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Palaeomagnetism of three dyke swarms in Nansen Land, north Greenland (83° N)

N. Abrahamsen[1], H-J. Bengaard[2], J.D. Friderichsen[2] & R. Van der Voo[3]
[1] *Department of Earth Sciences, Aarhus University, DK-8200 Aarhus N, Denmark;* [2] *Geological Survey of Greenland, Øster Voldgade 10, DK-1350 Copenhagen, Denmark;* [3] *Department of Geological Sciences, University of Michigan, Ann Arbor, MI 48109-1063, U.S.A.*

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Abstract

Three basic dyke swarms of post-Ellesmerian (post-Early Carboniferous) age in Nansen Land (83° N, 43° W) are still not dated numerically, but cross-cutting relationships show Group 1 to be older than Group 2, while Group 3 is the freshest and likely the youngest. Group 1 (the most northerly swarm) strikes N-S; Group 2 NW-SE, and Group 3 (the most southerly swarm) E-W. From more than 200 dykes 234 specimens from 28 sites were investigated palaeomagnetically. Group 1 dykes show unexpected shallow inclinations with a cleaned mean direction of (Dm, Im) = (151°, −5.8°), N = 7, k = 18.5, α_{95} = 13.9°. They show hydrothermal alterations, some remagnetization by lightning, and the low inclination indicates a low palaeo latitude. The palaeopole is (Plat, Plon) = (8.9° S, 14.0° W) with (dp, dm) = (7°, 14°), and is close to the North American Early Carboniferous mean pole, suggesting a syn- or early late-tectonic dyke injection. The polarity is reverse.

Groups 2 and 3 of presumed Cretaceous or Tertiary age show dominantly normal and reverse polarities, respectively. Their mean directions per polarity are well grouped, with (Dm, Im) = (−30.6°, 76.7°), n = 13, k = 191.4, α_{95} = 3.9°, and (Dm, Im) = (133.4°, −76.7°), n = 10, k = 87.5, α_{95} = 5.9°, respectively. They are antipodal within 95% significance, and combining both swarms gives (Dm, Im) = (−37.5°, 76.8°), n = 23, k = 124.3, α_{95} = 2.7°, corresponding to a mean pole of (Plat, Plon) = (70.0° N, 185.1° E) with (dp, dm) = (4.7°, 5.0°), for which the spline of Late Cretaceous-Tertiary poles for all Greenland indicates a palaeomagnetic age of 57 ± 10 Ma. This pole (in present-day coordinates) is very close to the Late Cretaceous North American pole, in accordance with the fact that Greenland belongs to the North American craton, and that the two younger swarms are essentially postdating the opening of Baffin Bay.

Introduction

Greenland is a big island, covering latitudes from 60° to 83° N. It may even be considered a subcontinent, the area being 2.17 million km^2 (Figure 1). The central ice-cap covers 84% of the area, but still some 342 000 km^2 are left uncovered by the ice along the coastal areas, which may vary in width between 0 and 200 km. Most of the geological evolution of the Earth is represented in different parts of Greenland (Escher & Stuart Watt 1976), and some of the oldest rocks known on Earth are found in SW Greenland (the Isua Complex, some 3.7×10^9 years old).

Considering the size of Greenland and the time scale covered, the only 50 palaeomagnetic papers published so far can hardly give more than a rather patchy palaeomagnetic record. Based on published palaeomagnetic results (extracted from the Global Palaeomagnetic Data Base, cf. Lock & McElhinny 1991), the palaeolatitudinal and rotational changes of Greenland during the last 600 Ma may be roughly sketched as shown in Figures 2a and b.

Obviously the scatter is considerable even in the younger Mesozoic and Tertiary parts, and there are wide time gaps in derived apparent polar wander (APW) paths between 250 and 500 Ma, as well as in

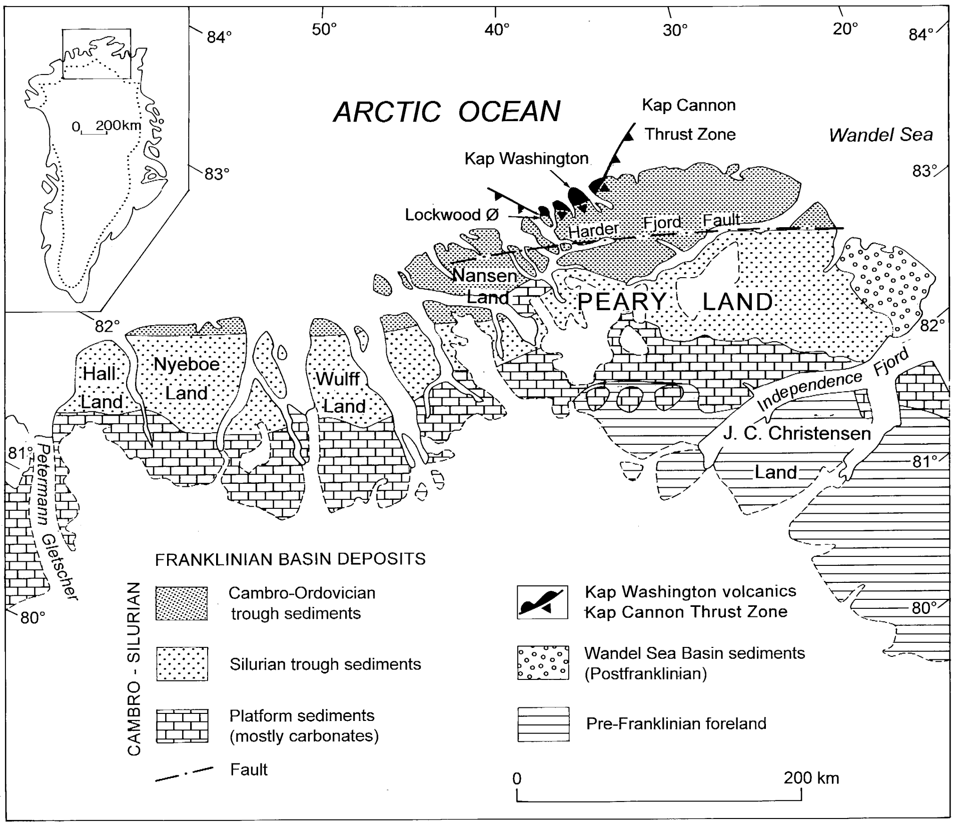


Figure 1. Geologic map of central north Greenland, with index map top left. North of the Franklinian Basin deposits (Cambro-Silurian platform and trough sediments) the North Greenland Fold Belt occurs, including Nansen Land, with the dykes investigated. The Lower Tertiary Kap Washington volcanics are situated in the north. Dashed line indicates outline of icecap.

