Deformation at the southern boundary of the late Archaean Atâ tonalite and the extent of Proterozoic reworking of the Disko terrane, West Greenland

John Grocott and Steven C. Davies

The *c.* 2800 Ma old Atâ tonalite in the area north-east of Disko Bugt, West Greenland has largely escaped both Archaean and Proterozoic regional deformation and metamorphism. At its southern margin the tonalite is in contact with migmatitic quartz-feldspar-biotite gneiss and to the south both are progressively deformed in a high-grade gneiss terrain. The main deformation in the high grade gneisses involved hanging wall north-west displacements on a system of low-angle ductile shear zones that structurally underlie the Atâ tonalite. This shear zone system is folded by a large-scale, steeply inclined and north-west-trending antiform defined by the change in dip of planar fabrics. Minor folds related to the antiform are present and there is some evidence that folding was synkinematic with emplacement of a suite of *c.* 1750 Ma old ultramafic lamprophyre dykes.

In much of the north-east Disko Bugt area it remains difficult to separate Archaean from Proterozoic structures and hence the extent of the Archaean terrane that has escaped intense Proterozoic reworking remains uncertain.

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North-east of Disko Bugt in West Greenland, Archaean plutonic igneous rocks have escaped both Archaean and Proterozoic regional deformation and metamorphism near the abandoned settlement of Ataa on Arveprinsen Ejland (Fig. 1). The plutonic rocks have been known as the 'Atâ granite' (Escher & Burri 1967; Kalsbeek *et al.* 1988), but, because hardly any granites are present (Kalsbeek & Skjernaa 1999, this volume), the term 'Atâ tonalite' (Garde 1994) is employed in the present volume. The Atâ tonalite has an age of *c.* 2800 Ma (Kalsbeek *et al.* 1988; Nutman & Kalsbeek 1999, this volume) and is intrusive into strongly deformed, high-grade amphibolites and metasedimentary rocks of an Archaean greenstone belt (Fig. 1; Kalsbeek 1990). On Anap Nunaa, 20 km north-east of Ataa, Archaean supracrustal rocks are overlain unconformably by low-grade, and less deformed, Proterozoic sedimentary rocks (Garde & Steenfelt 1999, this volume). North of Anap Nunaa, intensity of Proterozoic deformation and grade of Proterozoic metamorphism increase across Nuussuaq (Garde & Steenfelt 1989, 1999, this volume) toward the Rinkian orogen (Fig. 2; Grocott & Pulvertaft 1990).

On Arveprinsen Ejland, south of a line between Vaskebugt and Ataa (Fig. 3), tonalitic rocks become progressively more deformed southwards, and the southern half of the island is underlain by high-grade gneisses. Escher & Pulvertaft (1976) identified a lineament which transects these gneisses along the inlet Paakitsoq (Fig. 1) as the boundary between the Proterozoic Rinkian and Nagssugtoqidian orogenic belts (Fig. 2). However, Kalsbeek *et al.* (1988) showed that the Rinkian belt and the Nagssugtoqidian orogen are not in direct contact in the area north-east of Disko Bugt, but are separated by an Archaean domain which includes the Atâ tonalite. This domain may be part of the Burwell terrane of northern Labrador and eastern Baffin Island (Grocott 1989; Hoffman 1990), although the existence of the Burwell terrane as a distinct tectono-stratigraphic entity in its type area of the north-east
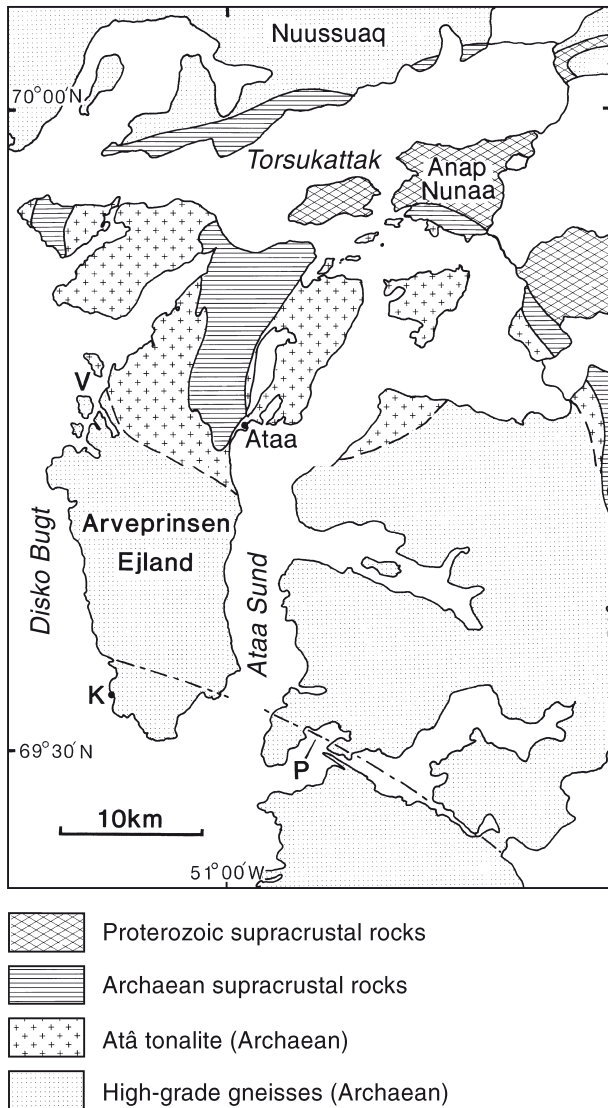
Fig. 1. Precambrian rocks of the north-east Disko Bugt region. V = Vaskebugt; K = Klokkerhuk; P = Paakitsoq lineament. From Kalsbeek (1989).

proterozoic magmatic arc rocks in the Nagssugtoqidian orogen south of the Disko Bugt area, and infer that a cryptic suture, marking the southern boundary of the terrane, exists in the central part of the orogen (Fig. 2). However, the northern limit of reworking of the Disko terrane by deformation in the Nagssugtoqidian orogen is unknown. The high-grade gneiss terrain south of the Atâ tonalite may well be the result of intense Proterozoic reworking of Archaean rocks, but there is no geochronological evidence supporting this and, on available evidence, intense deformation at the southern margin of the Atâ tonalite could be of Archaean age or could have both Archaean and Proterozoic components. Therefore, high-grade gneisses on
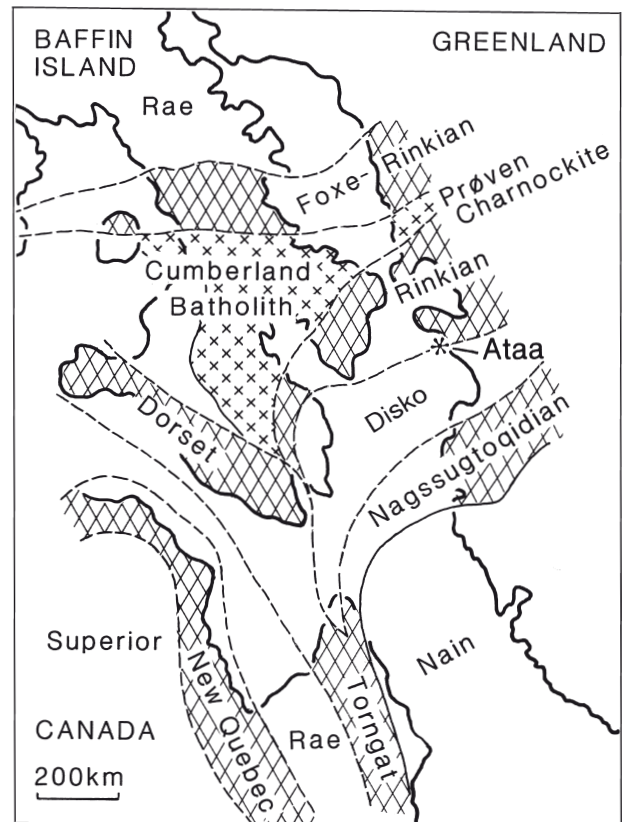

Fig. 2. Location of Ataa in relation to the Precambrian tectonic framework of NE Canada and West Greenland. Archaean terranes (Rae, Superior, Disko and Nain) largely unaffected by Proterozoic reworking are shown in white. Proterozoic belts (New Quebec, Torngat, Dorset, Nagssugtoqidian, Rinkian and Foxe–Rinkian) are shown cross-hatched. The belts include Archaean rocks reworked during the Proterozoic as well as rocks of Proterozoic age. The southward extent of unreworked Archaean rocks in the Disko terrane in West Greenland is speculative. Modified from Grocott (1989); Hoffman (1990); Van Kranendonk (1993).

