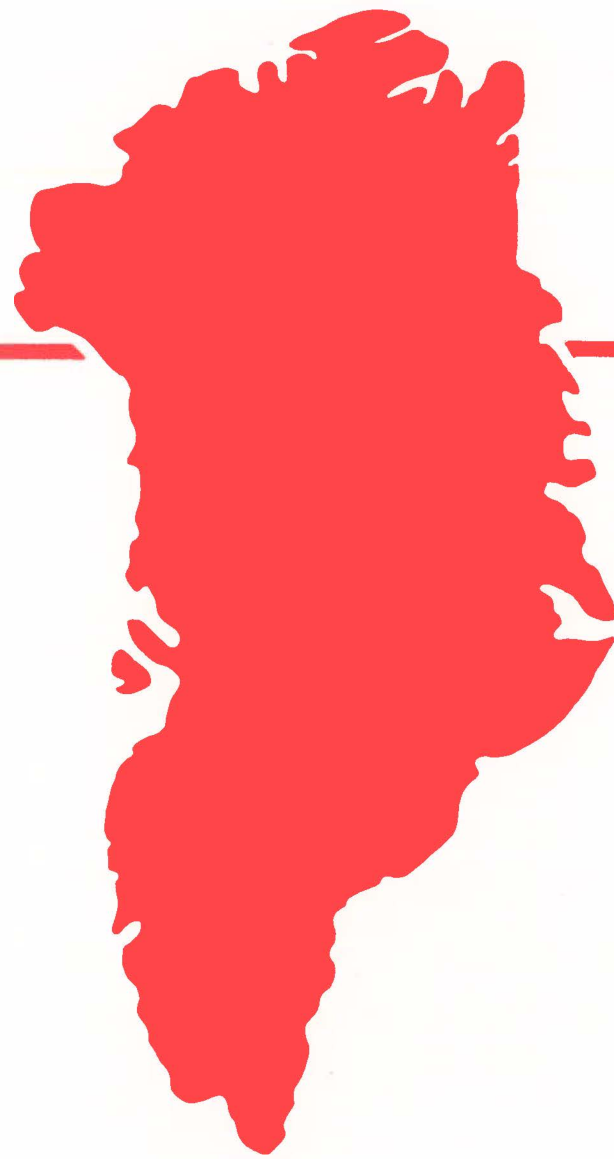
Research and bibliography on the Nagssugtoqidian orogenic belt, West Greenland



Feiko Kalsbeek

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
Ujarassiortut Kalaallit Nunaanni Misissuisoqarfiat
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Abstract

This paper presents a brief overview of research in the early Proterozoic Nagssugtoqidian orogenic belt of West Greenland, together with a comprehensive bibliography.

Contents

Introduction

Study of the Nagssugtoqidian orogen was initiated by the paper of Ramberg (1949) 'On the petrogenesis of the gneiss complexes between Sukkertoppen and Christianshaab, West Greenland'. Ramberg demonstrated that a swarm of basic dykes, the 'Kangâmiut dykes', which are well preserved in the area between Sukkertoppen and Søndre Strømfjord, become strongly deformed and metamorphosed further north in the area south of Holsteinsborg (for localities see attached figure). This deformation and metamorphism was obviously due to later orogenesis, and the resulting orogenic belt was by Ramberg (1949) termed 'the Nagssugtoqides' after the fjord Nagssugtoq (Nordre Strømfjord). In later papers this orogen is most commonly referred to as 'the Nagssugtoqidian mobile belt'. Ramberg's work gained international attention through Noe-Nygaard's (1948, 1952) presentation at the 18th International Geological Congress in London, 1948.

Most later work on the Nagssugtoqidian belt was carried out by geologists from the Universities of Aarhus and Liverpool. Aarhus geologists, sponsored by GGU, worked in the Agto region in two periods: the 'Agto 1 project' from 1966-1969 under the direction of E. Bondesen (see papers in Bondesen, 1970a), and the Agto 2 project from 1975-1978 under direction of N.Ø. Olesen and K. Sørensen. The work resulted in a detailed map of the Agto region, scale 1:100 000 (Olesen, 1984), and a number of theses and papers in international journals. About simultaneously, the Liverpool group, with participants from other U.K. universities, studied the southern boundary of the belt under the 'Liverpool University Precambrian Boundary Programme', led by J. Watterson. Also this programme resulted in a number of theses and publications. In October 1978 a seminar on the geology of the Nagssugtoqidian belt was held at Aarhus, with participants of both groups, and results of the work were published in GGU's Report 89 'Nagssugtoqidian Geology' edited by Korstgård (1979a).

The only regional geological map covering the belt is GGU's 1:500 000 sheet 3, Søndre Strømfjord-Nûgssuaq (Escher, 1971). This map is only partly based on field mapping: reconnaissance along the fjords and coast by Noe-Nygaard and Ramberg (1961), by GGU in the southern part of the belt (Escher, 1966; Escher et al., 1970) and, in the north, by Henderson (1969). For large parts of the area, however, the geology

Fig 1. Geological sketch map of the Nagssugtoqidian belt, West Greenland

shown on the map is based on the interpretation of aerial photographs, and the map is therefore less reliable in most inland areas.

Regional aeromagnetic and radiometric surveys have been carried out during the 1970's over large parts of the Nagssugtoqidian belt by L. Thorning and K. Secher. An aeromagnetic map covering most of the belt is available (Thorning, 1984), and a detailed aeromagnetic map has recently become available over the northernmost part of the belt (Thorning, 1993). Radiometric maps are under preparation.