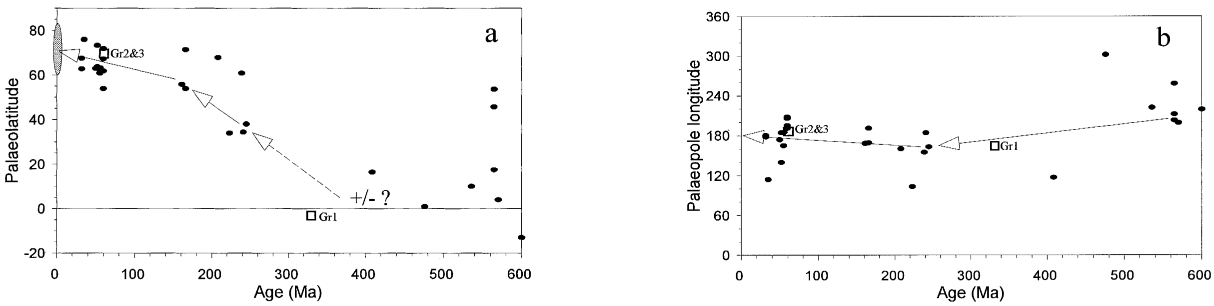


Figure 2. Palaeolatitude (a) and palaeopole longitudes (b) for Greenland, as estimated from Phanerozoic palaeomagnetic data from all regions in Greenland. Dots are data extracted from the data base of Lock & McElhinny (1991); squares are new data for dyke Groups 1 to 3. Oval at 0 Ma is the latitudinal range of present-day Greenland (60 to 83.5° N). The possible equatorial cross-over of Greenland in the Early Palaeozoic (shown as $\pm$?) is unresolved due to incomplete knowledge of the polarity scale beyond 250 Ma. Combining the Greenland data with the APW path of the North American craton, however, it becomes most likely that Greenland moved over the equator in Silurian-Devonian time (Abrahamsen 1991, Stearns et al. 1989).

older segments. As the polarity is not well constrained before 200 Ma, the hemispherical position of Greenland cannot be resolved with Greenland data alone. Prior to the opening of Baffin Bay in Middle Cretaceous to Early Tertiary time, however, Greenland may be considered as part of Laurentia, and hence a general

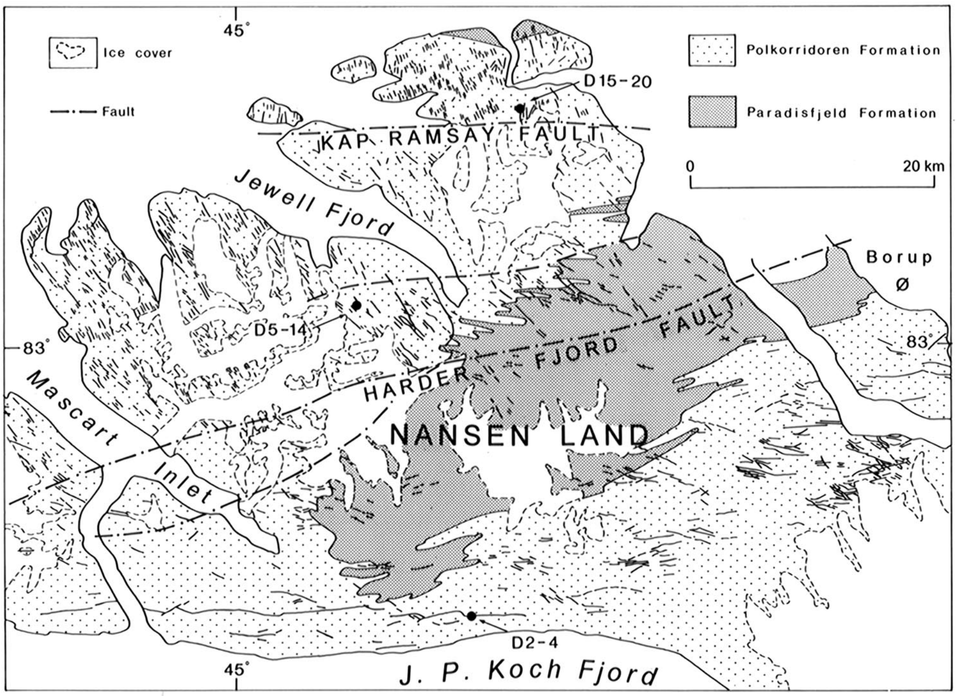


Figure 3. Geology of Nansen Land. Heavy lines (–·–) are major faults. The dykes are indicated as thin lines (not all dykes are shown). Dyke sampling areas are shown with dots, the sites clustering in three groups (D2–4, D5–14, and D15–20). The oldest dykes (Group 1, trending N-S) dominate north of the Kap Ramsay Fault, the dykes of intermediate age (Group 2, NW-SE) dominate between the Harder Fjord Fault and Kap Ramsay Fault, and the youngest dykes (Group 3, E-W) dominate south of the Harder Fjord Fault.

and more detailed palaeomagnetic record for Greenland may be obtained by combining with the more extensive data of the North American craton (e.g. Van der Voo 1993, McEnroe 1996).

Most of the palaeomagnetic information from within Greenland originates from investigations of late Archean, early Proterozoic and Tertiary formations in SW Greenland and from Early Tertiary volcanics in central east Greenland. From north Greenland, only a few magnetic results of Proterozoic, Silurian and Pliocene rocks have been published so far (Abrahamsen & Marcussen 1980, 1986, Abrahamsen & Van der Voo 1987a, b, Funder et al. 1985, Marcussen & Abrahamsen 1983, Stearns et al. 1989).

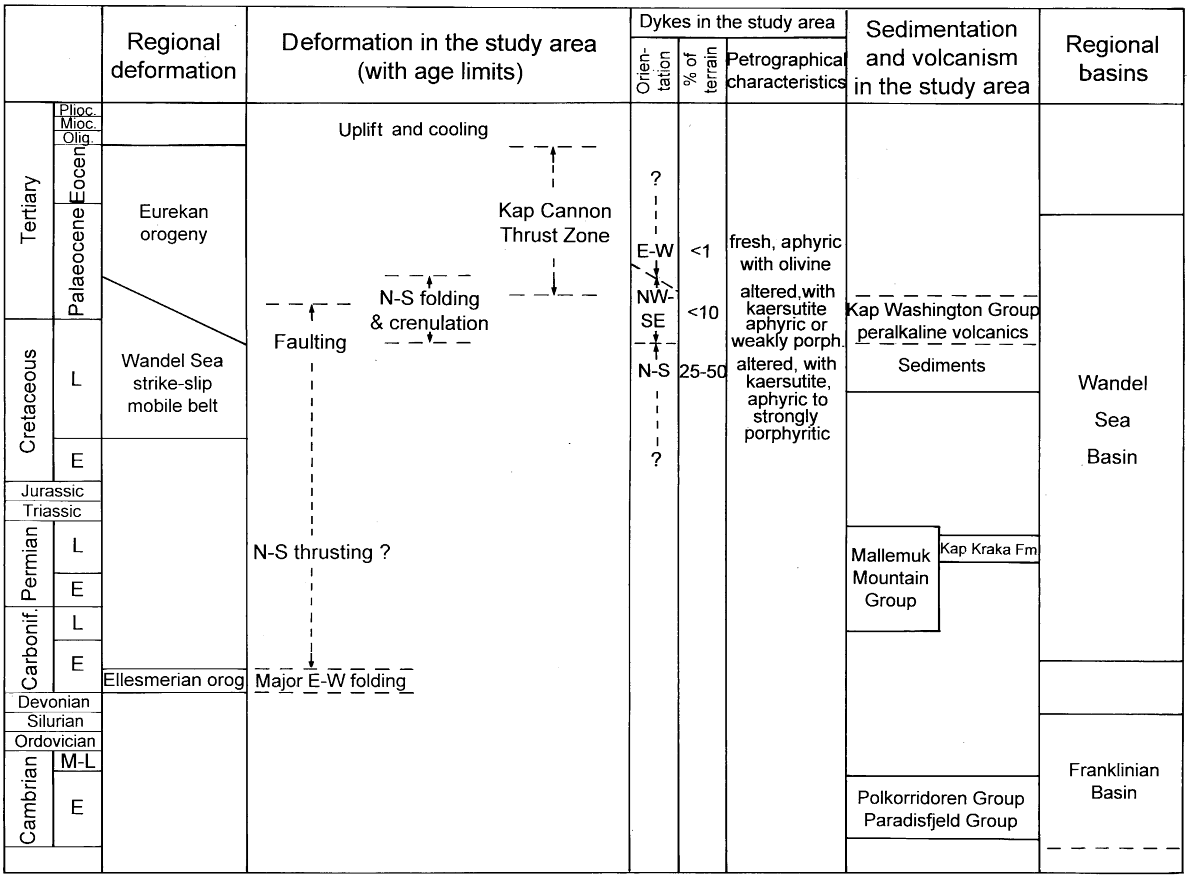
The purpose of the present communication is to present rock- and palaeo-magnetic results as well as related tectonic information of three Phanerozoic dyke swarms occurring in Nansen Land, north Greenland.