Torngat orogen in Labrador has recently been questioned (Van Kranendonk *et al*. 1993; Wardle *et al*. 1993). These authors continue to interpret Archaean rocks in the area north-east of Disko Bugt and on south-east Baffin Island as elements of a distinct tectono-stratigraphic terrane for which, in view of the demise of the Burwell terrane, they have proposed the name 'Disko terrane' after the exposures of dated Archaean crust in the Disko Bugt area (Fig. 2; Kalsbeek *et al*. 1988).

The location of orogenic sutures at the boundaries of the Disko terrane in West Greenland, and the extent of intense Proterozoic reworking within it, remain uncertain. Kalsbeek *et al*. (1987) have identified Palaeo-

Arveprinsen Ejland and the adjacent mainland together with the Atâ tonalite may both be elements of the Disko terrane in which there has been little Proterozoic deformation and metamorphism (Fig 2; Kalsbeek *et al.* 1988).

In this paper we describe the structure and the structural history of high grade gneisses in central and southern Arveprinsen Ejland and consider whether the structures described are of Archaean or Proterozoic age. Our field work involved structural mapping at 1:20 000 scale and focused on the western half of the island (Fig. 3). Reconnaissance mapping by A.A. Garde and A. Steenfelt (personal communication 1992) and our own reconnaissance mapping and aerial photograph interpretation enabled us to trace some structures eastward across the island.

The southern margin of the Atâ tonalite

Tonalites belonging to the Atâ tonalite at Vaskebugt in central Arveprinsen Ejland (Figs 1, 3) are cut by synkinematic, medium-grained granitic rocks and granite pegmatites (Fig. 4a). Primary compositional layering in the tonalites strikes north–south (Fig. 4b), parallel to the planar element of weak shape fabrics defined by recrystallised plagioclase (Fig. 4c). The planar fabrics are folded (Fig. 4c, e) and become transposed to a mylonitic foliation in NW–SE-striking and north-east-dipping ductile shear zones (Figs 3, 4d). Stretching fabric orientations (Figs 3, 5a), asymmetric porphyroclasts (Fig. 4f) and *S-C* fabrics reveal that right normal-slip displacements occurred on these shear zones. The proportion of rock affected by ductile shear zones increases south-west of Vaskebugt and domains of low fabric intensity are uncommon south-west of the Laksebugt – Kuussuup Tasia valley (Fig. 3).

Between Vaskebugt and Laksebugt, rocks belonging to the Atâ tonalite are in contact with coarse, migmatitic biotite-quartz-feldspar gneisses (Fig. 4e). Both tonalites and migmatites are cut by younger, often pegmatitic, granitoid intrusions. The relative age of the tonalites and the migmatites is difficult to interpret in the field. Folded sheets of Atâ tonalite occasionally appear to cut across banding in the migmatitic gneiss (Fig. 4e), implying that the tonalite is younger than migmatisation (see also Escher *et al.*1999, this volume). On the other hand, enclaves of tonalite are present in the migmatitic gneisses implying that the latter are younger, and this interpretation is in accord with avail-

able geochronology (Kalsbeek *et al.* 1988). South of Laksebugt, increase in the proportion of rock affected by strong ductile deformation coincides with an increase in the proportion of migmatitic biotite-quartz-feldspar gneiss which becomes the main lithology on southern Arveprinsen Ejland. However, tonalitic rocks of similar mineralogy and appearance to the main rock type in the western part of the Atâ tonalite occur in domains of low fabric intensity throughout southern Arveprinsen Ejland.

Niaqornaarsuk to Klokkerhuk

Reverse-slip ductile shear zones (D_m)

In southern Arveprinsen Ejland, anastomosing ductile shear zones are present in migmatitic biotite-quartz-feldspar gneisses with rare horizons of anorthosite, amphibolite and garnet-mica schist (Figs 3, 6). In a domain of low fabric intensity 1 km north of Niaqornaarsuk (Fig. 3), the gneisses contain an upper amphibolite facies assemblage of garnet-diopside-hornblende-biotite-quartz-feldspar. Within the shear zones the assemblage hornblende-biotite-quartz-feldspar implies that during D_m the rocks were metamorphosed at amphibolite grade.

Foliation in the shear zones strikes WSW–ENE, dips south-south-east (Fig. 5g), and the gneisses contain strong stretching lineations that plunge south-east (Fig. 5c). Kinematic indicators, viewed parallel to the kinematic *XZ* plane (perpendicular to the foliation and parallel to the stretching lineation), allow shear sense to be determined. At Niaqornaarsuaq (Fig. 3), narrow, generally concordant, amphibolite dykes show asymmetric foliation boudinage implying right reverse-slip displacement on the shear zones (Fig. 7a). This interpretation is supported by asymmetric porphyroclast systems and north-west vergence of sheath folds viewed in the kinematic *XZ* plane. Ductile shear zones are the main structural element between Niaqornaarssuk and Klokkerhuk.

Low fabric intensity domains between D_m shear zones

In domains of low fabric intensity between the shear zones, *L* or *L > S* tectonite fabrics are present in migmatitic biotite-quartz-feldspar gneisses. Major folds of gneissic banding are present 1 km north of Niaqor-
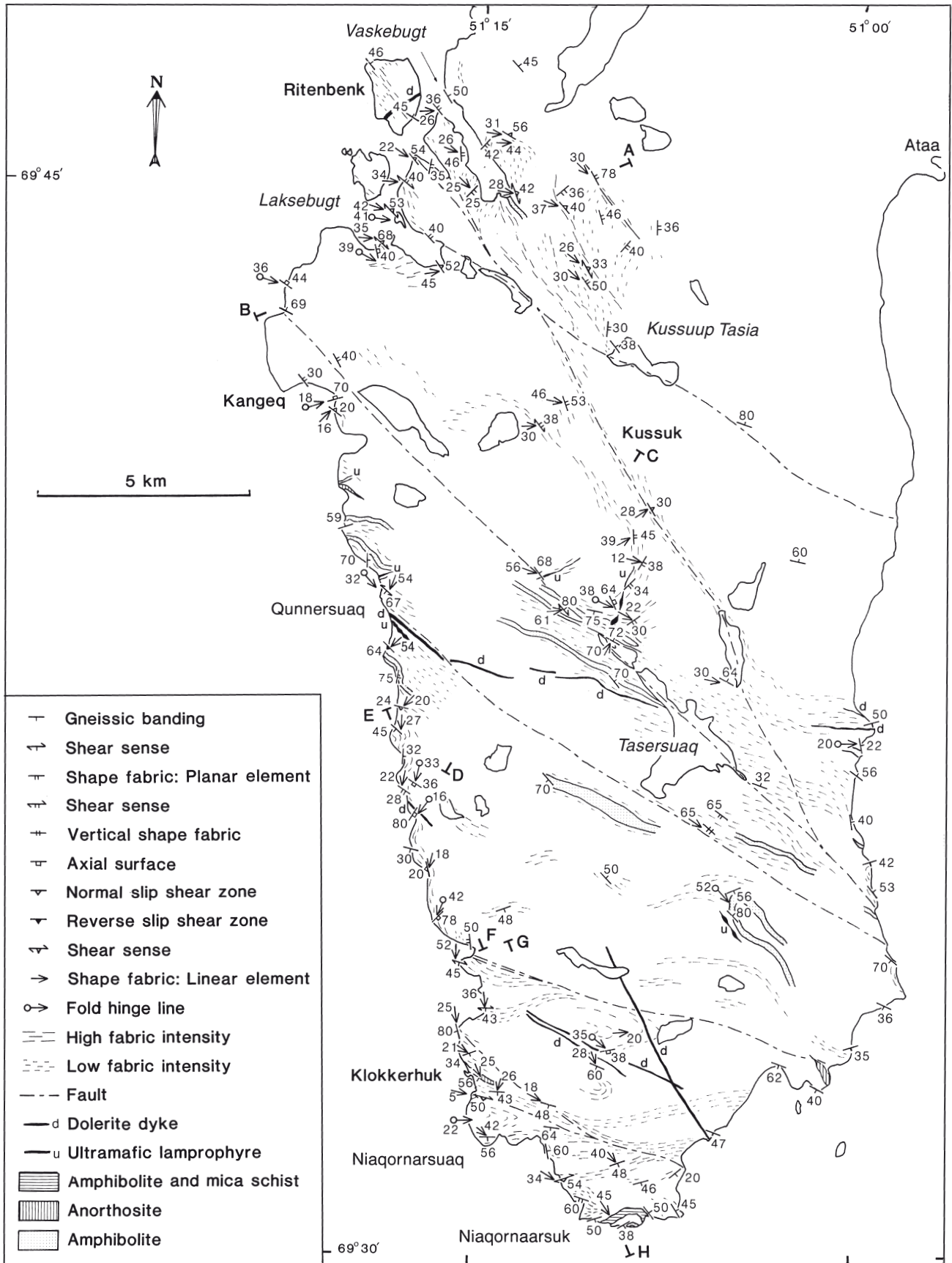
Fig. 3. Structural map of central and southern Arveprinsen Ejland, north-east Disko Bugt. South-west of a line between Vaskebugt and Kuussuup Tasia the main lithology is migmatitic biotite-quartz-feldspar gneiss. The Atâ tonalite is exposed north-east of this line. Sections A–B, C–D and E–H are given in Fig. 9.