Regional geochemical studies, based on stream sediments, have recently been carried out by A. Steenfelt, and geochemical maps are available for most of the belt (Steenfelt & Dam, 1991; Steenfelt et al., 1992, 1993). In combination with aeromagnetic data these maps give important information on the subdivision of the belt into distinct crustal domains. Furthermore, they give clues to sites of potential economic interest (Steenfelt, 1992).

Apart from the regional geochemical mapping programme few studies have dealt with the mineral potential of the Nagssugtoqidian belt. Results of these investigations are briefly described at the end of this paper. Documentation of this work is available in a few published papers and in company reports archived at GGU.

The list of references in this report contains most publications on the area containing the Nagssugtoqidian orogen. Papers on quaternary geology and glaciology are not included, but most papers on other topics that have no direct relationship to the Nagssugtoqidian orogeny (e.g. on late kimberlite dykes and associated rocks in the Holsteinsborg district) are listed. Papers on the belt can be subdivided according to a number of main topics which are briefly treated in the following.

Main lithologies

Lithological and petrographic descriptions of selected areas as well as detailed structural data are available in a number of theses, mainly from Aarhus and U.K. Universities. These are not always easily available, but parts of the information have been published, mainly in GGU's Report series. A summary of lithology and structure within the Agto map sheet area was presented by Olesen et al. (1979), whereas more detailed descriptions are given in Henderson (1969), K. Sørensen (1970), Skjernaa (1973), Winter (1974) and Mengel (1983a). The main rock types are tonalitic to granodioritic gneisses with biotite, hornblende and hypersthene as main mafic minerals. Amphibolites (Mengel, 1983a) and metasedimentary rocks (commonly with marble layers) also occur in large proportions; ultramafic rocks are locally present as lenses. Although large parts of the area are in granulite facies, the presence of hypersthene is restricted to rocks with a suitable chemical composition (Korstgård, 1979b; Olsen, 1979).

Charnockitic augen granites occur at several localities, for example on the island Rifkol. Petrographic and chemical data for these rocks have been presented by Hansen (1979); they appear to belong to the anorthosite-charnockite suite. Kalsbeek et al. (1984) obtained an Archaean (c. 2650 Ma) Pb-Pb whole-rock isochron age for the granite on Rifkol. Granites are also present further east, in the inner part of the fjord system. Some are Archaean, others appear to be Proterozoic, and these have been interpreted as 'syn-collision' granites related to the formation of the Nagssugtoqidian belt (Kalsbeek et al., 1987).

Apart from the Kangâmiut dykes in the south, basic dykes are only locally present (e.g. Ellitsgaard-Rasmussen, 1951; Henderson, 1969; Glassley & Sørensen, 1979). Granodioritic dykes have been described from the area north of Holsteinsborg (Davidson & Park, 1978).

Supracrustal rocks

Both Archaean and Proterozoic supracrustal rocks are present in the Nagssugtoqidian belt, and it is as yet not always possible to infer their age from field observations.

Within the Agto map sheet area brown-weathering supracrustal sequences are very prominent. With the help of geochemical data, Rehkopff (1984) concluded that both pelitic metasediments and metavolcanic rocks of andesitic to dacitic composition are present. These sequences commonly contain marble layers. Calcareous amphibolites occur locally (Winter, 1974). Sm-Nd and Pb-Pb isotope data on metavolcanic rocks show they are of early Proterozoic origin, but the age is not well constrained (Kalsbeek et al., 1987). A Lu-Hf isotope study of detrital zircons from a metasediment sample collected by J. Korstgård yielded an early Proterozoic age (Stevenson & Patchett, 1990); apparently this sediment was derived from an early Proterozoic source area.

At the border between marbles and gneisses calc-silicates are common (P. B. Sørensen, 1970). Possible consequences of the silicification of marbles for the formation of granulite facies rocks have been discussed by Glassley (1983a, b).

Talbot (1979) described a supposed occurrence of Nagssugtoqidian supracrustal rocks at Sarfartup nunâ, south-east of Søndre Strømfjord. The outcrop was described as a klippe comprising a number of thrust sheets, each consisting of basement gneisses unconformably overlain by sediments and meta-pillow lavas. Steenfelt et al. (1993), however, were unable to confirm this interpretation. The age of the rocks in question is unknown.

Mica schists at Ikamiut, in the northern part of the Nagssugtoqidian belt have yielded Archaean Rb-Sr model ages (Kalsbeek, 1993). Similar mica schists in this part of the region are commonly associated with amphibolite (Henderson, 1969). Ellitsgaard-Rasmussen (1954) described well preserved metasediments, basic supracrustal rocks with pillow structures and basic intrusions from islands in the southern part of Disko Bugt. Appel (1988) found tourmaline-rich layers in mica schists on these islands.

Kangâmiut dykes and their deformation

Kangâmiut dykes form an intense swarm, some 60 km wide and more than 100 km long in the southern part and to the south of the Nagssugtoqidian belt. In the south the dykes have a north-northeastern trend and are 20-60 m wide. Several older generations of dykes can be recognised in the same area. Escher et al. (1976) regard the Kangâmiut dykes as part of a large 'North Atlantic Proterozoic dyke swarm' with representatives in Greenland, Scotland and Labrador.

The first detailed description of Kangâmiut dykes is from Windley (1970): many dykes south of the Nagssugtoqidian border are multiple intrusions, composed of hornblende dolerite along the margins and foliated (garnet) amphibolite or quartz diorite in the centres. Strongly foliated dyke centres may occur within dykes with totally undeformed margins. Windley (1970) concluded that the amphibolite cores of the dykes formed immediately upon intrusion, and not during later metamorphism, and that they crystallised from a water rich basic magma (Windley, 1970). Kangâmiut dykes are Fe-rich tholeiites (Windley, 1970; Fahrig & Bridgwater, 1976). Their age of emplacement is c. 1950 Ma (Kalsbeek et al., 1978).

