5	128	− 66	8	18.8
L16	6	109	− 64	22	11.0
L26	3	159	− 73	6	4.9
L90	2	130	− 70	3	41.6
L176	2	106	− 43	44	7.4
Intrusives					
P2	3	131	− 66	3	6.1
P3	2	148	− 47	6	14.6
M23	2	256	+ 56	6	37.5
M64	2	240	+ 64	6	10.9
M161	3	203	+ 9	24	5.0
T1	3	112	+ 13	45	2.2
T24	2	196	− 29	10	2.6
T25	3	151	− 29	80	2.7
T23	3	107	+ 23	32	4.7
M1	3	167	+ 52	49	4.2
Q193	3	135	− 40	59	6.1
T22	3	223	− 8	15	1.8
T21	3	272	+ 34	73	1.8
M34	3	150	− 2	27	1.7
B80	4	190	− 11	62	3.4
M140	2	89	+ 10	65	4.1
M125	3	173	− 19	67	3.6
P1	3	221	− 29	67	1.4
Q1	3	259	+ 33	80	2.4
M11	2	299	+ 25	90	3.1
T94	3	160	− 7	49	3.5

Decl. and Incl. are the mean declination and inclination of the most stable direction isolated during alternating magnetic field partial demagnetization and c. s. d. is the circular standard deviation of these directions about their mean. The average stability index is the geometric mean value.

$(x10^3/4\pi Am^{-1})$ peak fields. In contrast, the average initial intensity of lava samples decreased by only 4 % at 85 and 20 % at 170 oersted $(x10^3/4\pi Am^{-1})$.

The lavas, therefore, are characterized by lower susceptibility, higher initial remanence and also a much higher remanence after demagnetization than the intrusive rocks.