naarsuaq and east of Klokkerhuk (Fig. 3). The axial traces of the folds are parallel to the strike of the reverse-slip shear zones implying that they are the same age (D_m) but they could equally be older structures (Garde & Steenfelt 1999, this volume).

Right strike-slip ductile shear zone ($D_{m''}$)

A 200 m wide, south-dipping ductile shear zone which post-dates the reverse-slip shear zones is exposed 500 m south of Klokkerhuk and strikes ESE–WNW (Fig. 6). The stretching lineation plunges between 5° west to 18° east. Clockwise rotation of D_m stretching lineations in the northern margin of the shear zone, immediately east of Klokkerhuk (Fig. 3), implies that shear sense is right-lateral and this is confirmed by asymmetric porphyroclast systems (Fig. 7b) and S-C fabrics. Grain size reduction is extreme in some narrow zones in the shear zone which contain ultramylonitic rocks. The mineral assemblage biotite-hornblende-quartz-feldspar indicates that metamorphic grade was amphibolite facies during deformation.

Post-shear zone folds (D_p)

Some poles to foliation for the Klokkerhuk area scatter along a π-girdle when plotted stereographically and define a moderately east-south-east-plunging fold axis (Fig. 5g). The poles which plot on the girdle were measured from south-vergent minor folds exposed 2 km east of Niaqornaarsuaq. The folds have axial surfaces inclined to the north.

Klokkerhuk to Qunnersuaq

Folding of D_m ductile shear zones (D_n and D_p folds)

Steeply-inclined and moderately-plunging open folds (F_n), with a wavelength of about 1 km, deform the ductile shear zones between Klokkerhuk and Qunnersuaq (Figs 3, 6). The folds have NE–SW-striking, steeply-inclined axial surfaces and plunge gently to moderately south-west (Fig. 8a). The fold envelope trends NNW–SSE parallel to the coast (Fig. 3), and defines the limb of a major, open D_n fold between Qunnersuaq and Klokkerhuk. This fold is responsible for the change in the plunge direction of the D_m linear fabric from south-

east to south-west between Niaqornaarsuk and Qunnersuaq (Fig. 5c). D_n folding is not, in general, associated with overprinting of D_m fabrics, although crenulations, new planar fabrics and intersection lineations are present locally, particularly in hinge zones of D_n minor folds. The NE–SW trend of the D_n fold axial surfaces is consistent with folding during displacement on the right strike-slip shear zone exposed 500 m south of Klokkerhuk.
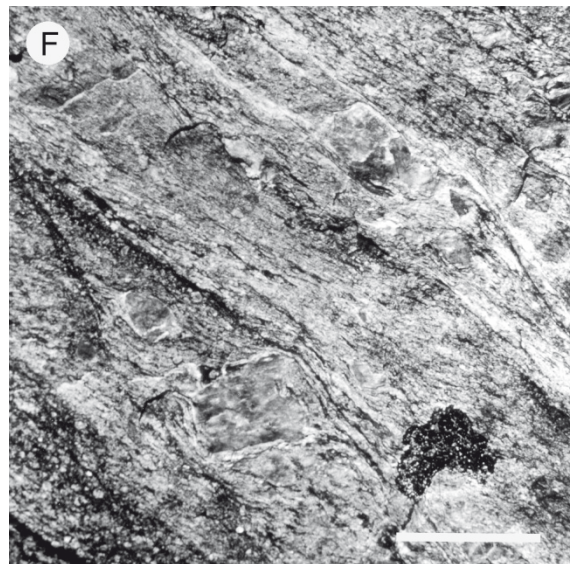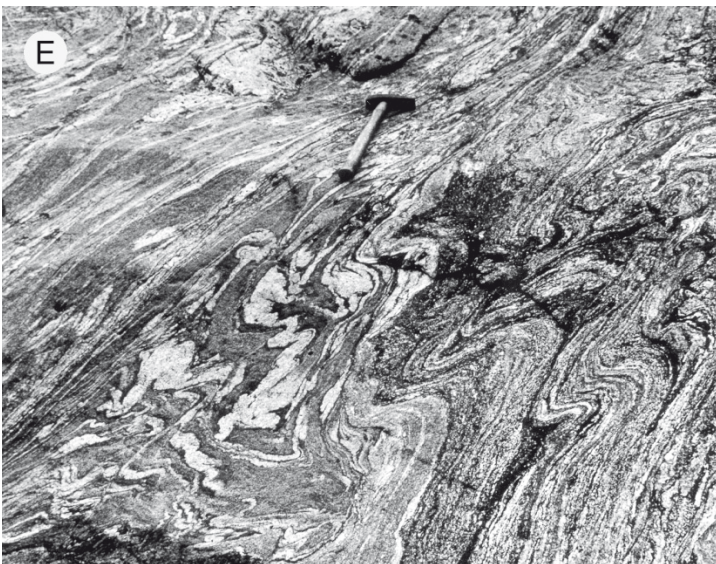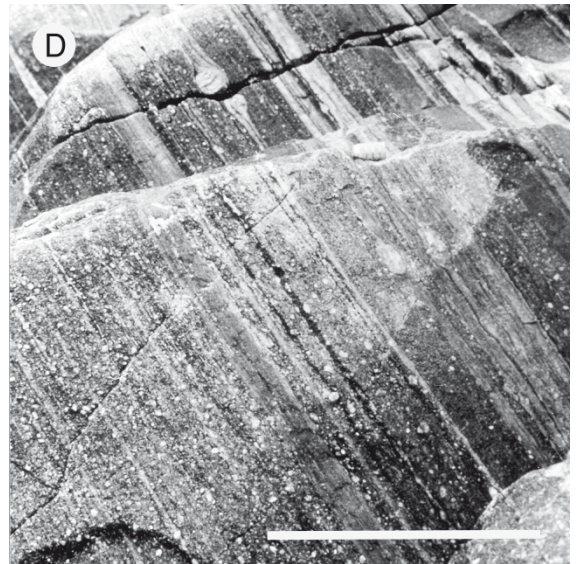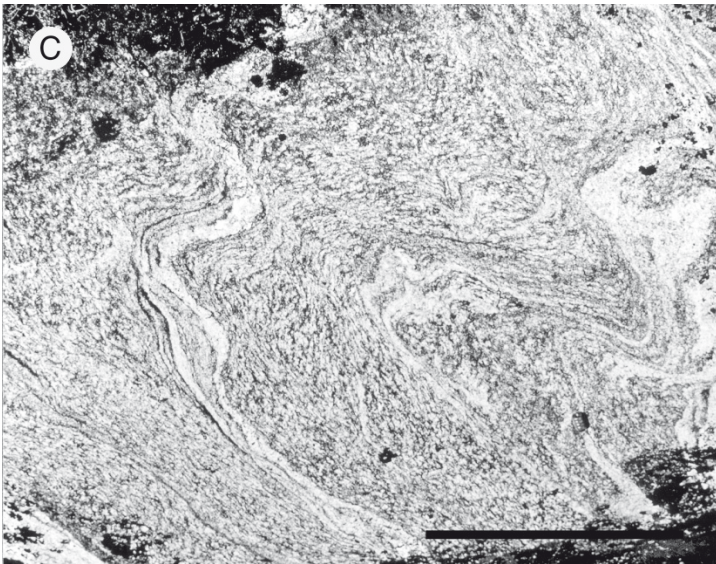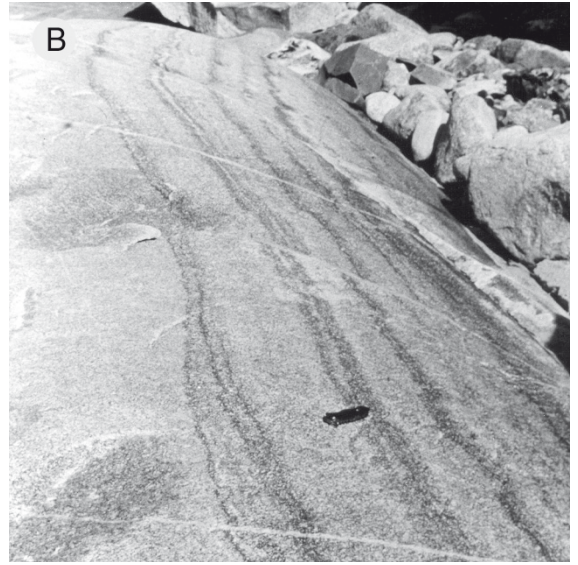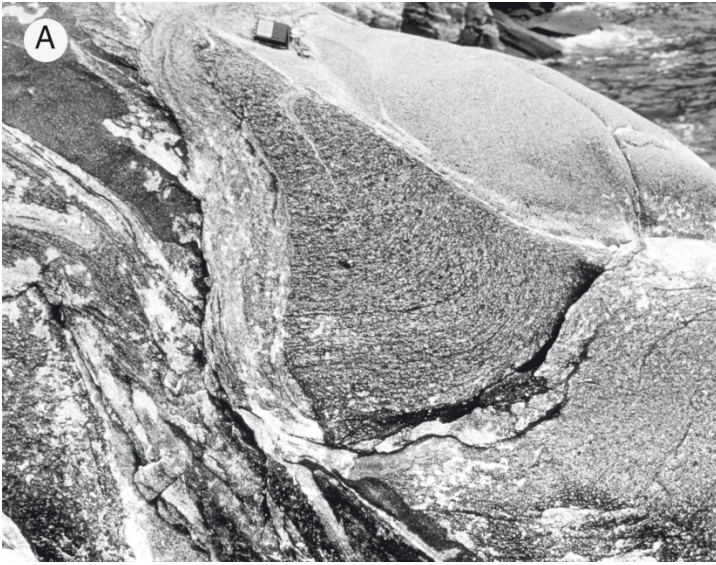
The reorientated D_m shear zones between Qunnersuaq and Klokkerhuk contain asymmetric porphyroclast systems and S-C fabrics which imply that displacement was reverse-slip (Fig. 7c). These kinematic indicators and the orientation of the stretching lineation shows that, in their present orientation, displacement on the shear zones was to the north at Klokkerhuk and to the north-east at Qunnersuaq (Figs 3, 6).