When entering the Nagssugtoqidian belt, the dykes are rotated clockwise into an easterly direction, parallel to the foliation in the surrounding gneisses. Simultaneously they become deformed and are transformed into amphibolites. The reorientation of the dyke swarm has been described in detail by Escher et al. (1975). According to these authors, deformation of the dykes was the result of rotational simple shear strain in a major thrust zone dipping c. 30° NW, with a direction of movement upward to the SE. Because two main dyke orientations are present south of the Nagssugtoqidian boundary it was possible to estimate the degree of crustal shortening from calculated shear strain as c. 66%. Escher & Watterson (1974) expand on these results in a general study of the reorientation of previous structures during crustal shortening normal to the strike of an orogenic belt.

In detail the relationship between Kangâmiut dyke intrusion and deformation proved to be more complex, especially in the western part of the area. Locally, undeformed dykes have been emplaced into earlier shear zones. Furthermore, in the border zone there is evidence for deformation during emplacement of the dykes (Bridgwater et al., 1973a; Watterson, 1974; Escher et al., 1975). In these cases the ENE orientation of the dykes may be controlled by the pre-existing structure of the country rocks rather than being the result of later reorientation. Within shear zones non-foliated and non-metamorphosed dykes may have lensoid outcrop patterns; this has been interpreted as an original intrusive feature rather than being the result of boudinage during later deformation (Nash, 1979a).

The inferred relationships between shear zone formation and Kangâmiut dyke intrusion has led to a subdivision of Nagssugtoqidian tectonic activity into two phases. An older event ('Nag.1') predating, or more or less simultaneous with dyke emplacement, and a younger phase ('Nag.2'), during which the dykes were deformed. Transcurrent shear zones in the southern margin of the mobile belt were regarded to be generated during Nag.1, and post-dyke thrusting to be a Nag.2 phenomenon (e.g. Bridgwater et al., 1973a). Later age determinations showed that some of the shear zones were formed during the late Archaean, much earlier than emplacement of the Kangâmiut dykes (Hickman, 1979), and Kalsbeek (1979) suggested that the use of the terms Nag.1 and Nag.2 should be avoided.

Korstgård (1979c) studied changing mineral parageneses in Kangâmiut dykes when followed northward into the Nagssugtoqidian belt. North of the fjord Ikertôq the dykes are in granulite facies. By comparing mineral parageneses in dykes and country rock it was possible to differentiate between Archaean and Proterozoic metamorphic zonation. Chemical changes accompanying transformation into amphibolites were studied by Zeck & Kalsbeek (1981) and Zeck et al. (1983). No drastic change in chemistry was found, but for some elements statistically significant differences were detected.

Main structures

On a regional scale, the Nagssugtoqidian belt comprises large lenticular areas, up to tens of km in size, charcterised by complex fold interference structures (e.g. K. Sørensen, 1970; Skjernaa, 1973). These areas are separated by major shear zones, the 'linear belts', in which the foliation has a strong ENE-trending preferred orientation. According to Bondesen (1969) the main units of supracrustal rocks occur exclusively within the synclinal cores of younger, ENE trending folds. Most structures in the centre of the belt, both folds and shear zones, appear to be of early Proterozoic origin (Kalsbeek et al., 1984).

The linear belts comprise both major thrusts (e.g. Escher et al., 1975) and transcurrent shear zones (e.g. Bak et al., 1975a). Because of the abundance of linear belts and the east-northeastern trends of late folds, the Nagssugtoqidian terrain has a very pronounced ENE striking tectonic grain which is also clearly reflected in the topography and on aeromagnetic maps (Thorning, 1984, 1993).

Shear zones

Investigation of the various shear zones has played a major role in the study of the Nagssugtoqidian belt. The most important are the Ikertôq-Itivdleq zone south of Holsteinsborg and the Nordre Strømfjord shear zone further north. The Itivdleq shear zone is regarded as a southern branch of the Ikertôq zone. Transcurrent shear zones represent the ductile deep-crustal expression of major transcurrent faults, with displacements of at least 100-150 km, and they are evidently related to large scale plate tectonic processes (e.g. Bak et al., 1975a; Watterson, 1978).

Ikertôq shear zone. The Ikertôq-Itivdleq shear zone lies near the southern margin of the Nagssugtoqidian belt. Its origin is complex: the southern Itivdleq zone was probably already in existence during the late Archaean (Hickman, 1979). Grocott (1979a) studied the northern part of the Ikertôq shear zone and showed that early transcurrent shear movement was followed by overthrusting in a south-southeasterly direction. Nash (1979b) obtained similar results in the western part of the Itivdleq shear zone: pre-Kangâmiut dyke transcurrent shearing was followed by a younger phase of deformation with N-S maximum principal stress direction. Further north, in the area north of Holsteinsborg, Davidson & Park (1978) determined the stress orientation for late Nagssugtoqidian deformation from deformed granodiorite dykes; it was the same as that observed in the Ikertôq shear zone.

Grocott & Watterson (1980) determined the shear strain in a 13 km profile across part of the zone, based on estimates of strain values (calculated from inter-limb angles of minor folds). Extrapolating to the whole shear zone an estimated dextral transcurrent displacement of some 175 km was calculated.

Relationships between deformation and metamorphic grade in and around the shear zones have been discussed by Korstgård (1979c) and Grocott (1979b). They are complex because the rocks were in Archaean granulite and amphibolite facies before being overprinted by early Proterozoic amphibolite to granulite facies metamorphism during shearing.

Van der Molen (1984; 1985) studied the mechanisms of deformation in the Ikertôq zone near Søndre Strømfjord airport. In Part I of Van der Molen's (1985) paper he discusses the importance of interlayer material transport during deformation, and in Part II the theoretical model is applied to structures (boudinage etc.) observed in the field.

