Dykes and deformation in the Ikertôq zone of the Nagssugtoqidian at Søndre Strømfjord Airport, West Greenland

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van der Molen, I.: Dykes and deformation in the Ikertôq zone of the Nagssugtoqidian at Søndre Strømfjord Airport, West Greenland. *Bull. geol. Soc. Denmark,* vol. 32, pp. 101–106. Copenhagen, September, 4th, 1984. https://doi.org/10.37570/bgsd-1983-32-06

The geology of the southern part of the Nagssugtoqidian of W Greenland is examined in a traverse of the amphibolite facies Ikertôq zone at Søndre Strømfjord Airport. The continuous fanning of the foliation, shallow dips near the Archaean – Nagssugtoqidian boundary and steeper dips further north, is not indicative of a two-stage history for the zone. The structures of the deformed Kangâmiut dykes and the gneisses in which they occur have been studied in some detail. It is concluded that deformation synchronous with and postdating the intrusion of the dykes has been intense enough to rejuvenate the fabric of the gneisses to a post-intrusive age.

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The geology of the Ikertôq zone – the amphibolite facies southern part of the Nagssugtoqidian in contact with the Archaean of W Greenland (Escher et al. 1976b; Bak et al. 1975) – is best known in the coastal area (see various papers in Rapp. Grønl. geol. Unders. *89,* 1979). Further inland, major outlines have been established by reconnaissance work (Escher et al. 1970) that resulted in the study of Escher et al. (1975) on the reorientation of the Kangâmiut dyke swarm. I have made a traverse across the Ikertôq zone near Søndre Strømfjord Airport (henceforth the airport). Results relevant to the regional interpretation are presented here. The discussion centers on two questions. Firstly, is there evidence in the inland portion of the zone for a two-stage history of transcurrent shear followed by southward thrusting, as established for the coastal area? Secondly, can the fabric of the gneisses at the airport be much older than intrusion of the dykes, as suggested by whole rock age determinations?

Observations

The map

The area visited (fig. 1) consists mostly of light-grey biotite gneisses and of basic dykes that have been deformed and metamorphosed to well-foliated, garnet-bearing amphibolites. Compositional variation occurs between and within dykes (cf. Escher et al. 1976b; Kalsbeek et al. 1978); some dykes have such large proportions of plagioclase and biotite that they are better described as dioritic gneiss. The frequency of dykes varies but they have been found across the full width of the Ikertôq zone. Minor dykes occur as far north as the kink in Isortôqelven, i.e. well into the granulite facies terrain characterised by hypersthene in the gneiss and by a brown weathering colour. In this area dykes are normally concordant amphibolite bodies, but in one case thin amphibolite layers were found to dip more steeply to NW than the foliation in the granulite gneisses.

Massive granulite and granitoid rocks with dark schlieren in the Archaean to the south are intruded by subvertical, NE-striking dykes that have a planar fabric of amphiboles in their margins and a directionless igneous texture in their centers (Escher et al. 1975).

The boundaries of the Ikertôq zone are not easily defined in the field, in part because the transitions are not sharp. Thus, at the northern limit, bands of light-grey gneiss alternate with brown gneiss over the width of a few kilometres;