A second phase of post-shear zone folds (F_p) is present between Klokkerhuk and Qunnersuaq. The folds are open to close and south to south-west vergent with a wavelength of 10 m to 25 m (Fig. 7d). They are moderately to steeply inclined to the north or north-east and most plunge gently south-east (Fig. 8b). There is no systematic change in D_p fold axial surface orientation between Niaqornaarsuk and Qunnersuaq from which we infer that the folds are later than the D_n deformation.

The Paakitsoq lineament

The Paakitsoq lineament trends ESE–WSW across southern Arveprinsen Ejland and intersects the coast 3 km north of Klokkerhuk (Fig. 1). It is one of a set of similarly orientated lineaments in central and southern Arveprinsen Ejland (Fig. 3). The lineament was chosen by Escher & Pulvertaft (1976) as the boundary between the Rinkian and the Nagssugtoqidian orogenic belts because it separated a terrain having north-east-striking steep belts (Nagssugtoqidian) from a terrain to the north with dome-and-basin or flat-lying structure (Rinkian).

In western Arveprinsen Ejland the Paakitsoq lineament is a fault marked by a 10 m thick crush breccia and epidote-quartz mineralisation. The fault has a left-slip separation of about 300 m. We have no slickenline orientation data or shear sense data from the crush breccia, but similarity of structural style, structural history and metamorphic grade on each side of the fault zone mitigate against there being large vertical displacements across it.
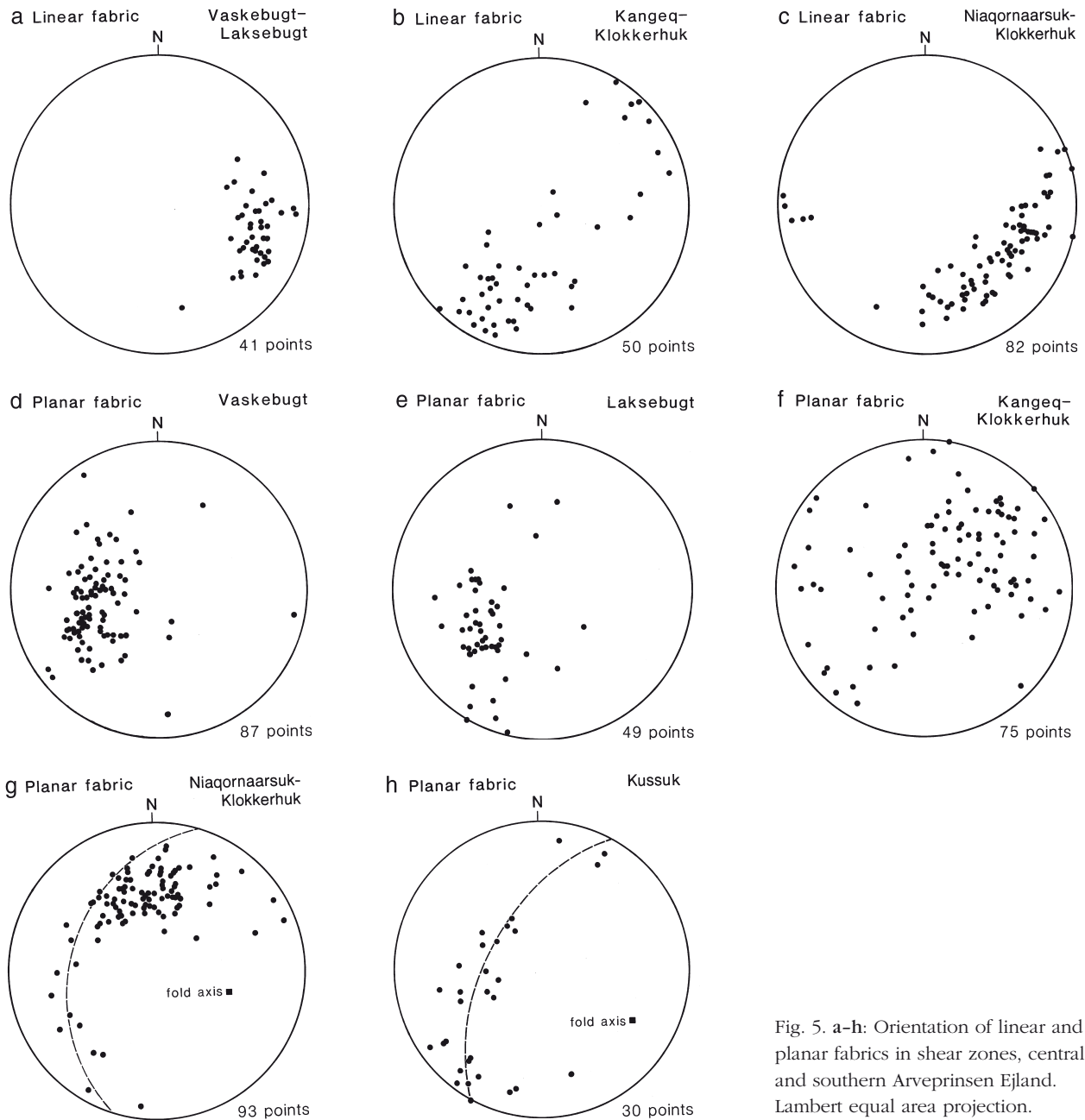
a Linear fabric   Vaskebugt–Laksebugt
N
41 points

b Linear fabric   Kangeq–Klokkerhuk
N
50 points

c Linear fabric   Niaqornaarsuk-Klokkerhuk
N
82 points

d Planar fabric   Vaskebugt
N
87 points

e Planar fabric   Laksebugt
N
49 points

f Planar fabric   Kangeq-Klokkerhuk
N
75 points

g Planar fabric   Niaqornaarsuk-Klokkerhuk
N
fold axis ■
93 points

h Planar fabric   Kussuk
N
fold axis ■
30 points

Fig. 5. a–h: Orientation of linear and planar fabrics in shear zones, central and southern Arveprinsen Ejland. Lambert equal area projection.