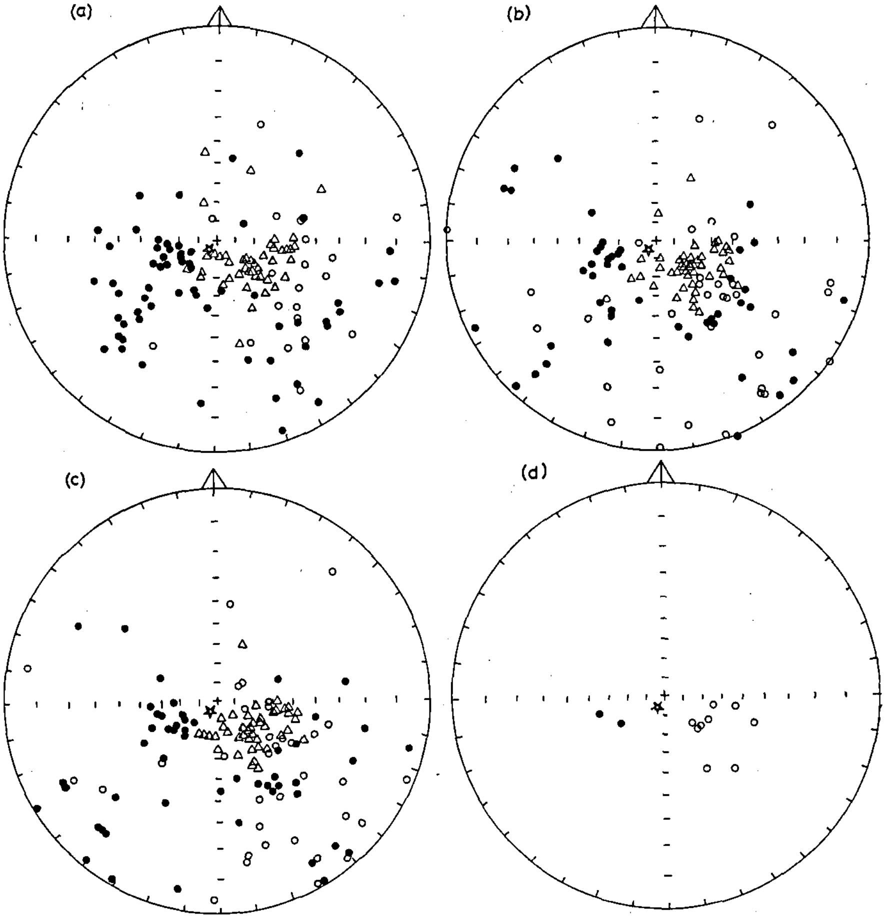

Fig. 2. Stereographic projections of directions of remanence in samples. (*a*) initial, (*b*) 85 and (*c*) 170 oersted ($10^3/4\pi Am^{-1}$); the lava directions are shown as triangles, (*d*) Directions of most stable remanence for pilot specimens with a stability index (Tarling & Symons 1967) greater than 5.0 (= high stability). Open symbols correspond to upward inclinations, solid to downward, positive inclinations. Present geomagnetic field direction is starred.

Demagnetization of Pilot Specimens

Between two and six pilot specimens were taken from each site and subjected to incremental alternating magnetic field demagnetization up to 840 peak oersteds (table 1 and fig. 2). The behaviour of the specimens was variable. Most pilot specimens showed a rapid decrease in intensity and scattered directions over the range of applied fields. Pilot specimens from sites in lavas and a few intrusives showed a much slower decrease in intensity and the directions remained more constant. In these more stable sites, the most stable