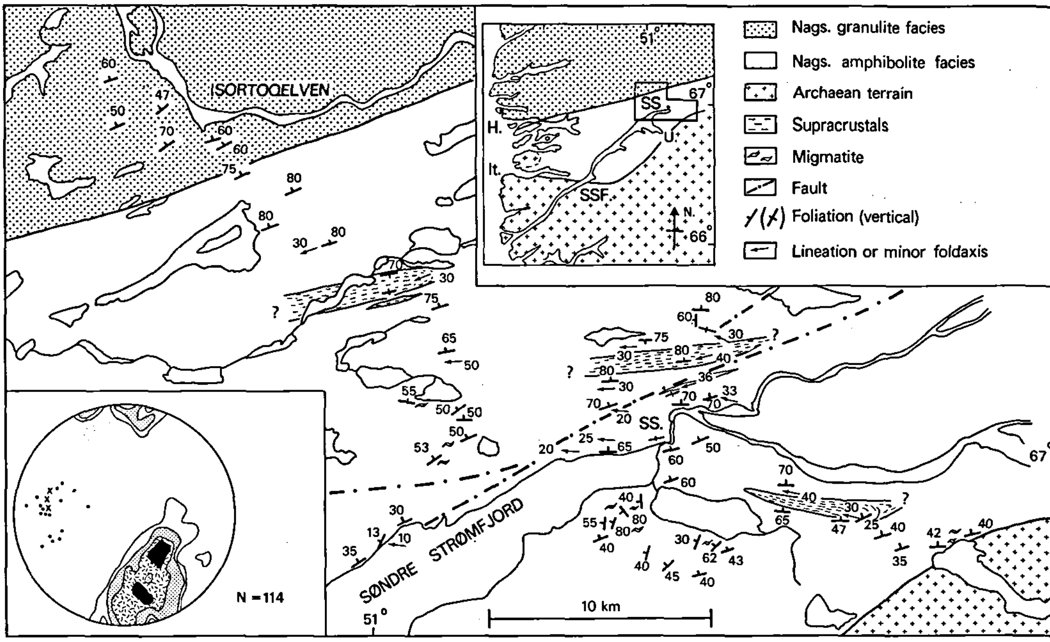

Fig. 1. Geological map of the Ikertôq zone at Søndre Strømfjord Airport. Inset: The W coast of Central Greenland: H., Holsteinsborg; It., Itivdleq; SSF., Søndre Strømfjord; SS., Søndre Strømfjord airport; U., Umîvît bay. Other inset: Poles to foliation (contoured at 1, 2½, 5 and 7½% per 1% area); lineations (dots) and fold axes (crosses).

similar bands, often coinciding with NE-striking dykes, are found at the southern contact with the Archaean terrain. The dip of the Archaean-Nagssugtoqidian boundary is not known.

There are three occurrences of supracrustals in the area. Their extent has not been mapped in detail, but scattered field evidence and photo-interpretation suggest tight synformal structures which close to the east. The supracrustals consist of mica schists (often graphitic) and fine-grained amphibolites. Sillimanite is a common mineral in the northernmost unit. In the southern occurrence, quartzite, quartzofeldspatic sediments, basic metavolcanics and calcsilicate rocks are encountered as well as garnet-mica schists. Talbot (1979) gave a description and a detailed structural analysis of a similar supracrustal unit some 80 km to the southwest of the present area.

Directly south of the head of the fjord dykes are agmatitically brecciated and invaded by a quartzofeldspathic groundmass in a generally poorly foliated area of gneiss and migmatite. Dykes trending or dipping differently from the weak fabric of the country rock are also found. This region may be interpreted as an augen in the Ikertôq zone, which remained relatively unaffected by the deformation giving rise to a penetrative foliation elsewhere.

Some large subvertical faults transsect the area. Brittle-ductile deformation and an incomplete retrogression to greenschist facies assemblages (epidote, quartz, chlorite) are restricted to the immediate vicinity of these faults.

Structure, discordant and concordant dykes

The orientation of the regional foliation varies, with steep dips dominating in the northern and central portions and shallower dips in the southern part of the Ikertôq zone (fig. 1). A N-S cross-section at the airport would show fanning of the foliation. There are no overprinting relations to suggest that the shallower dips have been formed later than the steeper dips further north. Where they occur, the axes of minor folds and mineral lineations in gneiss, in amphibolite dykes and in supracrustals are parallel to each other with a westward plunge of approximately 25° (fig. 1). This orientation does not change markedly upon approaching the Archaean terrain. The plunge