Fig. 4. Fabrics at the southern margin of the Atâ tonalite between Vaskebugt and Laksebugt. A: Weakly foliated tonalite cut by a medium-grained granite sheet, south side of Vaskebugt. Compass clinometer (top centre) is 12 cm long. B: Primary compositional layering in tonalite, south side of Vaskebugt. Pocket knife (centre) is 12 cm long. C: folded shape fabrics in tonalite, north side of Vaskebugt. The folds are viewed to the north-west and axial surfaces dip north-eastward. Scale bar is 30 cm long. D: Mylonitic migmatitic biotite-quartz-feldspar gneiss in $D_m + D_{m'}$ shear zone, north side of Laksebugt. The foliation is viewed to the north-west and dips north-eastward. Scale bar is 20 cm long. E: Folded migmatitic biotite-quartz-feldspar gneiss (left of photograph) and tonalitic gneiss derived from Atâ tonalite (right of photograph). The folds are viewed to the south-east and axial surfaces dip north-eastward. Fabric intensity in the migmatitic gneiss increases to the left. The hammer shaft (centre) is 35 cm long. F: Feldspar σ-porphyroclast system showing normal-slip displacement in a D_m shear zone south of Kussuk. The porphyroclasts are shown in the kinematic *XZ* plane of the shear zone viewed to the north-west. The planar fabric dips north-eastward. The scale bar is 3 cm long.
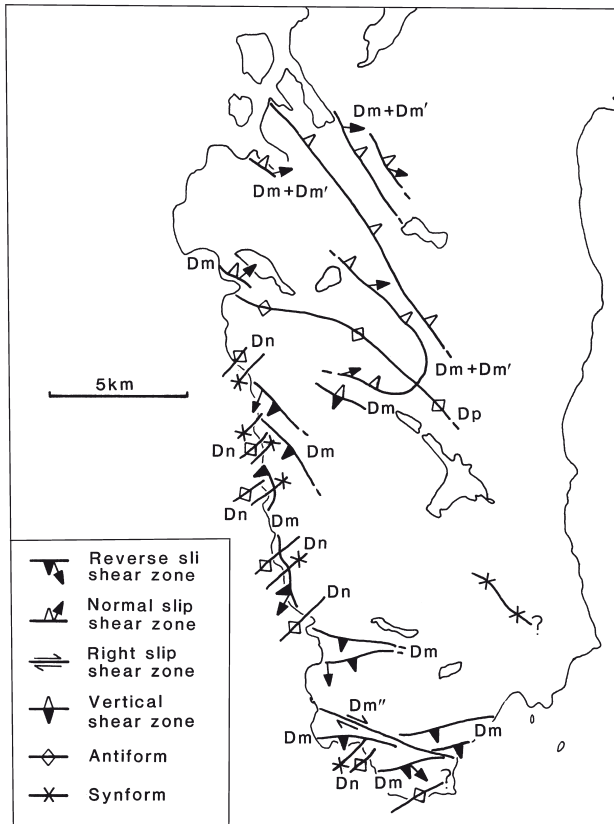
Fig. 6. Overview of major structures in the western and central part of central and southern Arveprinsen Ejland.

Fig. 8. **a**: Attitude of F_n folds between Kangeq and Klokkerhuk. **b**: Attitude of F_p folds between Kangeq and Klokkerhuk. Lambert equal area projection. Dots: poles to fold axial surfaces; squares: fold hinge lines.