Geology of Nansen Land

Nansen Land is situated in the northern part of the North Greenland Fold Belt, a segment of the Palaeozoic Franklinian Mobile Belt (Figure 3). Most of the North Greenland Fold Belt is developed on the side of the deep-water trough of the Franklinian Basin, where more than 6000 m of deep-water sediments were deposited from the Early Cambrian to the late Silurian (Higgins et al. 1991a, b). The fold belt suffered deformation and metamorphism during the Ellesmerian orogeny, dated to the Early Carboniferous (Soper & Higgins 1991a, Springer & Friderichsen 1994). Volcanism of Late Carboniferous age is known from the Canadian Arctic Islands. Table 1 summarizes the age relations between deformational episodes, sedimentation, volcanism and dyke intrusions as interpreted before this study.

In the Late Carboniferous, sedimentation was renewed in the area of the North Greenland Fold Belt. Shelf sediments of the Late Carboniferous to Permian Mallermuk Mountain Group are preserved in the Kap Cannon Thrust Zone (Stemmerik & Håkansson

Table 1. Summary of age relations between regional deformation, deformational episodes, sedimentation, volcanism and dyke intrusions in Nansen Land (N-S dykes as interpreted before this study).



1991), together with Late Cretaceous sediments and a thick pile of peralkaline volcanics known as the Kap Washington volcanics (Håkansson et al. 1991, Brown & Parsons 1981, Brown et al. 1987). Cretaceous sediments also occur locally in the Harder Fjord Fault Zone, together with a small area of Late Permian alluvial-fan conglomerates (the Kap Kraka Formation). Major northward thrusting took place in the Kap Cannon Thrust Zone during the Early Tertiary (Soper & Higgins 1991b).

In Nansen Land the country rock is a $>$ 3000 m-thick pile of Early Cambrian deepwater sediments, subdivided into the lower, calcareous Paradisfjeld Group and the upper, siliciclastic Polkorridoren Group (Bengaard et al. 1987). During the Ellesmerian orogeny the sediments were tightly folded and metamorphosed in low to medium greenschist facies. In southern Nansen Land, hinge planes dip north at 80 to 85°, while they are north-vergent in northern Nansen Land, with hinge-plane dips above 60° (Friderichsen & Bengaard 1985, Bengaard et al. 1987). The Ellesmerian folding is the major deformational event in Nansen Land and provides the structural background for the later episodes of dyke intrusion and deformation described below.

Three post-Ellesmerian deformational events are known from Nansen Land: an episode of northward thrusting, an episode of faulting, and an episode of folding along north-trending fold-hinge planes. In post-Ellesmerian times Nansen Land was also intruded by the three groups of dyke swarms investigated (Figure 3): a N-S trending swarm (Group 1), a NW-SE trending swarm (Group 2), and an E-W trending swarm (Group 3).

The earliest post-Ellesmerian deformation was a northward thrusting and shearing, strongest along the trace of the later Harder Fjord Fault. Here it gave rise to thick bands of south-dipping limestone mylonites, and reoriented the Ellesmerian folds, which became strongly overturned towards the north. It is not known from northern Nansen Land. The age of the thrusting is constrained to between Early Carboniferous and Late Cretaceous. The Kap Kraka conglomerates indicate Late Permian tectonic activity in the Harder Fjord Fault Zone, the thrusting being tentatively correlated with this activity.

The second deformation gave rise to large, E-W trending faults, generally with northern downthrow. The Harder Fjord Fault cuts the limestone mylonites, and faults are intruded by dykes petrographically similar to the NW-SE dyke swarm. The fault dykes are somewhat brecciated and slickensided but generally not strongly deformed. Most of the fault movement apparently took place before the dyke intrusion. The faulting gave rise to some block rotation of small magnitude.

The third deformational event gave rise to a steep, NNW-SSE trending crenulation cleavage, which is known from all of Nansen Land. In SW Nansen Land it gave rise to a kilometre-scale box fold, which is cut by one of the E-W dykes, while the crenulation cleavage in northern Nansen Land crosses the N-S dykes as a jointing. The age relations to the faulting are not known.

The N-S dykes are restricted to northernmost Nansen Land and are limited by the Kap Ramsay Fault, which may have accommodated the horizontal expansion associated with the dyke intrusion (A. K. Higgins, personal communication). It is a very dense swarm, which frequently constitutes 20 to 50% of the exposures. In the field the dykes are resistant to weathering; they are aphyric to porphyritic, occasionally strongly porphyritic. Under the microscope they show strong hydrothermal alteration, but kaersutite can occasionally be identified among the dark minerals. The swarm can be followed outside Nansen Land eastwards towards Lockwood Ø. In this area Carboniferous and Cretaceous sediments also occur, but no cross-cutting relationships have been observed. Volcanic material occurs in the sediments (which underlie the Kap Washington volcanics), mainly in the form of sills (Soper & Higgins 1991b; A.K. Higgins personal communication).

The NW-SE dykes occur in northern and central Nansen Land. Towards the north they locally form up to 10% of the exposures, but towards the south they are more scarce. The trend of the dykes is more variable than within the N-S swarm, and the NW-SE direction is only an average. They intrude the E-W faults (see above), and in one exposure a NW-SE dyke is observed cutting a N-S dyke. The dykes are aphyric to weakly porphyritic and weather easily to a brown grit. Under the microscope they show less hydrothermal alteration than the N-S dykes, and they frequently carry kaersutite.