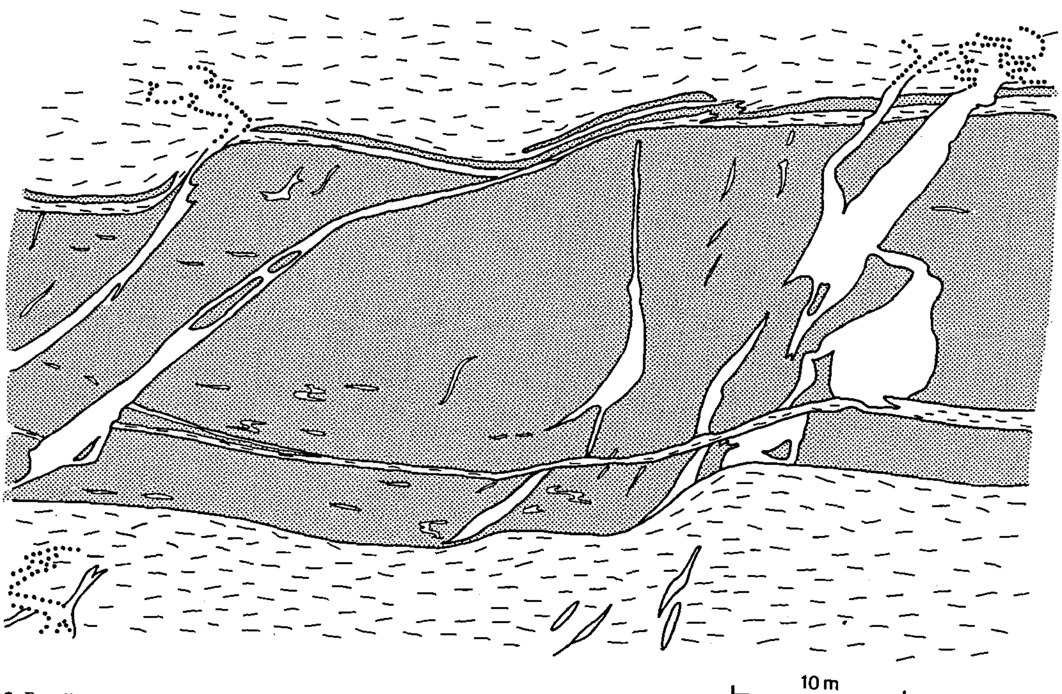

Fig. 2. Boudinaged basic dyke with pegmatite between separated boudins. Note folds of pegmatite outside the dykes. Outcrop behind Dining Hall of American Airbase at Søndre Strømfjord.

direction in the SE of the map area makes a small angle with the strike of the Nagssugtoqidian boundary.

The foliation in the Ikertôq zone gneisses is very rarely at an observable angle to the contact with major dykes. Thick dykes (5–50 m) are apparently not folded. One example of dyke intersection at a small angle has been found but in all other cases dykes are parallel. Offshoots of major dykes are locally discordant to the gneissic foliation; elsewhere apophyses are folded or rotated into close parallelism with parent dykes – if they have not always been so.

Within the gneisses, bands with a planar fabric alternate with highly elongate lenses containing numerous tight to isoclinal folds, both with and without axial-plane foliation but always with the long limbs of folds parallel to, or defining the enveloping surface of the lenses and the regional folation. Bands and lenses alternate on the m-scale and on much larger scales when their recognition depends on degree of exposure. In one lens, basic dykes 10–50 cm wide have been found subparallel to the axial plane of folds and cutting across the gneissic foliation in the hinges.

More commonly thin amphibolite layers are folded along with the gneiss. At the Inland Ice margin, 20 km ENE of the airport, 10 cm to m-wide dykes are found to cross-cut an early gneissic foliation and to be subsequently folded and refolded with the gneiss into parallelism with the regional foliation.

Boudinage and plastic deformation of the dykes

Boudinage of basic dykes is common in the area. Spectacular photographs of this structure at Søndre Strømfjord airport and at Umîvît bay (the southern head of the fjord, see inset fig. 1) were published by Ramberg (1955) and by Escher et al. (1975, 1976b). Pinch-and-swell structure predating the break-up of dykes is rare. Most boudinage commenced with the alignment of microfractures to produce parallel-sided strips or blocks of amphibolite that subsequently became separated while the spaces in between were filled with various proportions of pegmatite and gneiss.

The non-ductile component of layer-parallel extension reflected in the relative rotation and the separation of boudins varies widely from one dyke to the next in the area. For the dyke in fig. 2 it is about 25%. Its extension direction has been established from the orientation of the boudin separation planes and the dyke's enveloping surface to be 265/27, the direction of mineral lineations and minor fold axes in the area (*fig. 1*). Other dykes, with the same strike and in the same exposure, show unequal non-ductile components of extension from more than 50% to less than 5%. If the mutual parallelism of dykes is considered to be original one might conclude that the E-W horizontal strain component varies rapidly from one dyke to the next. It is more likely, however, that similar large horizontal extensions were imposed on all dykes. In some this has been achieved by early boudinage followed by separation of boudins, in others plastic deformation continued.

Ductile deformation preceded, coincided with and followed boudinage of the dykes. Boudins have a well-developed amphibole foliation, that is axial planar to internal isoclinal folds (fig. 2). Foliation and fold limbs are cross-cut by boudin-separating pegmatites. The plastic straining following the initial separation of angular boudins has caused their shape to be modified to lensoid cross-sections in evolved cases (cf. Wegmann 1932).

Fig. 3 shows an example of ductile layer-normal shortening in amphibolite. This shortening has been accompanied by ductile layer-parallel elongation in both the amphibolite and the gneiss.