Nordre Strømfjord shear zone. The Nordre Strømfjord shear zone has been studied in detail by Bak et al. (1975b) and Sørensen (1981, 1983). Sinistral displacement has been estimated as c. 120 km from the deformation and parallellisation of earlier structures. The shear zone narrows from a width of 15-20 km near the coast to c. 10 km near the Inland Ice. The orientation of the foliation varies fan-like from south to north across the shear zone, and it was concluded that the shear zone is wedge shaped, narrowing upwards. The eastern, narrower part, of the shear zone is thought to represent a (c. 10 km?) higher crustal level, in accordance with a lower grade of metamorphism in the east, amphibolite facies vs. granulite facies in the west. This feature has been used by Beckman et al. (1977) in a palaeomagnetic experiment on crustal uplift. Results of this study were not conclusive.

Sørensen (1983) considered the mechanisms of shear zone formation in terms of thermal and chemical weakening and subsequent hardening of the rocks. Chemical differences between the rocks within and outside the shear zone led to the suggestion that chemical ‘hydrolytic’ weakening may have played an important role. Based on chemical data for carefully collected samples, Sørensen & Winter (1989) elaborated further on the chemical differences associated with shear zone formation.

A detailed crystallographic analysis of the effects of deformation of intermediate plagioclase from rocks in the Nordre Strømfjord shear zone has been carried out by Olsen & Kohlstedt (1984, 1985).

Metamorphic evolution

The metamorphic evolution of the Nagssugtoqidian belt has not been investigated in detail. Korstgård’s (1979c) study of metamorphism of Kangâmiut dykes demonstrated zonation of Proterozoic metamorphism from low grade amphibolite facies to granulite facies in the area south of Holsteinsborg. The area east and north-east of Holsteinsborg is in early Proterozoic granulite facies, whereas Archaean amphibolite and granulite facies terrains are preserved south of the fjord Kangerdluarssuk.

P-T relations have been determined by Davidson (1979), Glassley & Sørensen (1980), Hansen (1981) and Mengel (1983b). Peak temperatures of the order of 900°C and pressures up to 10 kbar were reported. Mineral parageneses as orthopyroxene-sillimanite-quartz (Davidson, 1979) and garnet-clinopyroxene (replacing plagioclase + orthopyroxene; Hansen, 1981) testify to very high-grade metamorphism (garnet clinopyroxene granulite facies) in the centre of the belt. Glassley & Sørensen (1980) described the transition of amphibolite to granulite facies across a single metadolerite dyke under constant P and T in the Agto region. The variable mineral parageneses in these rocks were interpreted as the result of variations in water fugacity and activity of silica. Mengel (1983b) determined regional variations in P-T conditions along an E-W section through the Agto map sheet area. Metamorphic temperatures decrease in eastward direction, suggesting differential uplift in the west. The temperature profile is complex, however, and a major break (fault?) in the middle of the profile appears significantly to offset the isotherms.

Geochemistry

Ramberg (1951) noticed a significant difference in average chemical composition between granulite and amphibolite facies rocks in the Nagssugtoqidian belt, amphibolite facies rocks having, for example, significantly more SiO_2 and K_2O and less FeO, MgO and TiO_2 than rocks in granulite facies. Such differences have since been observed world wide, but their causes are still under debate. Ramberg explained them as the result of metasomatic basification in the lower crust simultaneously with granitisation of the upper crust.

Similar changes in chemical composition during strong shearing were described by Sørensen & Winter (1989) from the Nordre Strømfjord shear zone. Chemical changes were here believed to be related to fluid movements within the shear zone. However, the presence of many late granite sheets within the shear zone had a significant influence on average compositions within and outside the shear zone, and may invalidate their conclusions.

Hickman & Glassley (1984) discussed the role of metamorphic fluid transport in the resetting of Rb-Sr isotope systems in the Nordre Strømfjord shear zone. Well fitted Rb-Sr whole-rock isochrons yielding early Proterozoic ages were explained by these authors as the result of pervasive resetting of originally Archaean Rb-Sr systems (see further under geochronology).

Glassley (1983a) calculated the amount of CO_2 released during silicification of carbonate rocks. He concluded that 8% carbonate rock could release enough CO_2 to completely dehydrate an amphibolite terrain at deep crustal conditions. This might then result in the formation of granulite facies rocks. Glassley (1983b) discusses the effect of varying CO_2/H_2O ratios in metamorphic fluids and concludes that CO_2-rich fluids may significantly modify the chemical composition of rocks at deep crustal levels.

Geochronology

K-Ar biotite dating by Larsen & Møller (1968a) yielded ages of 1750-1600 Ma for rocks from the Nagssugtoqidian mobile belt. These were interpreted to represent uplift and cooling after Nagssugtoqidian metamorphism. The true age of the rocks was not known at that time. Chessex et al. (1973) obtained a few 'total lead' zircon ages of c. 2900-3000 Ma. No evidence of strong alteration of the U-Pb system in the zircons by an early Proterozoic event was detected, and it was suggested that Nagssugtoqidian deformation and metamorphism had taken place (much) earlier. Based on whole rock K-Ar dates compiled by Bridgwater (1970, 1971) and circumstantial palaeomagnetic evidence, the Kangâmiut dykes were believed to be c. 2500 Ma old (e.g. Fahrig & Bridgwater, 1976). The main phase of Nagssugtoqidian deformation was thought to have taken place at the end of the Archaean or the beginning of the Proterozoic (e.g. Bridgwater et al., 1973b; Escher et al., 1975).