Qunnersuaq to Kussuk

A major south-vergent fold pair that folds the D_m shear zones is exposed between Qunnersuaq and Kussuk (Figs 3, 6, 9). The antiform is a tighter and more prominent fold than the synform (Fig. 9, section C–D). The axial surface trace of the synform is located south of Qunnersuaq where shallow-dipping planar fabrics in D_m shear zones are folded into a belt of steeply-dipping rocks in the southern limb of the antiform (Fig. 9, section C–D). A north-dipping and north-vergent, axial-plane foliation overprints the D_m planar fabric in this steep belt. The antiformal axial surface trace is exposed to the north-east, 4 km south-east of Kussuk (Fig. 3), and plunges moderately south-east (Fig. 5h). The Qunnersuaq–Kussuk folds are attributed to D_p deformation based on style and orientation (compare Figs 5h and 8b). They can be traced to the south-east as a major structure on the mainland east of Ataa Sund (Escher *et al.* 1999, this volume).
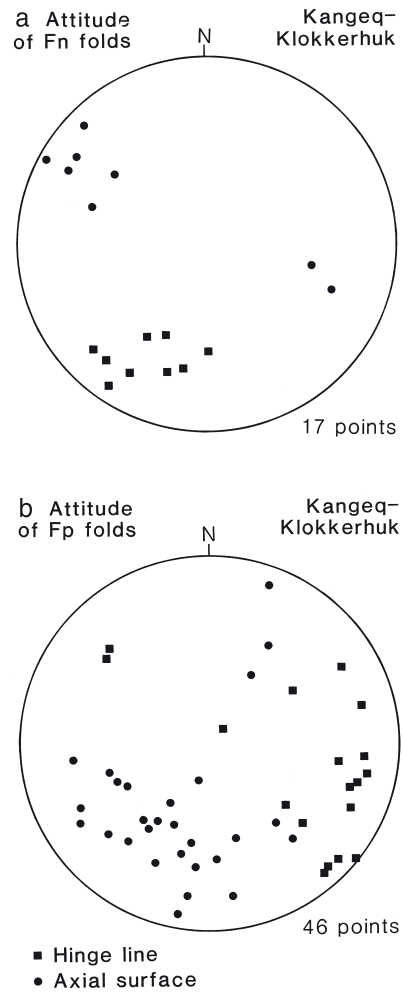
Fig. 7. Sense of shear indicators and minor folds, Niaqornaarsuk to Kangeq, Arveprinsen Ejland. **A**: Asymmetric boudinage of amphibolite dyke at Niaqornaarsuaq. Structure is viewed to the south-west in the kinematic *XZ* plane and foliation dips south. Sense of shear is right reverse-slip. The hammer shaft (centre) is 35 cm long. **B**: Right strike-slip, σ-porphyroclast system in $D_{m''}$ shear zone south of Klokkerhuk. The scale bar is 3 cm long. **C**: σ-porphyroclast system indicating reverse-slip displacement in D_m ductile shear zone at Qunnersuaq. The porphyroclast is shown in the kinematic *XZ* plane viewed to the south-east. The foliation dips to the south-west. The coin is 2.5 cm in diameter. **D**: South-vergent D_p folds 5 km south of Qunnersuaq. The folds are viewed to the east. The hammer shaft (centre) is 35 cm long. **E**: *S-C* mylonites in a D_m shear zone, 2 km south-east of Kangeq in the northern limb of the Qunnersuaq–Kussuk antiform. The structure is viewed to the south-west in the *XZ* kinematic plane. Displacement of the hanging wall was to the north-east. **F**: South-vergent D_p fold of narrow ultramafic lamprophyre dyke exposed 2.5 km south of Qunnersuaq.
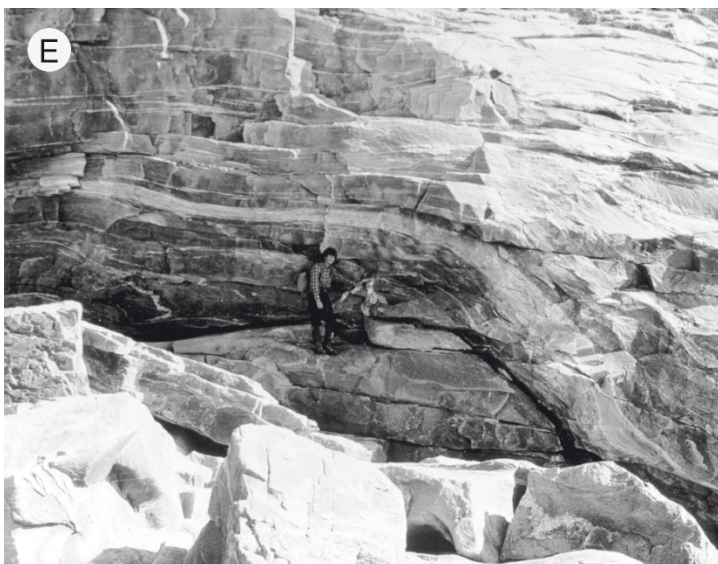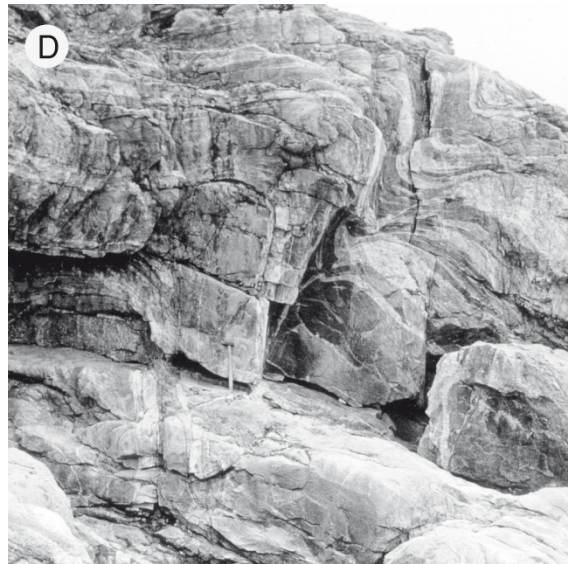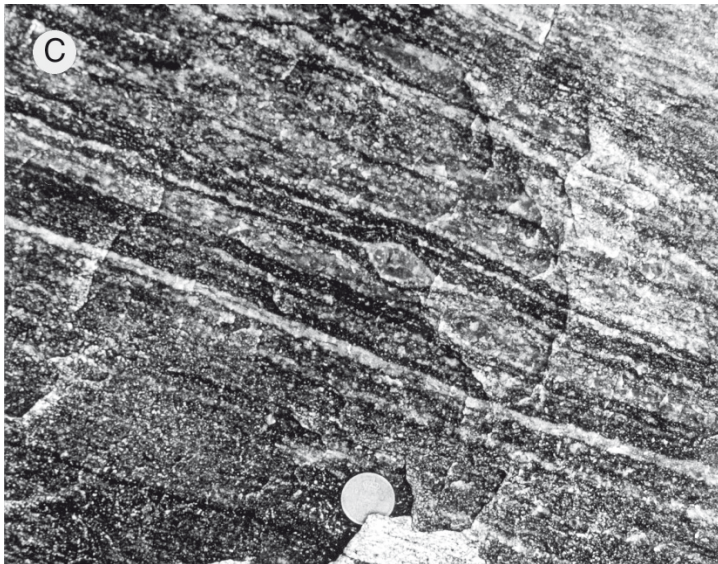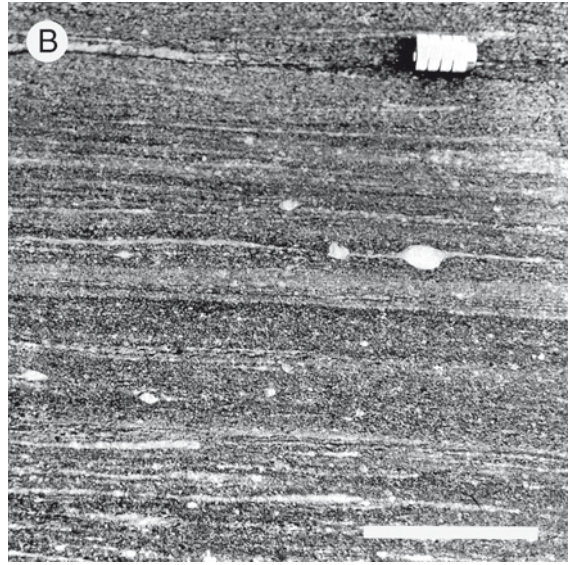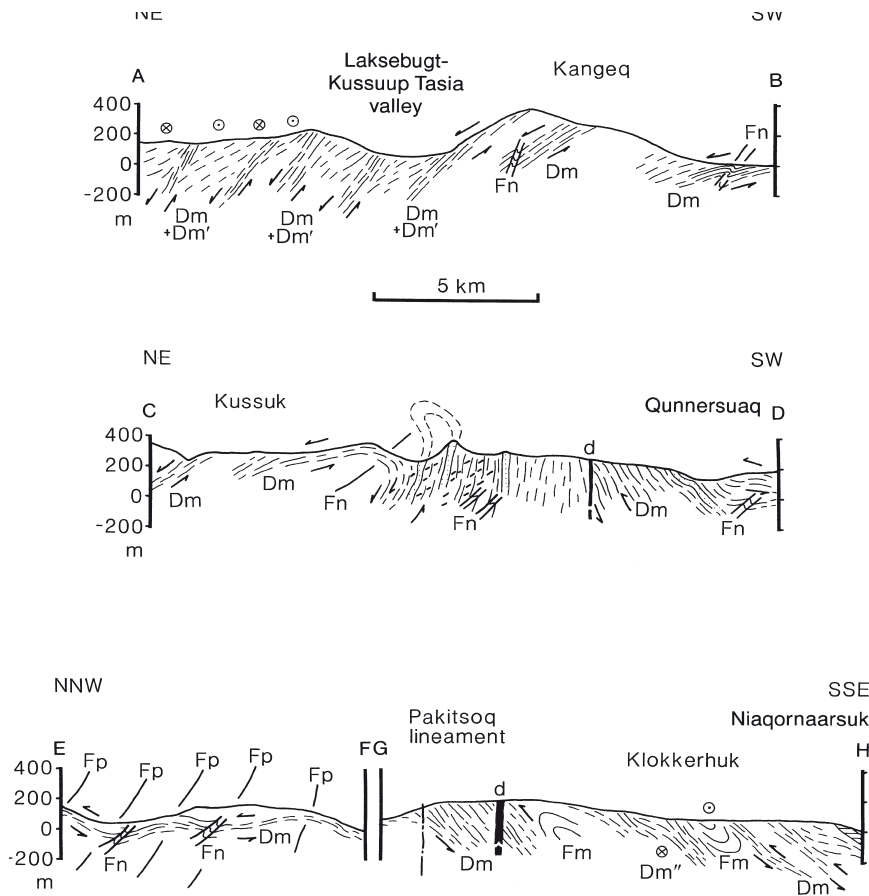
Kuussuup Tasia

This area is characterised by NW–SE-striking and north-east-dipping ductile shear zones on the north-east limb of the Qunnersuaq–Kussuk antiform (Figs 3, 6, 9). The width of the shear zones, and the proportion of the rocks affected by them, decreases north-east of Kuussuup Tasia toward the Atâ tonalite. The linear fabric plunges north-east at Kangeq and at Kussuk, but to the north it rotates clockwise to plunge south-east 4 km north of Kuussuup Tasia (Fig. 3). As it rotates, the pitch of the lineation in the foliation plane becomes shallower (Fig. 3).

This pattern is part of a general clockwise rotation of the linear fabric in the northern limb of the Qunnersuaq–Kussuk antiform (Figs 3, 6). Asymmetric porphyroclast systems in the shear zones imply that the sense of shear is right normal-slip, with an increasing right strike-slip component north-east of the Laksebugt – Kuussuup Tasia valley. The shear zones at Kuussuup

Tasia are along strike from the right normal-slip shear zones already described in the Vaskebugt–Laksebugt area (Fig. 3).