The E-W dykes occur scattered in southern Nansen Land, where individual dykes in places may be followed for more than 10 km. They are aphyric and weather into a brown grit. Under the microscope they are fresh and carry olivine, but no kaersutite. An E-W dyke cuts a large, steep N-S box fold in SW Nansen Land.

E-W and NW-SE trending dykes are also known from Peary Land east of Nansen Land, but relations to the dykes of Nansen Land are unknown.

No radiometric dates are yet published of the Nansen Land dykes. An attempt to date the dykes in Peary Land with K/Ar was unsuccessful due to excess argon (Dawes & Soper 1971). For general reasons the N-S dykes in the area south of Lockwood Ø have usually been related to the Late Cretaceous Kap Washington volcanics (Brown et al. 1987), and geologically it seemed plausible that the volcanics and the three dyke swarms are all part of a single alkaline magmatic province, active around the Cretaceous-Tertiary boundary, and related to the onset of sea-floor spreading in the Labrador Sea (Chalmers & Laursen 1995). The NW-SE and the E-W dykes are not dated relative to each other, but the latter dykes have been considered younger due to their fresher state.

To summarize shortly:

- The Group 1 dykes (N-S) cannot be older than Early Carboniferous (Ellesmerian orogeny).
- Group 1 shows hydrothermal alteration.
- Group 1 is cut by Group 2 dykes (NW-SE; age likely close to the Cretaceous-Tertiary boundary).
- Although numerous, Group 1 dykes have not been observed cutting Late Carboniferous or younger (Cretaceous) sediments.
- Early Carboniferous volcanism is known from the Canadian Arctic Islands.
- Group 3 dykes (E-W) are fresh, carry olivine, and cut a N-S box fold.
- Groups 2 and 3 are not dated relative to each other. The fresher state of Group 3 suggests that this group is the youngest.

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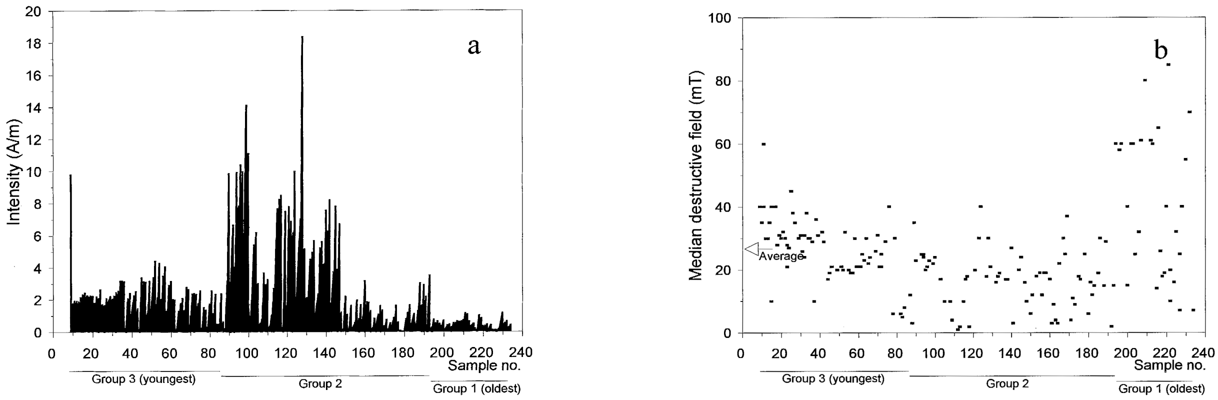
Figure 5. Alternating-field (AF) and thermal demagnetization of Nansen Land dyke samples. Stereograms (solid/open signature shows positive/negative inclination), intensity decay curves (units of 0.1 mT, or °C) and orthogonal Zijderveld plots (solid/open signature is horizontal/vertical projection, west is up). Top) *Group 1*: AF demagnetization of two samples (site D18 specimen 219A and site D19 specimen 222B). Three magnetic components are visible in either the Zijderveld diagram (219A) or the intensity decay curve (222B). The remanence directions of both samples migrate towards a gently dipping SSE to S direction, and both appear to have been somewhat remagnetized (by hydrothermal alterations or lightning). Center) *Group 2*: AF (137C) and thermal (141AS) demagnetization of two samples of normal polarity (site D9-1 specimen 137C and site D9-2 specimen 141). Apart from a low-coercive viscous component, presumably of recent origin, a well-defined linear migration of the primary TRM towards the origin is seen in both specimens. Bottom) *Group 3*: AF demagnetization of two samples of reverse polarity (site D2-2 specimen 36C and site D3 specimen 49A). A directionally stable univectorial migration of the primary TRM towards the origin is found in both specimens.