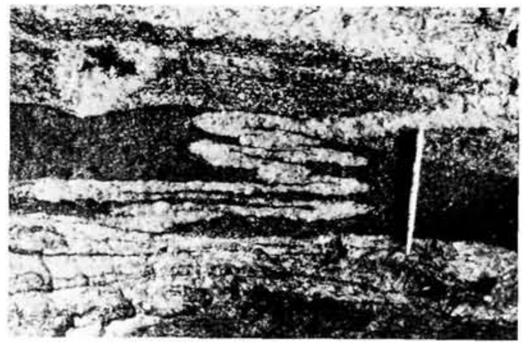

Fig. 3. Ductile layer-normal shortening of a minor amphibolite layer indicated by ptygmatic folding of a narrow vein. The less folded appearance of the same vein in adjacent gneiss points to different strain histories for gneiss and amphibolite. Layer-parellel extensions must have been the same in both, however.

Discussion

Post-intrusive strain

The regional structure immediately after intrusion of the dykes would have to be known to determine the magnitude of later strain and to evaluate the type of deformation causing it. Escher et al. (1975) calculated a shear strain of $\gamma \simeq 6$ associated with post-intrusive thrusting for a part of the southern margin of the Ikertôq zone halfway between the airport and the west coast, where there is evidence that dykes now within the zone had originally the same orientation as those in Archaean terrain to the south. The same cannot be assumed for the present area. When pre-emplacement or syn-emplacement deformation can be demostrated, intrusion may have occurred preferentially along existing planes of weakness, different in orientation from the attitudes attained in undeformed Archaean (e.g. Watterson 1974). The observed general parallelism of dykes is not indicative of high strains; it may be an original feature (see the cover photograph of Rapp. Grønl. geol. Unders. *89*, 1979). Nevertheless, the intensity of pre-boudinage deformation of dykes has been sufficient to cause minor isoclinal folds in them, a well-developed amphibole fabric and near-parallelism of dykes and apophyses, while the tabular shape of the dykes was maintained. Post-intrusive ductile deformation did not create widespread pinch and swell of the dykes despite likely rheological contrast with surrounding gneiss. Moreover, the demonstrated extension of the dykes, whether attained in a ductile or a non-ductile fashion, implies an equal dyke-parallel elongation in gneiss surrounding the dyke. Strain in the gneiss is likely to be different from that in the dykes (fig. 3), but the dyke-parallel component of strain is the same as shown by strain compatibility considerations (e.g. Cobbold 1977; Ramsay & Graham 1970).

The structural evidence presented does not require or support a two-stage deformation history for the Ikertôq zone gneisses at the airport. Unlike the sequence at the west coast, where southward thrusting has been shown to postdate dextral transcurrent shear (e.g. Watterson 1974; Grocott 1979; Korstgård 1979), and in contrast to an interpretation for the inland portion of the Ikertôq zone given by Talbot (1979), the fan-like arrangement of foliation planes may have formed during a single, extended deformation period with regional variation in the orientation, and probably in the intensity of the finite strains imposed. In this context, note that the steep, E-W striking foliation and the mineral lineation dipping 25°W are the same as those observed in the Itivdleq area (Nash 1979; Korstgård 1979). The difference is that these structures are pre-intrusive at the coast and post-intrusive at the airport as further argued in the next section.

Fabric ages

For lack of evidence to the contrary, the intrusion age of all dykes in the W Greenland dyke swarm is taken to be ~ 1950 my as determined with the Rb-Sr whole-rock method by Kalsbeek et al. (1978) on undeformed dykes in the Archaean terrain at the coast. Kalsbeek et al. (1978) correlated the Nagssugtoqidian orogeny with the Laxfordian of Scotland and the Hudsonian of Canada over the period ~ 2000–1700 my. There is satisfactory evidence that, within the Ikertôq zone, deformation occurred prior to, during and after intrusion. Questions are (1) whether the presently observed fabric further inland is caused mainly be pre-intrusive deformation (collectively referred to as 'Nag-1') and only moderately affected by post-emplacement deformation ('Nag-2') and (2) whether all Nag-1 fabrics, i.e. those to which dykes are intrusive, are indeed Naggsugtoqidian in age, or whether some are up to 600 my older as discussed by Kalsbeek (1979).