More reliable Rb-Sr whole-rock data for two Kangâmiut dykes, however, yielded an age of 1950 ± 60 Ma, interpreted to represent the time of intrusion of the dykes (Kalsbeek et al., 1978). This suggested that the Nagssugtoqidian orogeny took place between 1950 and 1600 Ma, and could be correlated with the Hudsonian event in Canada.

Hickman (1979) and Kalsbeek & Zeck (1978a, 1985) presented evidence that some of the shear zones near the southern border of the Nagssugtoqidian belt (e.g. the Itivdleq zone) were of Archaean origin, much older than the Kangâmiut dykes. The Nordre

Strømfjord shear zone, on the other hand, was formed during the Nagssugtoqidian orogeny, 1840 ± 44 Ma ago (Rb-Sr whole-rock data for synkinematic granite sheets; Hickman & Glassley, 1984).

Hickman & Glassley (1984) made a detailed Rb-Sr isotope study of gneisses and granites from Nordre Strømfjord. They demonstrated that most rocks were of Archaean origin but isotopically strongly disturbed during the Nagssugtoqidian orogeny. A few well fitted c. 1840 Ma isochrons were interpreted as evidence for total resetting of the Archaean isotope systems during Nagssugtoqidian reworking. Kalsbeek et al. (1984, 1987) also obtained both disturbed Archaean and Proterozoic ages (zircon U-Pb, Rb-Sr, Pb-Pb and Sm-Nd data). The granite on Rifkol, for example, yielded an Archaean Pb-Pb age, c. 2650 Ma, and the Arfersiorfik quartz diorite a zircon U-Pb age of 1920 Ma. The peak of Nagssugtoqidian metamorphism was dated at c. 1850 Ma, in accordance with Hickman & Glassley's (1984) data, and this was later confirmed by Pb-Pb dating of marbles from Nordre Strømfjord (1845 ± 23 Ma, Taylor & Kalsbeek, 1990). In contrast to Hickman & Glassley's (1984) interpretation that Proterozoic dates were the result of Proterozoic resetting of Archaean isotope systems, Sm-Nd and Pb-Pb data of Kalsbeek et al. (1984, 1987) indicated that some metavolcanic and plutonic rocks were of juvenile early Proterozoic origin.

Although the isotope systems in most Archaean rocks were strongly disturbed by Nagssugtoqidian metamorphism, granitic gneisses from Akugdlit north of Kangâtsiaq gave a well defined Rb-Sr isochron (c. 2675 Ma) and gneisses from Egedesminde yielded a well fitted Pb-Pb isochron (c. 2760 Ma; Kalsbeek et al. 1987). This suggests that Nagssugtoqidian disturbance was less significant north of Kangâtsiaq.

Plate tectonic setting

Already in early studies it was suggested that the Nagssugtoqidian mobile belt might represent an Alpine-type collisional orogen because of the considerable crustal shortening observed at its southern border (Bridgwater et al., 1973b; Escher et al., 1975). However, because most of the terrain appeared to consist of reworked Archaean crust (e.g. Pulvertaft, 1968) in later papers it has been regarded to be of 'ensialic' nature (e.g. Bak et al., 1975a; Myers, 1984). Watterson (1978) interpreted the ensialic deformation in the Nagssugtoqidian belt in terms of a plate collision within or to the south of the early Proterozoic Ketilidian belt in South Greenland.

New evidence on the plate tectonic setting of the belt was presented by Kalsbeek et al. (1987). These authors found mantle-derived early Proterozoic calc-alkaline metavolcanic and plutonic rocks in the centre of the belt, which, on the basis of geochemical evidence, they interpreted as having been formed at a destructive plate margin. Isotopic evidence indicates that these rocks do not include significant contributions derived from Archaean crust, and they may have formed in an island arc setting, far away from Archaean complexes. The present location of these rocks as strongly deformed units surrounded by Archaean gneisses led to the suggestion that the Nagssugtoqidian belt contains a suture between two Archaean continents.

Regional geochemical mapping based on stream sediment samples has resulted in the recognition of distinct geochemical domains, which in some cases are separated by major thrusts (Steenfelt & Dam, 1991; Steenfelt et al., 1992, 1993a, b). It is possible that these domains represent different crustal terranes brought together during Nagssugtoqidian collision.

Grocott & Pulvertaft (1990) used the collision model for the Nagssugtoqidian belt in an attempt to interpret the evolution of the early Proterozoic Rinkian belt further north in West Greenland. According to these authors the Rinkian belt developed on the site of an epicontinental marginal basin, formed in response to northward-dipping subduction in the Nagssugtoqidian belt.

Correlation with early Proterozoic orogens in Canada and northern Europe

Comparative studies suggest that the Nagssugtoqidian belt of West Greenland may be part of a major orogen, running from Labrador over West and South-East Greenland and northern Scotland to the northernmost part of the Baltic shield (Bridgwater et al., 1990). Korstgård et al. (1987) compare the structural evolution of the Nagssugtoqidian belt and the Torngat orogen in Labrador. Kalsbeek et al. (1993) discuss geochronological data from the Ammassalik/Nagssugtoqidian belt in South-East Greenland in relation to those of the Nagssugtoqidian belt in West Greenland and the rocks of the Lewisian complex in northern Scotland. The three areas are closely comparable in chronological evolution. There are, however, still major uncertainties about the relative geographical positions of these different areas during the early Proterozoic, and such correlations need further study.

Palaeomagnetism

Palaeomagnetic investigations have played a prominent role in the study of the Nagssugtoqidian belt. A detailed description of results has been presented by Piper (1985). One of the main conclusions was that in rocks which have undergone high-grade metamorphism, and cool slowly afterwards, magnetic pole positions do not relate to the age of formation of the rocks but to the time the rocks cooled to a temperature below which further reorientation of the magnetic field is not recorded. Where rocks of different ages, for example basic dykes and their country rock, pass together through this 'blocking temperature' they will show the same palaeopole positions. This has indeed been shown to be the case (Morgan, 1976a; Beckman, 1979).