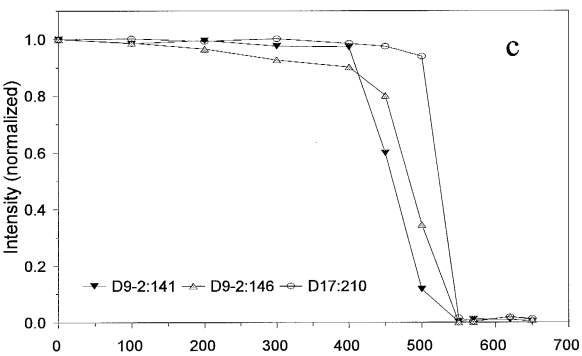


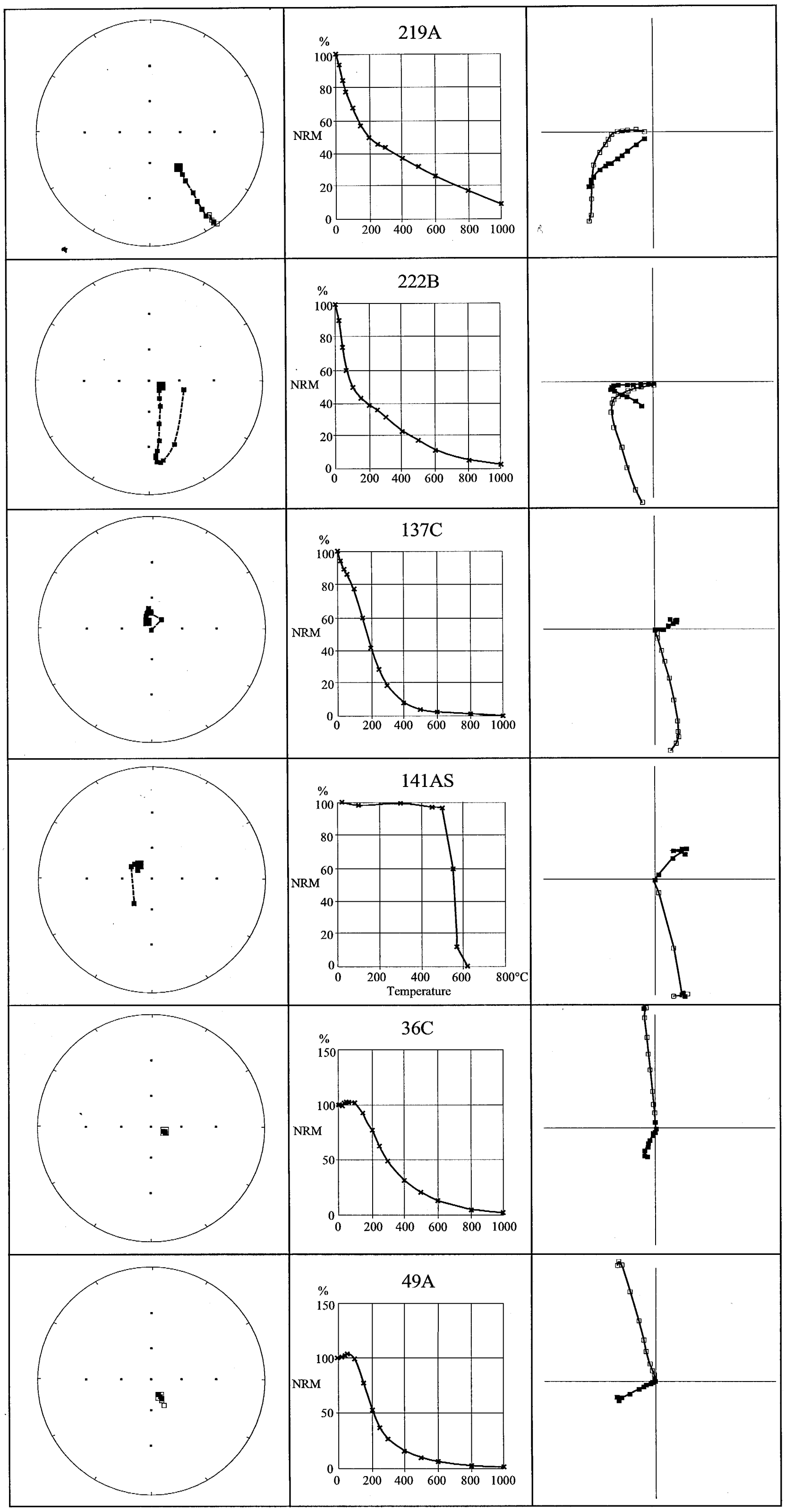
Figure 4. Rock-magnetic parameters. a) NRM intensities for all specimens investigated (Group 3: no. 9–87. Group 2: no. 88–193. Group 1: no. 194–234). b) Median destructive fields for all specimens investigated. c) Decay of remanent magnetization by thermal demagnetization for three Nansen Land samples. The dominating unblocking temperatures are just below 550 °C, indicating that the major remanence carrier is Ti-poor magnetite.

Magnetic results

From 20 dykes (29 sites) sampled, a total of 234 specimens from 97 cores have been investigated palaeomagnetically. The cores were drilled in the field by a portable, watercooled drill, the orientation being made by a sun compass. Later, standard specimens (22 mm × 25 mm) were cut in the laboratory. The remanent magnetizations were measured on a Molspin Ltd. spinner magnetometer, and the stepwise alternating-field (AF) demagnetizations in between were made up to peak fields of 100 mT. Also some thermal demagnetizations were performed to test the rock-magnetic properties.

Magnetic parameters of the natural remanent magnetization (NRM) are summarized in Figures 4a to c. For Group 3 (specimens 9–87), the NRM intensities are typically around 2 to 3 A/m. For Group 2 (specimens 88–193), they are scattered between 2 and 18 A/m, and for Group 1 (specimens 194–234) they are rather low, typically between 0.5 and 1 A/m. The bulk magnetic susceptibility varies mostly between 1 and 4×10^{-2} SI-units (see also Abrahamsen & Van der Voo 1987a, b), the Q-ratio (Königsberger ratio) being between $^1/_2$ and 3, with most values close to 1.

Median destructive fields (Figure 4b) vary mostly between 10 and 40 mT, but values down to 1 mT are found in Group 2, and scattered low as well as high values in Group 1. Some experiments with decay of the remanent magnetization by thermal demagnetization



219A
222B
137C
141AS
36C
49A
%
NRM
Temperature
800°C

Table 2. Nansen Land: Site means, Fisher statistics and palaeomagnetic poles. Site coordinates (Lat, Long), number of specimens measured (n_1) and included (n) in the mean calculations, cleaned characteristic site-mean directions (Decl, Incl), Fisher statistics (k, α_{95}) and apparent pole positions (Plat, Plon) with semi-axes of 95% ovals (dp, dm); (for further statistical specifications cf. Fisher 1953 or Butler 1992).

Dyke swarm: strike & age	Site	Lat N	Long E	n_1	n	Decl (°)	Incl (°)	k	α_{95} (°)	Plat N	Plon E	dp (°)	dm (°)	Polarity
Group 1: N-S	D15	83.18	–43.33	8	8	149.0	-3.2	27.4	10.8					R
Oldest	D16	83.18	–43.33	6	7	139.8	–13.2	19.8	13.9					R
	D17	83.18	–43.33	6	6	144.9	–27.7	33.6	11.7					R
	D18	83.18	–43.33	8	8	153.4	9.6	25.2	11.2					R
	D19	83.18	–43.33	8	8	164.2	22.2	17.4	13.6					R
	D20	83.18	–43.33	5	4	161.1	–15.7	16.0	23.7					R+N
	site mean				6	152.8	-4.8	16.0	15.6	–8.4	–15.1	7.8	15.8	R
	great circles			39		144.8	–11.6		7.4					R
	site mean of all				7	151.0	–5.8	18.5	13.9	–8.9	–14.0	7.0	14.0	R
Group 2: NW-SE	D5-1	83.02	–44.12	8	6	–29.5	75.9	272.3	4.1					N
Intermediate	D5-2	83.02	–44.12	9	8	–19.9	76.0	341.2	3.0					N
	D6	83.02	–44.12	10	9	–12.1	82.4	71.9	6.1					N
	D7	83.02	–44.12	8	9	–20.1	77.2	139.5	4.4					N
	D8	83.02	–44.12	6	5	–40.8	69.3	272.3	4.6					N
	D9-1	83.02	–44.12	10	10	–28.2	74.1	273.5	2.9					N
	D9-2	83.02	–44.12	9	8	–37.1	71.0	346.8	3.0					N
	D10n	83.02	–44.12	5	5	–44.3	75.5	418.3	3.7					N
	D10s	83.02	–44.12	6	5	–35.4	73.8	562.5	3.2					N
	D11n	83.02	–44.12	7	7	–16.8	78.3	58.7	7.9					N
	D11s	83.02	–44.12	4	4	154.4	–77.1	232.0	6.0					R
	D12	83.02	–44.12	8	6	179.2	–74.9	68.8	8.1					R/Dual polarity
	D13	83.02	–44.12	8	6	–34.5	71.9	127.4	6.0					N
	D14	83.02	–44.12	8	7	–34.7	78.9	227.6	4.0					N/Dual polarity
	mean				14	–28.5	75.7	321.5	3.0	68.9	172.9	5.0	5.5	N
Group 3: E-W	D2-1	82.80	–43.50	8	10	107.1	–74.1	288.6	2.8					R
Youngest	D2-2	82.80	–43.50	8	9	77.1	–74.8	361.3	2.7					R
	D2-3	82.80	–43.50	8	8	94.0	–77.2	497.6	2.5					R
	D2-4	82.80	–43.50	8	6	110.6	–75.9	245.2	4.3					R
	D3-1	82.80	–43.50	10	8	162.3	–76.4	136.9	4.8					R
	D3-2	82.80	–43.50	10	11	146.6	–74.5	212.6	3.1					R
	D3-3	82.80	–43.50	7	6	161.2	–72.4	151.8	5.5					R
	D3-4	82.80	–43.50	7	6	132.0	–68.7	173.0	5.1					R
	D4	82.80	–43.50	13	12	72.4	88.6	54.9	2.5					N
	mean (excl. D4)				8	125.3	–76.1	92.1	6.0	67.1	205.1	10.2	11.0	R
Group 1		83.18	–43.33		7	151.0	-5.8	18.5	13.9	–8.9	–14.0	7.0	14.0	R
Group 1 (in NA frame of reference)										–14.6	–31.4	7.0	14.0	R
Group 2 & 3 (All normal)		83.00	–44.00		13	329.4	76.7	191.4	3.9	70.4	176.5	6.7	7.2	N
Group 2 & 3 (All reverse)		83.00	–44.00		10	133.4	–76.7	87.5	5.9	69.0	195.8	10.2	11.0	R
Group 2 & 3 (All sites combined to normal polarity)					23	322.5	76.8	124.3	2.7	70.0	185.1	4.7	5.0	N+R
Group 2 & 3 (All samples combined to normal polarity)					171	321.5	77.5	69.3	1.3	71.1	187.1	2.3	2.4	N+R