Talbot (1979, fig. 1) ascribed the tectonic fabric at and north of the airport to Nag-1, restricting dominant Nag-2 influence to a ~ 15 km wide strip at the southern margin of the Ikertôq zone. Kalsbeek (1979) concluded from a 2600 my Rb-Sr whole rock age for gneiss collected from a quarry at the airport that "the strong shearing and metamorphism of the rocks did not take place during Nag-2". I suggest that the presently observed fabric of the gneisses generally postdates intrusion of the dykes for the following reasons: (1) the foliation and the mineral lineation in the gneiss are parallel to the foliation and the mineral lineation in the amphibolitised dykes, as well as to those in nearby supracrustals. (2) The described plastic deformation of dykes before, during and after the initial stage of break-up into boudins cannot have occurred without concomitant deformation of the gneisses in which they occur. (3) Cross-cutting pegmatites between moderately separated boudins were dated by Hickman (1979, preliminary results) at ~ 1700 my. Occasionally such pegmatites are found to extend into the gneiss and to be folded with the gneissic foliation in the axial plane (fig. 2).

The 2600 my age, then, does not reflect the time of the last deformation affecting the fabric observed. One may ask therefore whether similar ages for gneisses with a pre-intrusive fabric (Kalsbeek 1979; Kalsbeek & Zeck 1978a) do not also reflect an older event which did not cause that foliation. It is common after all that systems remain closed and that ages are retained despite younger events affecting the rocks. However, the old ages were determined on layered gneiss specimens and Kalsbeek & Zeck (1978) and Kalsbeek (1979) argued that Rb was sufficiently mobile for the Rb-Sr whole-rock system to reset when the gneisses acquired a metamorphic layering. One would wish for a better agreement between absolute ages and relative ages. Metamorphic segregation and resetting of Rb-Sr ages during the Nagssugtoqidian may have occurred only locally such that conflicting interpretations are obtained from separate outcrops between which structural relations cannot be established without ambiguity. An exposure ideally suited to settle this question is found at the Inland Ice margin ENE of the airport. The intensity of post-dyke deformation in this continuous outcrop varies rapidly so that gneissic banding older than the dykes has been preserved locally while postintrusive deformation and segregation are marked elsewhere.

Discordances between country-rock fabric and dyke contact are *per se* not conclusive evidence of significant chronological lapses between deformation and intrusion. Kalsbeek & Zeck (1978a,b) studied minor amphibolite facies shear zones enveloping dykes intruded into granulite facies gneisses south of the Ikertôq zone. Placing emphasis on locally preserved discordance, they proposed that dykes were emplaced into pre-Nagssugtoqidian shear zones, the former closely following the outline of the latter. However, inspection of the clearly presented field evidence (Kalsbeek & Zeck 1978b, figs 16 and 17) favours the less complex interpretation that the dykes intruded while the shear zone developed. Parallelism and obvious discordance may both result from intrusion during a deformation event.

Conclusion

Regardless of a possible 2600 my event, the fabric of the gneisses in the Ikertôq zone at Søndre Strømfjord Airport has been caused by deformation postdating intrusion of the dykes. There are no indications to suggest that steep dips in the north existed prior to intrusion while only shallow dips to the south developed afterwards. The variable attitude of foliation is a reflection of the regional variation of deformation during and after dyke intrusion. This finding does not preclude the distinct possibility that the localisation, orientation and intensity of early Proterozoic, Nagssugtoqidian strain have been influenced by preexisting structures in the crust.

Acknowledgements. This work was done while I was associated with Cornell University, Ithaca, NY (USA). T. S. Olsen (Aarhus/Cornell) accompanied me in the field and reviewed the manuscript. His help, that of Profs. D. L. Kohlstedt and J. M. Bird and Dr. M. S. Weathers at Cornell, and that of Dr. K. Sørensen (DTH, Lyngby, Denmark) are gratefully acknowledged. Funding was provided by USGS 14-08-0001-10119 to Bird and Kohlstedt.

Dansk sammendrag

De geologiske forhold i den sydlige del af Nagssugtoqiderne i Vestgrønland er blevet undersøgt i en travers igennem amfibolitfacies Ikertôq zonen ved Søndre Strømfjord lufthavn. Den jævne vifteform tegnet af foliationen (lave hældninger tæt ved grænsen mellem de archæiske gnejser og Nagssugtoqiderne og stejlere hældninger længere nordpå) tyder ikke på, at Ikertôq-zonen her har gennemgået en to-trins strukturel udvikling under den Nagssugtoqidiske orogenese. Strukturerne i deformerede Kangâmiut gange og i de tilgrænsende gnejser er blevet undersøgt i detaljer. Konklusionen er at deformation samtidig med og kort efter gangintrusionen var intens nok til at overpræge gnejserne med et helt nyt, post-gangintrusion, strukturelt mønster.

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