Blocking temperatures in slowly cooled terrains are lower than the Curie point (578°C for magnetite), for some minerals perhaps as low as 200°C. Since it is difficult to determine at which time blocking temperatures were passed, it is problematic to attach a particular age to any pole position. K-Ar dates may be close to the time the lowest magnetic blocking temperatures were reached. Beckman & Mitchell (1976) used K-Ar isochron plots for whole rock and mineral samples (to overcome the problem of excess argon) in order to obtain the best estimate of the age for some of their palaeopoles.

Different minerals, for example magnetite and haematite, have different blocking temperatures. As a consequence, progressive thermal demagnetisation of a sample during measurement will result in a range of pole positions, belonging to increasing ages of magnetisation. Such poles would fall at different places on the 'apparent polar wander' path for North America. This has indeed been confirmed (Morgan, 1976a). Morgan & Smith (1981) studied by transmission electron microscopy which minerals were main carriers of magnetism. They showed that sub-micron sized magnetite inclusions in feldspar play an important role in this respect.

The principles outlined above have been employed in several uplift studies. In case of slow uplift it would be expected that samples at high structural level would show older magnetisation than samples from lower levels. This has been tested by Beckman et al. (1977) and Piper (1981a). The Beckman et al. (1977) results were not very conclusive. Piper's (1981a) data, however, suggested to him apparent polar wandering of 1-2°/Ma (very fast) and a rate of crustal uplift of 10-20 m/Ma, about an order of magnitude lower than Phanerozoic uplift rates.

Palaeomagnetic studies have also been performed on specific rock units: Fahrig & Bridgwater (1976) made a detailed study of the Kangâmiut dyke swarm and their country rocks; Piper (1981b) investigated the kimberlite-lamprophyre suite, and Piper (1981c) studied pseudotachylites from the Ikertôq shear belt. The pseudotachylites and the kimberlites etc. have similar pole positions, and may have a close temporal relationship.

Kimberlites and lamprophyric rocks

Lamproites, kimberlites and associated rocks occur as thin dykes at many localities within the Nagssugtoqidian belt. They are of two main age groups: 1210-1240 Ma lamproites in the Holsteinsborg-Nordre Strømfjord area, and c. 600 Ma kimberlites in the Søndre Strømfjord region around Sarfartôq and in the Holsteinsborg area. At Sarfartôq there is also a major c. 600 Ma carbonatite body (Secher, 1986). Elsewhere in western Greenland similar rocks of Archaean and early Proterozoic age are also present. Reviews of these rocks has been presented by Larsen et al. (1983) and, more recently, by Larsen & Rex (1992).

Escher et al. (1970) and Escher & Watterson (1973) were the first to report on the presence of kimberlites and associated rocks in the Søndre Strømfjord-Holsteinsborg region. Acounts on the mineralogy, geochemistry and petrogenesis of these rocks (and xenoliths within them) have been presented by Brooks et al. (1978), Scott (1977, 1979, 1981), Scott-Smith (1987), Scott-Smith & Skinner (1984), and Thy et al. (1987). Paul & Potts (1976) and Paul et al. (1976) report on REE abundances and F and Cl concentrations, respectively, whereas Nelson (1989) studied isotopic characteristics. A palaeomagnetic study of kimberlites and lamprophyres has been carried out by Piper (1981b).

Larsen & Rex (1992) discuss the chemistry of the dykes in relation to the plate-tectonic setting of their country rocks. For example, kimberlites in the Archaean craton have less Al_2O_3 and higher MgO than those within the Nagssugtoqidian belt. This is regarded to be a consequence of thicker lithosphere underneath the Archaean craton. Although they are some 600 Ma younger than the Nagssugtoqidian orogeny, ultrapotassic lamproites in the Nagssugtoqidian belt occur near the sites of early Proterozoic subduction. The data suggest that both northward and southward subduction may have taken place.

Pseudotachylites

Pseudotachylites have been described both from the Agto area and from the southern border zone of the Nagssugtoqidian belt, i.e. from the two best known parts of it. It is not quite clear whether they occur preferentially within earlier shear zones or if they are more randomly scattered throughout the area.

Pseudotachylites from the Agto area were first described by Jensen (1968). In a later paper in Nature, Jensen (1971) related some pseudotachylites (hyalomylonites) to shock metamorphism due to Precambrian meteorite impact.

Grocott (1981) described the fracture geometry related to pseudotachylite formation. In the area studied by Grocott (the Ikertôq shear zone) pseudotachylites are associated with previously sheared rocks. Since brittle (seismic) deformation is characteristic of higher crustal levels than ductile (aseismic) deformation, this association permits the study of ancient fault zones at different depths within the crust in one place (Grocott, 1977). Watterson (1975) interpreted the repetitive use of the same zones of tectonic activity as the result of mechanical weakening of these zones through grain size reduction.

Piper (1981c) determined palaeomagnetic pole positions for some pseudotachylites. They were the same as those for kimberlitic rocks from the same area, and the rocks may be of approximately the same age (c. 580 Ma).

Mineral occurrences

Few studies have dealt with the mineral potential of the Nagssugtoqidian belt. Known mineralisation is hosted in supracrustal rocks and comprises occurrences of graphite and of semi-massive pyrrhotite with minor copper and zinc sulphides. Additionally a potential for gold mineralisation has been indicated by rock and stream sediment geochemistry.

Graphite has been mined on a small scale at Akuliaruseq in the beginning of the century (Ball, 1922; Nielsen, 1976; Bondam, 1992). More recently this occurrence was studied in detail by Kryolitselskabet Øresund A/S (Morthorst & Keto, 1984; Keto et al., 1987).