are shown in Figure 4c. The dominating unblocking temperatures of all four specimens fall just below 550° C, indicating that the major carrier of remanence is Ti-poor titanomagnetite.

Six examples of demagnetization experiments are shown in Figure 5, two from each dyke group. These examples are characteristic and representative for the behaviour of the remanent magnetization for each group.

Group 1: The AF demagnetization of two samples (D18-219A and D19-222B) shows three magnetic components, which are visible in either the Zijderveld diagram (specimen 219A) or in the intensity decay curve (in specimen 222B coercivity spectra of three highly overlapping components are visible). The directions of both samples migrate towards a gently dipping SE or S direction by cleaning, and both may have

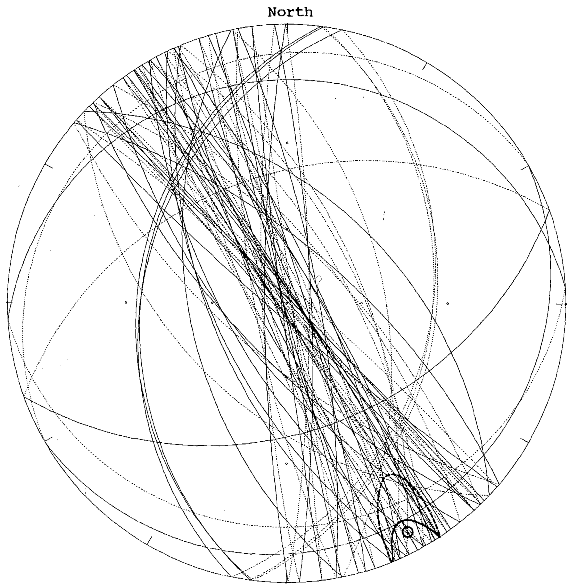


Figure 6. Great-circle trends from Group1 dykes (39 specimens) by AF-demagnetization. Although scattered, the great circles clearly define a magnetic cross-over direction around (D, I) = (145°, −12°).

been remagnetized due to hydrothermal alterations or to lightning.

Group 2: The AF (137C) and thermal (141AS) demagnetization of two samples of normal polarity (D9-1-137C and D9-2-141AS) show that, apart from a low-coercive viscous component, presumably of fairly recent origin, a well-defined linear migration towards the origin of the primary thermoremanent magnetization (TRM) is found in both specimens.

Group 3: The AF demagnetization of two samples of reverse polarity (D2-2-36C and D3-49A) shows a directionally stable univectorial migration of the primary TRM towards the origin in both specimens.

Table 2 lists the site coordinates, numbers of specimens measured (n_1) and included (n) in the mean calculations, cleaned characteristic site-mean directions (Decl, Incl), Fisher (1953) statistics (k, α_{95}) and apparent pole positions (Plat, Plon) with 95% ovals (dp, dm). The mean directions were determined by the principal component analyses (PCA) of Kirschvink (1980), using the program for interactive analysis of palaeomagnetic data (IAPD) by Torsvik (1986). Most younger dyke sites are of reverse, and most intermediate dyke sites of normal polarity. The polarity of the oldest dyke swarm (Group 1) is indeterminate in itself, as the stable remanence has a low inclination; two opposite stable directions being present in dyke D20. Comparing, however, with the apparent polar wander (APW) path of North America (see later), the polarity for this group obviously is reverse.

In contrast to Groups 2 and 3, Group 1 does not give an expected steep (either normal or reverse polarity) characteristic direction. In about half of the Group 1 specimens, the median destructive field (m.d.f.) is above 30 mT (Figure 4b). This may be related to the presence of hematite (Figure 4c) due to hydrothermal alterations, as noted earlier. The very steep (low-coercive) decay of the NRM of some of the specimens during the first steps of AF-demagnetization (0–10 mT), however, is also indicative of an isothermal remanent magnetization (IRM) of low coercivity, which may be due to lightning. Considering the topographical location of these specimens (sites D15 to D20, cf. Table 2), which were sampled along a narrow mountain crest, it is most likely that some of the dykes have indeed been partly remagnetized by lightning.

To illustrate further the complex behaviour of the dykes in Group 1, great-circle migrations of the remanence decay during AF demagnetization are shown in Figure 6. Although somewhat scattered, the crossovers of the great circles do define a magnetic mean with a low up-dip SSE-direction around (D, I) = (145°, −12°), α_{95} = 7.4°, in fair accordance with the cleaned high-coercive components (Dm, Im) = (152.8°, −4.8°), n = 6, α_{95} = 15.6 (cf. Table 2).

Cleaned mean directions of the three dyke groups are illustrated in Figure 7. For Group 1, characteristic magnetic components (PCA) of individual specimens, with maximum angular deviation (MAD) circles are indicated in Figure 7a. The directions are well grouped around a mean low-dip SSE direction, one dyke showing both polarities. Site means of Group 1 (6 sites, and the great circle mean) give (Dm, Im) = (151°, −5.8°), with n = 7, k = 18.5, α_{95} =13.9°, as illustrated in Figure 7b.