Structural relationships

The map (Fig. 6) and cross-sections (Fig. 9) imply that Qunnersuaq–Kussuk folds are responsible for the change in dip direction of the ductile shear zone system across central Arveprinsen Ejland. Apparently, the north-east-dipping, right normal-slip shear zones north of the antiform belong to the same system as the south-west- or south-dipping, right reverse-slip shear zones at Qunnersuaq. This interpretation can be tested stereographically by simply unfolding the planar fabrics by rotation about the fold axis. As expected, this rotation brings the linear fabric in shear zones exposed in the northern limb of the Qunnersuaq–Kussuk antiform at Kangeq (Fig. 7e) to the same orientation as the lin-
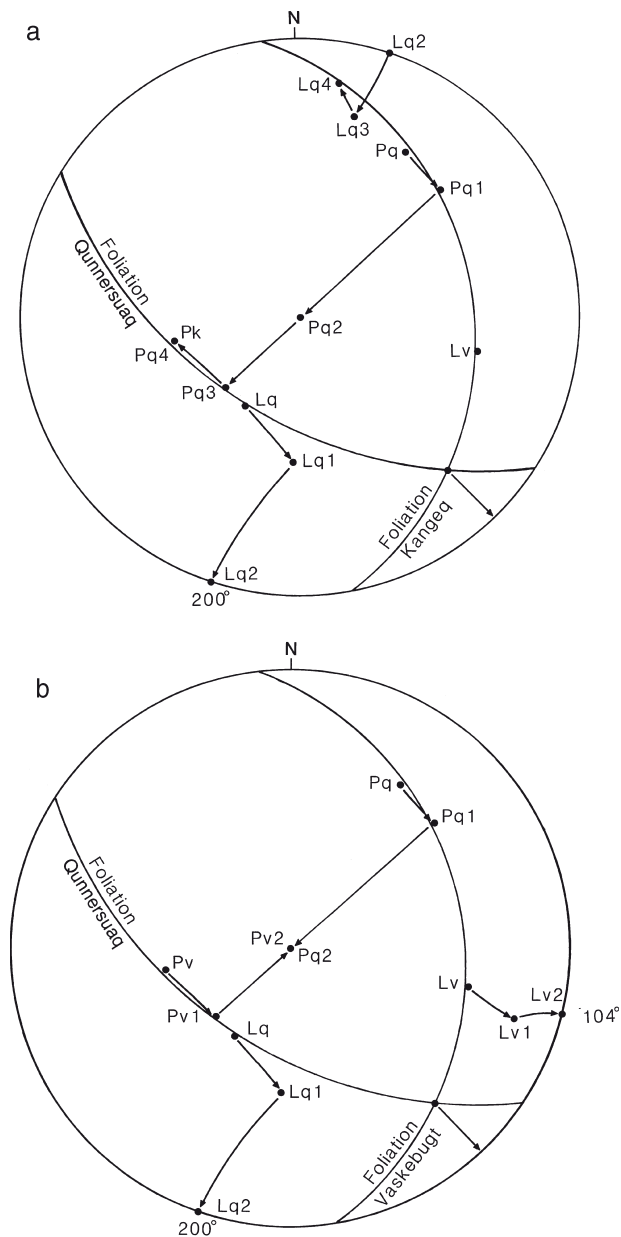
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Fig. 10. Structural analysis of the Qunnersuaq–Kangeq antiform. **a**: Rotation of the foliation at Qunnersuaq (P_q) to the orientation of the foliation at Kangeq (P_k) about the hinge line of the antiform (stages P_q–P_{q1}–P_{q2}–P_{q3}–P_{q4}) causes the lineation at Qunnersuaq (L_q) to rotate to a north-east plunge direction (L_{q4}) through stages L_q–L_{q1}–L_{q2}–L_{q3}–L_{q4}. This plunge direction is the plunge direction of the stretching fabric in D_m shear zones exposed at Kangeq (see Fig. 5b). The plunge direction of the lineation at Vaskebugt (L_v) is shown for comparison. **b**: Rotation of the planar fabrics at Qunnersuaq and Vaskebugt to a common orientation about the axis of the Qunnersuaq–Kussuk antiform (paths P_q–P_{q1}–P_{q2} and P_v–P_{v1}–P_{v2} respectively). The linear fabrics in each limb do not restore to a common orientation (paths L_q–L_{q1}–L_{q2} and L_v–L_{v1}–L_{v2}).

ear fabric in the southern limb of the antiform at Qunnersuaq (Fig. 10a).

The orientation of the linear fabric cannot be accounted for so easily everywhere in the northern limb of the antiform. When the planar fabrics measured at Vaskebugt are rotated stereographically about the axis of the Qunnersuaq–Kussuk antiform so that they coincide with the orientation of the planar fabric at Qunnersuaq, the reoriented lineations do not coincide (Fig. 10b). Clearly, the orientation of the east- or south-east-plunging linear fabric typical of most of the northern limb of the Qunnersuaq–Kussuk antiform cannot be simply explained by folding.

Clockwise rotation of the linear fabric in the northern limb of the Qunnersuaq–Kussuk antiform (Fig. 6) might imply that D_m linear fabrics have been progressively deformed and reorientated during ductile shearing ($D_{m'}$) at the southern margin of the Atâ tonalite. In this view, the sense of rotation of the linear fabric is consistent with right strike-slip deformation (Fig. 11). However, we have found no overprinting relationships allowing D_m and $D_{m'}$ fabrics to be separated in the shear zones in the northern limb of the antiform, and we have observed only a single linear fabric in the shear zones interpreted as a resultant fabric (Grocott 1979). Lack of overprinting and the fact that we have not documented a strain gradient northward or southward across the northern limb of the antiform associated with the rotation of the lineation means that our conclusion that D_m is earlier than $D_{m'}$ is provisional.

Finally, it is tempting to correlate $D_{m'}$ with the deformation responsible for the right strike-slip ductile shear zone exposed south of Klokkerhuk ($D_{m''}$). This is unlikely, however, because such shear zones would show a left strike-slip displacement in map view in the northern limb of the Qunnersuaq–Kussuk antiform.

Age of the structures

Samples from the Atâ tonalite have given U-Pb zircon ages of 2794 ± 15 Ma and 2803 ± 4 Ma and it is likely that its crystallisation age is close to 2800 Ma (Kalsbeek *et al.* 1988; Nutman & Kalsbeek 1999, this volume). At Laksebugt, samples of migmatitic biotite gneiss have given a Rb-Sr whole-rock isochron age of 2672 ± 52 Ma, significantly younger than the Atâ tonalite; this is suggested as the date of the migmatisation event (Kalsbeek *et al.* 1988). The migmatitic rocks lie to the south of the Atâ tonalite and are deformed by D_m and $D_{m'}$.
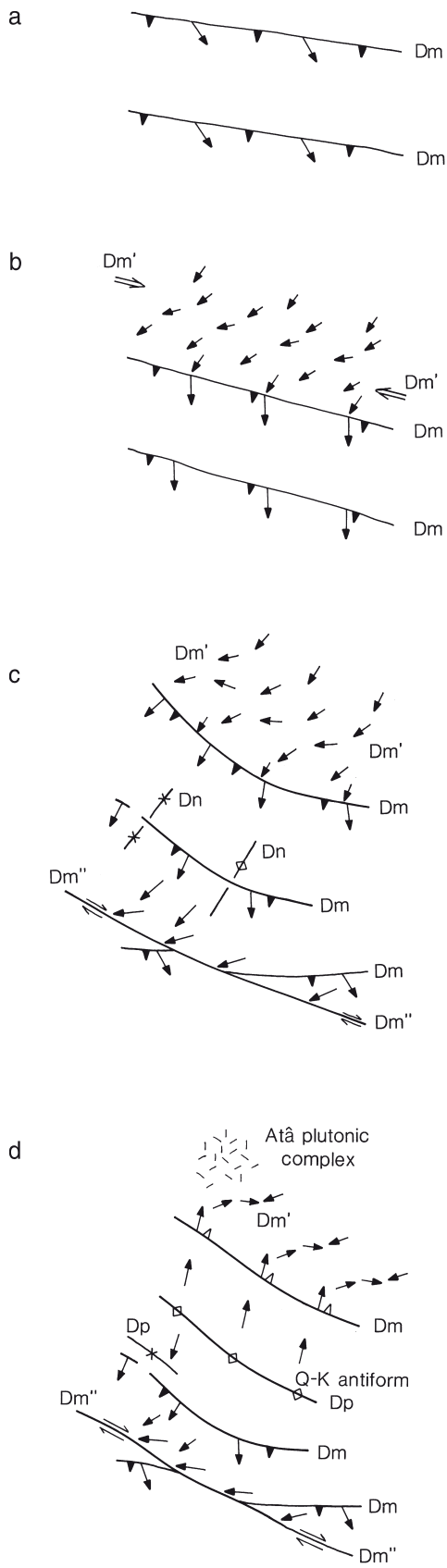
Reworking of Archaean gneisses during the Proterozoic is often reflected by disturbance of the Rb-Sr isotope system (Kalsbeek 1981; Dawes *et al.* 1988), but this is not always the case (Andersen & Pulvertaft 1985). The migmatitic biotite-quartz-feldspar gneisses at Laksebugt yield well-fitted Rb-Sr whole-rock isochrons. If these isochrons date migmatisation, then the later deformation and metamorphism have not significantly disturbed the isotope system. This could imply that the ages of both D_m and $D_{m'}$ are close to the age of migmatisation; about 2700 Ma. However, given that it is difficult to predict the resilience of the Rb-Sr system to resetting, this argument for an Archaean age for these deformations is not strong.