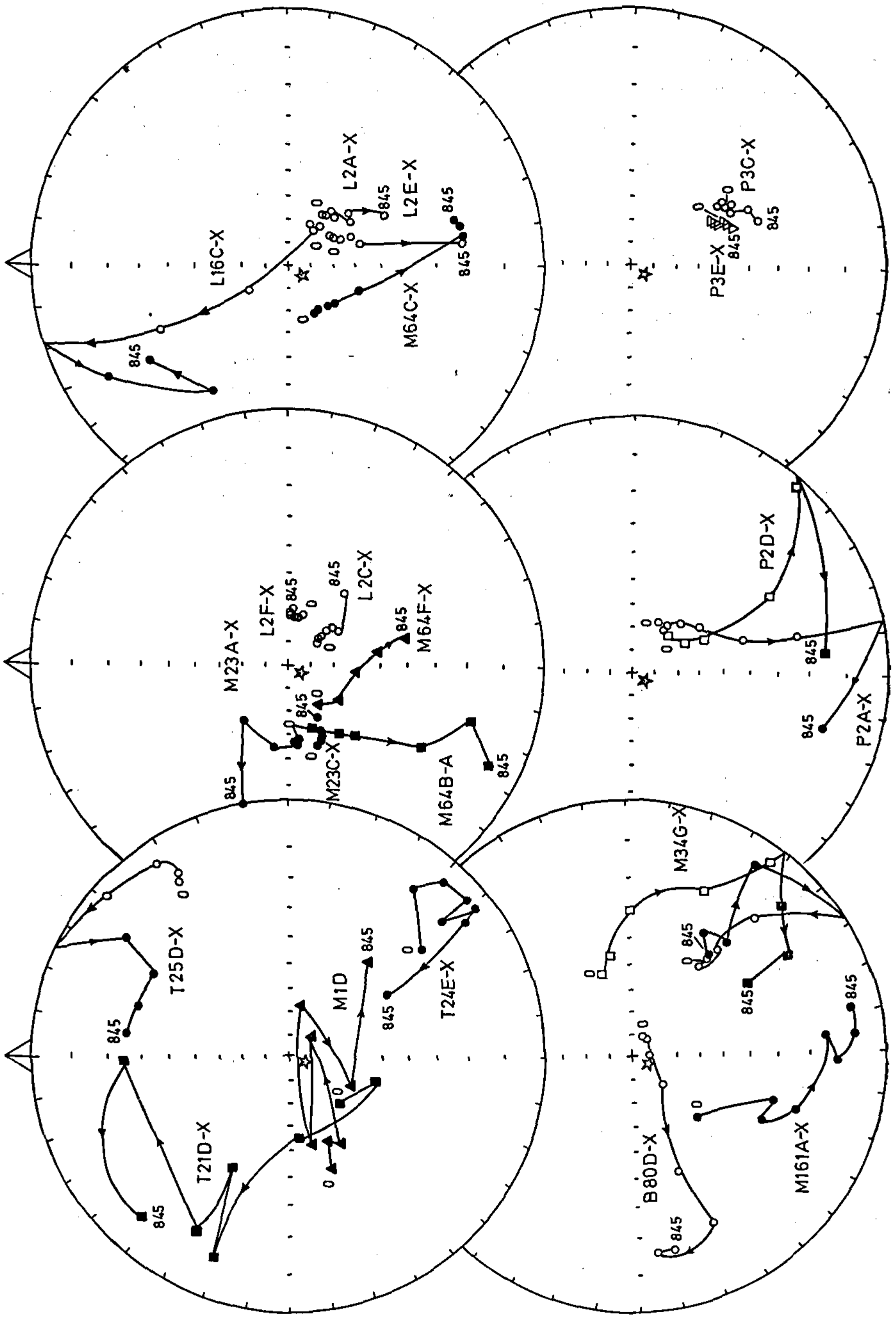

Fig. 3. Direction changes during alternating magnetic field demagnetization. The changes of direction are shown from 0 to 85, 170, 255, 338, 507, 675 and 845 (peak) oersted ($10^3/4\pi Am^{-1}$). Lavas carry the prefix L. Present geomagnetic field direction is starred.

direction was isolated in the region of 170 oersted ($x10^3/4\pi Am^{-1}$) (peak) and there was some indication that the scatter in other pilot specimens was slightly less in that region. An analysis of stability (Tarling & Symons, 1967) showed that the lavas and some dykes had a high stability index (table 1 & fig. 2) and the whole collection was then demagnetized at peak fields of 85 and 170 oersted ($x10^3/4\pi Am^{-1}$) in order to remove the viscous components of remanence.

(c) *Directions of Remanence*

The initial directions of remanence were very scattered and no clear grouping existed within them, although most directions were southerly. After partial demagnetization at 85 and 170 oersted ($x10^3/4\pi Am^{-1}$) (peak), most directions of remanence changed radically, although generally southerly and steep directions still persisted. Eight of the sites, however, showed little change in directions of remanence at successive fields and these were all characterised by south-easterly declinations with moderately steep upward inclinations (shown as triangles in fig. 3).

Thermomagnetic analysis

At least one specimen per site was chosen for thermomagnetic analysis. Although no distinct Curie points were distinguishable below 350° C, about half of the specimens showed some inflections. Most of the remainder had distinct Curie points between 500 and 530 ° C, corresponding to a solid solution of 16–18 % ilmenite in magnetite. There appears to be no correlation between the thermomagnetic properties, stability of remanence or mode of cooling (intrusive or extrusive), but all curves were irreversible suggesting physico-chemical changes during the heating process.

Discussion

Stability of remanence

Most of the intrusive rocks showed very poor stability to partial demagnetization and sample directions were very scattered at 170 oersted ($x10^3/4\pi Am^{-1}$) peak alternating field. The lavas showed much geater stability and smaller within- and between-site scatter of directions. It is considered, therefore, that the remance isolated in the samples of lava at 170 oersted ($x10^3/4\pi Am^{-1}$) is a stable remanence, probably acquired at the time of extrusion. The mean of these directions isolated in these six sites (118°, –64.5°, $\alpha = 7$) is therefore though to be repensentative of the geomagnetic field direction in

Table 2. Site mean properties.