Semi-massive sulphide occurrences have been investigated at Lersletten and Nordre Strømfjord by Kryolitselskabet Øresund A/S (Vaasjoki, 1965) and Nunaoil A/S (Grahl-Madsen, 1992). The latter report also presents geochemical evidence for gold mineralisation in these areas.

Bibliography, Nagssugtoqidian belt (West Greenland)

Allaart, J. H. & Jensen, S. B. 1979: Completion of 1:500 000 reconnaissance mapping in the Precambrian of the Evighedsfjord - Søndre Strømfjord - Itivdleq region, southern West Greenland. *Rapp. Grønlands geol. Unders.* **95,** 72-76.

Allaart, J. H., Escher, A. & Kalsbeek, F. 1974: Outline of the Precambrian geology of southern West Greenland. *Geol. Mijnbouw* **53,** 85-98.

Appel, P. W. U. 1988: Tourmaline in Precambrian supracrustal rocks from Aasiaat, central West Greenland. *Rapp. Grønlands geol. Unders.* **140,** 44-46.

Bak, J., Sørensen, K., Grocott, J., Korstgård, J. A., Nash, D. & Watterson, J. 1975a: Tectonic implications of Precambrian shear belts in western Greenland. *Nature* **254,** 566-569.

Bak, J., Korstgård, J. A. & Sørensen, K. 1975b: A major shear zone within the Nagssugtoqidian of West Greenland. *Tectonophysics* **27,** 191-209.

Ball, S. H., 1922: The mineral resources of Greenland. *Meddr Grønland* **63,** 1-60.

Beckmann, G. E. J. 1979: A review of Nagssugtoqidian palaeomagnetism. *Rapp. Grønlands geol. Unders.* **89,** 115-124.

Beckman, G. E. J. 1983: Palaeomagnetism of some Precambrian rocks in south-east Greenland. *Phys. Earth Planet. Inter.* **32,** 85-99.

Beckman, G. E. J. & Mitchell, J. E. 1976: Palaeomagnetic and geochronological work in central West Greenland. *Earth Planet. Sci. Lett.* **30,** 269-280.

Beckman, G. E. J., Olesen, N. Ø. & Sørensen, K. 1977: A palaeomagnetic experiment on crustal uplift in West Greenland. *Earth Planet. Sci. Lett.* **36,** 269-279.

Berthelsen A. & Noe-Nygaard, A. 1965: The Precambrian of Greenland. *In* Rankama, K. (ed.) *The Precambrian,* Vol. **2,** 113-262. New York: Interscience Publishers.

Bondam, J. 1992: Graphite occurrences in Greenland. A review. *Open File Ser. Grønlands geol. Unders.* **92/6,** 32 pp.

Bondesen, E. 1966: Research on the high-metamorphic complexes of the Agto area. *Rapp. Grønlands geol. Unders.* **11,** 20-23.

Bondesen, E. 1968: Research on the high-metamorphic complexes of the Agto area. *Rapp. Grønlands geol. Unders.* **15,** 19-21.

Bondesen, E. 1969: Research on the high-metamorphic complexes of the Agto area. *Rapp. Grønlands geol. Unders.* **19,** 25-26.

Bondesen, E. (ed.), 1970a: *Colloquium on Nagssugtoqidian geology.* Geological Institute, Aarhus University, 92 pp. (14 short contributions, duplicated.)

Bondesen, E. 1970b: Field work in the Agto - Nordre Strømfjord region. *Rapp. Grønlands geol. Unders.* **28,** 17-19.

Bridgwater, D. 1971: Routine K/Ar age determinations on rocks from Greenland carried out for GGU in 1979. *Rapp. Grønlands geol. Unders.* **35,** 52-60.

Bridgwater, D. 1973: General compilation of isotopic work on rocks from Greenland. *Rapp. Grønlands geol. Unders.* **55,** 51-60.

Bridgwater, D., Escher, A., Nash, D. F. & Watterson, J. 1973a: Investigations on the Nagssugtoqidian boundary between Holsteinsborg and Kangâmiut, central West Greenland. *Rapp. Grønlands geol. Unders.* **55,** 22-25.

Bridgwater, D., Escher, A. & Watterson, J. 1973b: Tectonic displacements and thermal activity in two contrasting Proterozoic mobile belts from Greenland. *Phil. Trans. R. Soc. Lond.* **A. 273,** 513-533.

Bridgwater, D., Escher, A. & Watterson, J. 1973c: Behaviour of dyke swarms at major Precambrian boundaries. *In* Park, G. & Tarney, J. (ed.) *The Lewisian of Scotland and related rocks of Greenland*, 126-133. Keele Univ. Press.

Bridgwater, D., Austrheim, H., Hansen, B. T., Mengel, F., Pedersen, S. & Winter. J. 1990: The Proterozoic Nagssugtoqidian mobile belt of southeast Greenland: A link between the eastern Canadian and Baltic shields. *Geosci. Canada* **17,** 305-310.

Brooks, C. K., Noe-Nygaard, A., Rex, D. C. & Rønsbo, J. G. 1978: An occurrence of ultrapotassic dikes in the neighbourhood of Holsteinsborg, West Greenland. *Bull. geol. Soc. Denmark* **27,** 1-8.

Chessex, R., Delaloye, M., Gülacar, F. & Escher, A. 1973: U-Pb isotopic ages of zircons from Precambrian rocks of West Greenland. *Fortschr. Mineral.* **50,** Beiheft 3, 60-61.

Davidson, L. M. 1978: Granulite facies rocks bordering the Ikertôq shear belt, central West Greenland. Unpublished Ph.D. thesis, Univ. Liverpool.