Shear zones of the D_m and $D_{m''}$ deformation phases are cut by strongly discordant Proterozoic ultramafic lamprophyre dykes on Arveprinsen Ejland (Larsen & Rex 1992). Several narrow dykes are exposed at the coast between Qunnersuaq and Klokkerhuk (Fig. 3) where D_n and D_p folds are common. The dykes post-date D_n folds but are deformed to varying degrees of intensity by moderately-inclined, gently south-east-plunging D_p folds (Fig. 7f). There is also a spatial relationship between D_p folds and the ultramafic lamprophyre dykes which further implies that dyke emplacement may be synkinematic with D_p. Partial or complete recrystallisation of the dykes to hornblende schist accompanied folding.

East of Ataa Sund (Fig. 1) ultramafic lamprophyres cut Palaeoproterozoic metasedimentary rocks (Marker & Knudsen 1989; Thomsen 1991). Two ultramafic lamprophyre dykes, exposed on the mainland east of Ataa, have yielded K-Ar ages of 1782 ± 70 Ma and 1743 ± 70 Ma respectively (Larsen & Rex 1992; see also Rasmussen & Holm 1999, this volume). These ages are similar to a Rb-Sr whole-rock age of 1760 ± 185 Ma for fine-grained Palaeoproterozoic sediments on Anap Nunaa (Kalsbeek *et al.* 1988) and probably reflect cooling

Fig. 11. Structural evolution of central and southern Arveprinsen Ejland. **a**: D_m shear zones developed throughout the area with displacement of the hanging wall to the north-west. **b**: A right strike-slip shear zone ($D_{m'}$) has reworked D_m shear zones at the southern margin of the Atâ tonalite. Reworking is reflected by rotation of linear fabrics. **c**: D_n folding associated with a right strike-slip shear zone ($D_{m''}$) on southern Arveprinsen Ejland. **d**: Folding (D_p) of the shear zones on central Arveprinsen Ejland by the Qunnersuaq–Kussuk antiform. D_m shear zones retain a reverse-slip shear sense in the southern limb of the fold (closed triangles) but have a normal-slip shear sense in the northern limb of the fold (open triangles).

following low-grade metamorphism in the metasedimentary rocks and in the dykes. Since ultramafic lamprophyres post-date D_m and $D_{m'}$ shear zones, these ages provide an upper age bracket for D_m and $D_{m'}$ deformations on Arveprinsen Ejland.

Proterozoic reworking of the Disko terrane

The Atâ tonalite and the greenstone belt on Arveprinsen Ejland are virtually unaffected by Proterozoic deformation over a wide area north-east of Disko Bugt (Kalsbeek *et al*. 1988). These Archaean rocks represent the type area for the Disko terrane as defined by Van Kranendonk *et al*. (1993). Migmatitic, biotite-quartz-feldspar gneisses to the south of the Atâ tonalite are also of Archaean age, but the age of intense ductile deformation and amphibolite facies metamorphism in these high grade gneisses is uncertain. More geochronology is therefore required to identify the extent of intense Archaean and Proterozoic deformation in the Disko terrane in the Disko Bugt region.

The structural style of the high-grade gneisses on central and southern Arveprinsen Ejland (low-angle ductile shear zones folded by major, upright antiformal or dome-like structures – the Qunnersuaq–Kussuk antiform) is typical of surrounding Palaeoproterozoic belts. In central Baffin Island, upright gneiss domes fold low-angle, polyphase, ductile shear zones (Henderson *et al*. 1988, 1989) and later sinistral strike-slip deformation was superposed on the structures (Henderson 1981). Farther north in West Greenland, upright folds of flat-lying structures are typical of the structural style of the Rinkian belt (Henderson & Pulvertaft 1967; Grocott & Pulvertaft 1990). Closer to north-east Disko Bugt, there are also strong similarities between the structural style on eastern Nuussuaq, where Archaean crust has been affected by strong Proterozoic deformation in the Rinkian belt, and in the domain south of the Atâ tonalite on the mainland east of Ataa Sund (Escher *et al*. 1999, this volume). In the latter area, basic and picritic sills in the vicinity of Paakitsoq thought to be of Proterozoic age are affected by west-vergent, low-angle ductile shear zones that may correlate with D_m shear zones in central and southern Arveprinsen Ejland. All these points mitigate in favour of the main shear zone deformation in central and southern Arveprinsen Ejland (D_m) being of Proterozoic rather than Archaean age.

On the other hand, Archaean supracrustal rocks

south-east of Anap Nunaa contain thrusts that appear to be truncated by the unconformity at the base of Proterozoic sedimentary rocks (Garde & Steenfelt 1999, this volume). These thrusts can be traced to the south into the high-grade gneiss terrain east of Ataa Sund described by Escher *et al*. (1999, this volume) where they are presumably reworked by Proterozoic structures. This implies that strong Archaean as well as strong Proterozoic deformation, both characterised by low-angle shear zones, has affected the high-grade gneiss terrain south of the Atâ tonalite.

Conclusions

The main phase of deformation in the high-grade gneiss terrain of central and southern Arveprinsen Ejland involved displacements to the north-west on flat-lying ductile shear zones (D_m in Fig. 11a). The shear zones structurally underlie the Atâ tonalite which was consequently displaced north-west in the hanging wall of this shear zone system. The D_m shear zones were reworked by NE- to ENE-striking, right strike-slip shear zones responsible for clockwise rotation of the linear fabric near the southern margin of the Atâ tonalite ($D_{m'}$ in Fig. 11b) and an isolated right strike-slip shear zone south of Klokkerhuk ($D_{m''}$ in Fig. 11c). Locally, D_m shear zones are deformed by open to close, steeply-inclined, south-west-plunging D_n folds which have north-east-striking axial surfaces. The D_m-$D_{m'}$ shear zone system was deformed by major folds associated with the final phase of ductile deformation (D_p) between Qunnersuaq and Kussuk (Fig. 11d). Major and minor folds associated with D_p deformation have NW–SE-trending axial surfaces steeply inclined to the north-east and with gently south-east-plunging hinge lines.

The age of deformation in D_m and $D_{m'}$ ductile shear zones remains uncertain. At Laksebugt deformed rocks yielded an Rb-Sr whole rock isochron giving an age of 2672 ± 52 Ma suggested to date pre-shear zone migmatisation. This establishes the Archaean age of the rocks in the high-grade gneiss terrain on southern Arveprinsen Ejland and provides a lower limit on the age of deformation. It does not necessarily mean that the deformation was of Archaean age. Structural style in the high-grade gneiss terrain on Arveprinsen Ejland is similar to that in the Rinkian belt to the north of the Atâ tonalite where Archaean rocks have been strongly affected by Proterozoic deformation and metamorphism. Moreover, there is evidence from the mainland east of Ataa Sund that intense deformation on low-

angle shear zones, with similar displacement patterns to the D_m shear zones on Arveprinsen Ejland, is of Proterozoic age. The last phase of folding on Arveprinsen Ejland (D_p) appears to be the same age as a suite of ultrabasic lamprophyre dykes which have given K-Ar mineral ages of about 1750 Ma. This provides an upper limit on the age of the main D_m and $D_{m''}$ deformations on Arveprinsen Ejland.

Acknowledgements

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