Site No.	No. of samples.	Initial					85 oersted ($10^3/4\pi$ Am^{-1})				169 oersted ($10^3/4\pi$ Am^{-1})					
		$\varkappa$	M	Decl.	Incl.	c. s. d.	M	Decl.	Incl.	c. s. d.	M	Decl.	Incl.	k	α	c. s. d.
LAVAS																
L1	6	8	94	98	−55	4	88	97	−56	4	73	97	−54	549	3	4
L2	5	9	28	102	−71	30	27	126	−70	9	23	126	−70	72	9	10
L16	6	24	46	106	−61	22	38	106	−63	22	24	108	−65	14	19	22
L26	6	1	2	199	−75	9	2	192	−77	15	2	184	−71	169	5	6
L90	3	5	29	123	−65	9	26	127	−66	6	23	128	−67	211	8	6
L176	6	12	9	124	−61	14	9	121	−58	13	8	119	−58	32	12	14
INTRUSIVES																
P2	6	35	144	123	−67	13	84	132	−67	4	35	129	−64	47	10	11
P3	6	4	5	148	−66	34	5	148	−54	6	5	147	−55	164	5	6
M23	6	4	10	254	60	7	7	253	60	7	4	248	60	180	5	6
M64	6	4	8	243	66	7	6	242	68	5	4	235	67	14	19	22
M161	6	18	10	223	29	12	4	213	20	22	4	214	20	19	18	19
T1	5	32	20	102	2	19	19	113	−10	14	11	115	−2	26	14	16
T24	6	32	20	143	23	14	16	139	−4	11	10	149	−12	5	33	36
T25	6	34	42	111	−59	31	28	106	−54	31	13	113	−51	4	37	40
T23	6	28	129	129	43	45	5	122	35	35	1	129	27	7	24	30
M1	7	28	9	212	60	20	5	142	50	23	4	142	46	17	17	20
Q193	6	10	11	119	−45	36	11	140	−58	36	8	121	56	9	44	27
T22	3	47	47	224	34	14	11	204	−40	22	10	221	−23	3	49	50
T21	6	39	53	198	74	21	10	179	55	28	5	197	60	9	23	27
M34	6	4	3	91	−40	52	1	125	−61	35	1	118	−60	4	54	42
B80	4	17	4	175	−26	68	3	155	−46	37	3	170	124	2	63	54
M140	4	27	14	134	−42	40	13	92	−41	58	10	91	−47	12	27	23
M125	6	20	4	154	11	48	3	165	−17	56	3	142	−7	4	45	42
P1	5	5	2	239	43	21	1	233	0	40	1	215	3	3	58	51
Q1	5	5	4	276	52	26	3	293	43	36	2	287	38	2	69	61
M11	6	7	1	160	87	49	1	116	63	57	1	114	66	2	71	62
T94	6	14	10	129	−31	61	8	143	−43	61	6	160	−20	2	71	62

$\varkappa$ is geometric mean suspectibility in Am^{-1} T^{-1} × 10^3 and M is the geometric mean intensity in Am^{-1} × 10^{-1}. Decl. and Incl. are the site mean declination and inclination, and c. s. d., k and α are the circular standard deviation, estimate of precision (Fisher, 1953) and radius of the cone of 95 % confidence associated with the mean direction at 0, 85 and 170 oersted (× $10^3/4\pi Am^{-1}$) peak alternating magnetic fields calculated giving equal weight to each sample observation.

West Greenland in Paleocene times (about 65–70 million years ago).

There is some stability in a few of the intrusive rocks which appear to reflect both normal and reversed fields existing during their intrusion, but unfortunately the general stability is not adequate for the recognition of any representative field direction. Clearly further work in this region should be concentrated on the extrusive rocks for the most efficient determination of the average geomagnetic field direction during this period.

Table 3. Palaeomagnetic pole determinations for Lower Tertiary rocks in the North Atlantic Region.

	No. of sites	Pole Position		Errors		Reference
		N	E	dm	dp	
West Greenland lavas	6	54	208	18	15	–
Cape Dyer, Baffin Is.	5	83	305	12		Kristjansson & Deutsch (1971)
South Disko	37	62	191	9	8	Kristjansson & Deutsch (1971)
East Greenland lavas	28	63	174	14	11	Tarling (1966)
Faeroe Islands	253	77	171	3	2	Tarling (1970)
British Tertiary*	(16)	77	161	(6)	(5)	–

* Mean of a variety of published results, see Tarling (1970).
dm and dp are the axes of an ellipse of 95 % confidence about the mean pole position.