In Figure 7c the cleaned characteristic directions of 97 specimens of normal, and 74 specimens of reverse polarity from dyke swarms 2 and 3 are shown together, and in Figures 7d and e the site-mean directions of these swarms with their α_{95} circles of confidence are illustrated. The site mean direction (Table 2) for Group 2 is (Dm, Im) = (−28.5°, 75.7°), for Group 3 (Dm, Im) = (125.3°, −76.1°), and for the combined normal polarity of Groups 2 and 3 (Dn, In) = (−30.6°, 76.7°) with (n, k, α_{95}) = (13, 191.4, 3.9°) and (Plat, Plon, dp, dm) = 70.4°, 176.5°, 6.7°, 7.2°), while for the reverse polarity it is (Dr, Ir) = (133.4°, −76.7°) with (n, k, α_{95})

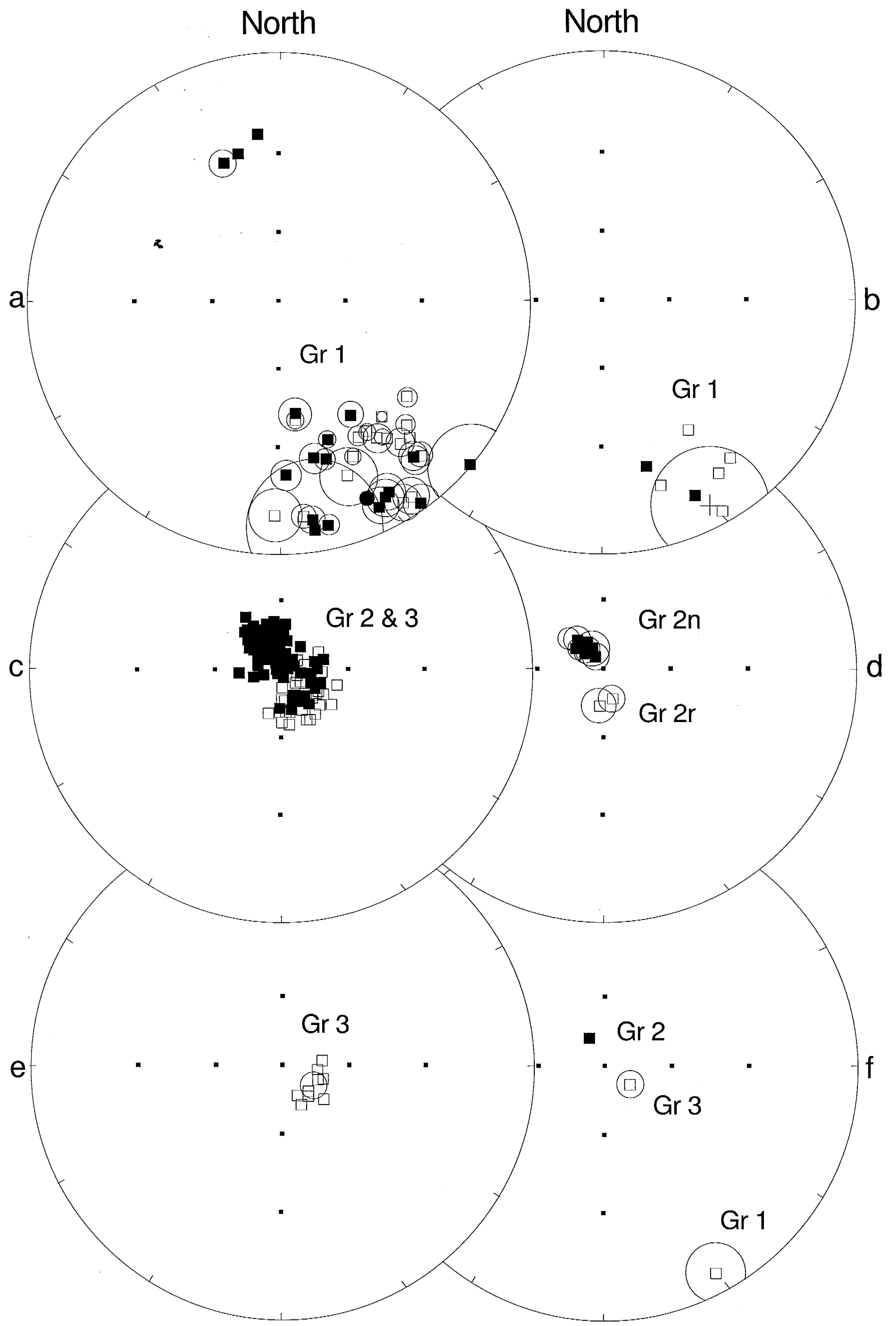


Figure 7. Cleaned mean directions. a) Characteristic magnetic components from principal component analyses (PCA) of individual specimens from Nansen Land, with maximum angular deviation (MAD) circles. The magnetic directions are gently dipping towards SSE, one dyke showing both polarities. Solid (open) signature indicates positive (negative) inclination (stereographic projection). b) Site means of Group 1 (6 sites, and the great circle mean), α_{95} = 13.9°. c) Cleaned characteristic directions of 97 specimens of normal (solid) and 74 specimens of reverse (open) polarity from Groups 2 and 3 (stereographic projection). The two clusters of opposite polarity are directionally indistinguishable (they pass the polarity test within 95% significance). d) Site-mean directions of normal (solid) and reverse (open) polarity of Group 2. Circles of α_{95} are also shown for each site mean (stereographic projecton). e) Site-mean directions of Group 3 (omitting dyke D4, which is of normal polarity). f) Overall mean directions of Group 1 (low inclination, reverse polarity), Group 2 (normal polarity) and Group 3 (reverse polarity), cf. Table 2.

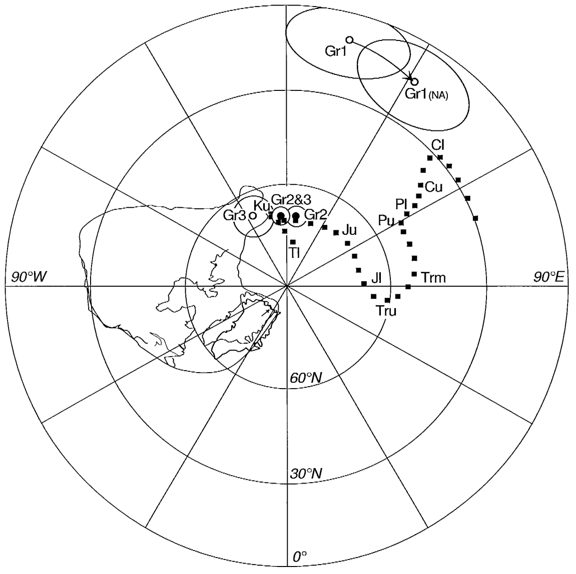


Figure 8. Laurentia, including Greenland (two positions: thick line present-day, thin line pre-Baffin Bay), and the post-Devonian spline of the apparent polar wander path for the North American craton (solid squares). The spline is calculated from data given in Van der Voo (1993: Table 5.1), using the GMAP program by Torsvik et al. (1990). The data used meet three or more palaeomagnetic reliability criteria (quality factor Q $>$ 3). The mean palaeomagnetic poles from north Greenland (Nansen Land) in present-day coordinates are labelled Gr1, Gr2, Gr3, and Gr2&3. The north Greenland younger mean pole Gr2&3 (in present-day coordinates) is very close to the North American pole Ku for the Late Cretaceous, which is in accordance with the fact that Greenland belongs to the North American craton, and that the younger dykes (Groups 2 and 3) of Nansen Land postdate the opening of Baffin Bay. In contrast to this, the older north Greenland pole Gr1, when rotated to the North American frame of reference in position Gr1(NA), gives a better fit with the North American spline for the Early Carboniferous (when closing Baffin Bay by the pre-anomaly-24 fit, rotating Greenland 18° clockwise around an Euler pole at 70.5° N and 94.4° W (Bullard et al. 1965)).