Comparisons with other data

Results from other regions can only be compared by the use of mean palaeomagnetic pole positions (table 3) because of the spatial variation of the geomagnetic field. Comparisons with data from Disko Island and Cape Dyer have been discussed by Kristjansson & Deutsch (1971) and clearly the differences between the pole positions determined for these areas reflects partially age differences but mainly the low statistical reliability of the Cape Dyer and Ubekendt Ejland samples. The data for Disko and the East Greenland Tertiary basalts are statistically identical confirming their contemporaneity. These two observations differ from those of the Faeroes and Britain because of the subsequent development of the Norwegian Basin (Tarling, 1966b).

Conclusions

The intrusive rocks are almost entirely unstable or unreliable so that the only palaeomagnetic directions which can be attributed to the Paleocene Earth's magnetic field are found in six lavas. The data are insufficient to establish the presence or absence of age differences between these rocks and other rocks of similar age in the North Atlantic. Both palaeomagnetic and radio-active age estimates, however, are consistent with observation that most igneous rocks of the North Atlantic Igneous Province (excluding Iceland) were erupted during a single reversed polarity period which only lasted some 5 million years or less. Further palaeomagnetic work, particularly on extrusive rocks, must be undertaken before such age differences can be established.

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Dansk sammendrag

Forfatterne påviser, at paleocæne intrusiver på Ubekendt Ejland er magnetisk ustabile, medens seks lavastrømme – omkring 64 mill. år gamle – gav stabile magnetiske udsving svarende til en polposition 54 nord og 152 vest. De palæomagnetiske og radiometriske bestemmelser er ikke tilstrækkeligt nøjagtige til at skelne aldersforskellene mellem disse bjergarter og bjergarterne fra den Nordatlantiske Basaltprovins; men en forskel på omkring 5 mill. år regnes for sandsynlig.

References

Clarke, D. B. 1968: Tertiary basalts of the Baffin Bay area. Unpublished Ph. D. thesis, Edinburgh.

Collinson, D. W. 1970: An astatic magnetometer with rotating sample. *Geophys. J.* **19,** 547–549.

Collinson, D. W., Molyneux, L. & Stone, D. B. 1963: A total and anisotropic magnetic susceptibility meter. *J. Sci. Instrum.* **40,** 310–312.

Creer, K. M. 1959: A. C. demagnetization of unstable Triassic Keuper Marls from S. W. England. *Geophys. J.* **2,** 261–275.

Creer, K. M. & de Sa. A. 1970: An automatic translation balance for recording variation of magnetization. *J. Sci. Instrum.* **3,** 74–75.

Drever, H. 1968: Geological results of four expeditions to Ubekendt Ejland, West Greenland. *Arctic,* **11,** 199–210.

Fisher, R. A. 1953: Dispersion on a Sphere. *Proc. roy. Soc. A,* **217,** 295–305

Henderson, G. 1969: Oil and gas prospects in the Cretaceous-Tertiary basin of West Greenland. *Rapp. Grønlands geol. Unders.* **22,** 63 pp.

Kristjansson, L. G. & Deutsch, E. R. 1971: Magnetic properties of rock samples from the Baffin Bay Coast. Offshore Symposium, *Geol. Surv. Canada, paper* **71–23** (in press).

Rosenkrantz, A. & Pulvertaft, T. C. R. 1969: Cretaceous-Tertiary stratigraphy and tectonics in northern West Greenland. *Mem. Amer. Ass. Petrol. Geol.* **12,** 883–898.

Tarling, D. H. 1966 a: The magnetic intensity and suspectibility distributions in some Cenozoic and Jurassic basalts. *Geophys. J.* **11,** 423–432.

Tarling, D. H. 1966 b: The palaeomagnetic properties of some Tertiary Lavas from East Greenland. *Earth Planet. Sci. Letters,* **3,** 81–88.

Tarling, D. H. 1970: Palaeomagnetic Results from the Faeroe Islands. *In* Runcorn, S. K. (ed.): *Palaeogeophysics,* 193–208. London: Academic Press.

Tarling, D. H. & Symons, D. T. A. 1966: A stability index of remanence in palaeomagnetism. *Geophys. J.* **12,** 443–448.