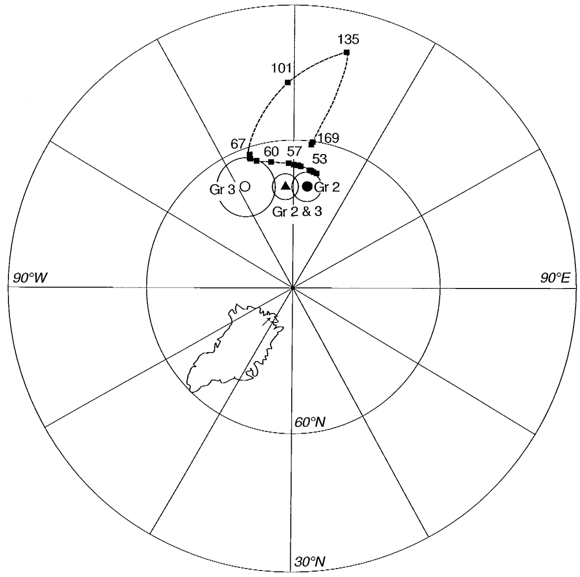


Figure 9. Spline of the apparent polar wander (APW) path for Greenland, as based upon all published Cretaceous and Tertiary poles (ages in Ma) from east, west and southwest Greenland extracted from the global palaeomagnetic data base of Lock & McElhinny (1991), applying the GMAP program (Torsvik et al. 1990). The Nansen Land poles of Group 2 (●) and Group 3 (○) as well as their overall mean pole Gr2&3 (▲) are also shown. Based upon the dates on the Greenland APW-spline, a palaeomagnetic age of 57 $\pm$ 10 Ma (Paleocene or Early Eocene) may be assigned to the two dyke swarms of Groups 2 and 3.

= (10, 87.5, 5.9°) and (Plat, Plon, dp, dm) = (69.0°, 195.8°, 10.2°, 11°).

The reversal test shows, that the normal and reverse directions of the two younger groups are antipodal within the 95% significance level. If the polarities were not antipodal, this could have indicated a small age difference, and hence there might have been a slight plate movement in between the times of intrusion.

Discussion

Laurentia, including Greenland, and the post-Devonian spline of the APW path for North America are shown in Figure 8. Greenland is shown in two positions relative to North America, before and after the opening of Baffin Bay in the Late Cretaceous. The spline is based upon palaeomagnetic data from North America (including Greenland), which meet three or more palaeomagnetic reliability criteria (quality factor Q $>$ 3). The spline for North America is calculated from data listed in Van der Voo (1993: Table 5.1), using the GMAP program (Torsvik et al. 1990). The mean palaeomagnetic poles from the dyke swarms in Nansen Land in present-day coordinates are labelled Gr1, Gr2, Gr3, and Gr2&3, respectively.

The younger Nansen Land mean pole Gr2&3 (in present-day coordinates) is very close to the North American pole Ku for Late Cretaceous time (67–96 Ma), which is in accordance with the fact that Greenland belongs to the North American craton, and that the younger dykes (Groups 2 and 3) postdate the opening of Baffin Bay. In contrast, the older pole Gr1, when rotated to position Gr1(NA), gives a better fit with the North American spline for the Early Carboniferous, when closing Baffin Bay by the pre-anomaly-24 fit (determined by rotating Greenland 18° clockwise around an Euler pole at 70.5° N, 94.4° W), the Bullard-fit (Bullard et al. 1965).

Finally, Figure 9 shows the spline of the APW path for Greenland, as based upon all Cretaceous and Tertiary poles published from east, west and south-west Greenland extracted from the data base of Lock & McElhinny (1991), applying the GMAP program (Torsvik et al. 1990). The mean poles for Nansen Land of normal and reverse polarity are also indicated. As Group 2 (mostly normal) is older than Group 3 (mostly reverse), the time-sequence of the pole positions does not fit the trend of the APW-spline. However, as the normal and reverse poles are not significantly different at the 95% level, this conflict is due to statistical uncertainties only. The over-all mean pole for Groups 2 and 3 is also shown. From this graph, based upon the dates assigned to the Cretaceous-Tertiary APW-spline for Greenland, a palaeomagnetic age of 57 ± 10 Ma may be assigned to these groups.

The opposed polarities of the NW-SE and E-W dykes of Groups 2 and 3 support the idea of two different swarms, hitherto based mainly upon petrographic differences and strike. As stated above, there is no direct evidence of the age relationship between both swarms, but in any case their age difference seems to be small.

Within the palaeomagnetic accuracy (directional resolution of 5–10°) the magnetic dating of these swarms to 57 ± 10 Ma places them in the Palaeocene to Early Eocene (or latest Cretaceous). During this period sea-floor spreading was still active in the Labrador Sea, and north Greenland and the Canadian Arctic Islands underwent within-plate deformation to accommodate the resultant counter-clockwise rotation of Greenland (Okulitch & Trettin 1991). The Kap Cannon Thrust Zone is regarded as belonging to this deformation (Soper & Higgins 1991b). The NW-SE dykes can possibly be related to the stress field of this zone (Friderichsen & Bengaard 1985).

The N-S dykes (Group 1) have generally been interpreted as an on-shore expression of Late Cretaceous rifting in the Arctic Basin (Brown et al. 1987). This view is based upon their petrologic similarity to the volcanics, and a young age is also supported by their petrologic similarity to the NW-SE swarm. No field evidence, however, is present, and our palaeomagnetic observations suggest that the Group 1 swarm relates to an Early Carboniferous rifting episode which generated hot-spot effects in the Peary Land-Nansen Land region. More data will be necessary to support this interesting hypothesis.

Conclusions

In conclusion, we may summarize, that:

1) The sites investigated from the oldest, N-S-trending, Group 1 dyke swarm carry a primary remanent magnetization, the pole of which is close to the Early Carboniferous mean palaeomagnetic pole for North America. This magnetisation is considerably older than that found in dyke Groups 2 and 3. If this magnetization age is correct, the Group 1 swarm is most likely associated with the initiation of the Sverdrup Basin.
2) The two younger dyke swarms of Groups 2 (NW-SE) and 3 (E-W), are dominated by normal and reverse polarities, respectively.
3) A reversal test shows that the normal and reverse polarities of the two younger dyke swarms combined are antipodal within the 95% significance level, the difference in age of the swarms being below the resolution power of the palaeomagnetic data.
4) Based upon the APW-spline for the whole of Greenland, a palaeomagnetic age of 57 ± 10 Ma may be assigned to the two younger dyke swarms combined.
5) The combined pole of the two younger dyke swarms falls close to the North American Late Cretaceous pole, which is in accordance with the facts that Greenland belongs to the North American craton, and that these swarms, within the accuracy of the palaeomagnetic data, postdate the opening of Baffin Bay.

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