Davidson, L. M. 1979: Nagssugtoqidian granulite facies metamorphism in the Holsteinsborg region, West Greenland. *Rapp. Grønlands geol. Unders.* **89,** 97-108.

Davidson, L. M. & Park, R. G. 1978: Late Nagssugtoqidian stress orientation derived from deformed granodiorite dykes north of Holsteinsborg, West Greenland. *J. geol. Soc. Lond.* **135,** 283-289.

Diggens, J. N. 1977: Aspects of the geology of the Nagssugtoqidian rocks of West Greenland (abstract). *Circ. geol. Ass. Lond.* **798,** 1 only.

Diggens, J. N. & Talbot, C. 1974: Nagssugtoqidian supracrustal metavolcanic rocks of Sarfartup nunâ, Søndre Strømfjord, central West Greenland. *Rapp. Grønlands geol. Unders.* **65,** 37-39.

Ellitsgaard-Rasmussen, K. 1951: A West Greenland globule dyke. *Meddr dansk geol. Foren.* **12,** 83-101.

Ellitsgaard-Rasmussen, K. 1954: On the geology of a metamorphic complex in West Greenland (The islands of Anarssuit, Isuamiut, and Eqûtit). *Bull. Grønlands geol. Unders.* **5,** 70 pp.

Escher, A. 1966: New geological reconnaissance mapping in the area between Nordre Strømfjord and Ikertoq fjord. *Rapp. Grønlands geol. Unders.* **11,** 24-25.

Escher, A. (compiler) 1971: Geological map of Greenland 1:500 000, Sheet 3, Søndre Strømfjord - Nûgssuaq. Copenhagen: Grønlands Geologiske Undersøgelse.

Escher, A. & Watt, W. S. 1976: Summary of the geology of Greenland. *In* Escher, A. & Watt, W. S. (ed.) *Geology of Greenland*, 11-16. Copenhagen: Geol. Surv. Greenland.

Escher, A. & Watterson, J. 1973: Kimberlites and associated rocks in the Holsteindborg - Søndre Strømfjord region, central West Greenland. *Rapp. Grønlands geol. Unders.* **55,** 26-27.

Escher, A. & Watterson, J. 1974: Stretching fabrics, folds and crustal shortening. *Tectonophysics* **22,** 223-231.

Escher, A., Escher, J. C. & Watterson, J. 1970: The Nagssugtoqidian boundary and the deformation of the Kangâmiut dyke swarm in the Søndre Strømfjord area. *Rapp. Grønlands geol. Unders.* **28,** 21-23.

Escher, A., Escher, J. C. & Watterson, J. 1975: The reorientation of the Kangâmiut dyke swarm, West Greenland. *Can. J. Earth Sci.* **12,** 158-173.

Escher, A., Jack, S. & Watterson, J. 1976: Tectonics of the North Atlantic Proterozoic dyke swarm. *Phil. Trans. R. Soc. Lond.* **A. 280,** 529-539.

Escher, A., Sørensen, K. & Zeck, H.P. 1976: Nagssugtoqidian mobile belt in West Greenland. *In* Escher, A. & Watt, W. S. (ed.) *Geology of Greenland,* 77-95. Copenhagen: Geol. Surv. Greenland.

Fahrig, W. F. & Bridgwater, D. 1976: Late Archaean-Early Proterozoic paleomagnetic pole positions from West Greenland. *In* Windley, B. F. (ed.) *The early history of the Earth,* 427-439. London: John Wiley and Sons.

Getreuer, F. 1980: Grundfjeldsgeologien i Marranguit-Kangilerssua-området, Nordre Strømfjord, den centrale del af de vestgrønlandske Nagssugtoqider. Del 2a: Deformationsmekanismer i kvartsrige bjergarter. Unpublished cand. scient. thesis. Univ. Aarhus.

Getreuer, F. & Rehkopff, A. 1980: Grundfjeldsgeologien i Marranguit-Kingilerssua-området, Nordre Strømfjord, den centrale del af de vestgrønlandske Nagssugtoqider. Del 1: Petrografi og strukturer. Unpublished cand. scient. thesis. Univ. Aarhus.

Glassley, W. E. 1982: Carbonates as deep crustal CO_2 sources. *Eos* **63,** 450 only.

Glassley, W. E. 1983a: Deep crustal carbonates as CO_2 fluid sources: evidence from metasomatic reaction zones. *Contr. Mineral. Petrol.* **84,** 15-24.

Glassley, W. E. 1983b: The role of CO_2 in the chemical modification of deep continental crust. *Geochim. Cosmochim. Acta* **47,** 597-616.

Glassley, W. & Sørensen, K. 1979: The effects of solid and vapour phase compositional variations on the amphibolite facies to granulite facies transition in the Agto metadolerites. *Rapp. Grønlands geol. Unders.* **89,** 109-111.

Glassley, W. & Sørensen, K. 1980: Constant P_S-T amphibolite to granulite facies transition in Agto (West Greenland) metadolerites: implications and applications. *J. Petrol.* **31,** 69-105.

Grahl-Madsen, L. 1992: Avannaa 1992. Geological reconnaissance in the Nordre Strømfjord, the Lersletten, and the Kangersuneq areas. Internal report, Nunaoil A/S. Vol. 1, 52 pp. + Vols 2-3 (plates).

Grocott, J. 1977: The northern boundary of the Ikertôq shear belt, West Greenland. Unpublished Ph.D. thesis. Univ. Liverpool, 179 pp.

Grocott, J. 1977: The relationship between Precambrian shear belts and modern fault systems. *J. geol. Soc. Lond.* **133,** 257-262.

Grocott, J. 1979a: Shape fabrics and superimposed simple shear strain in a Precambrian shear belt, West Greenland. *J. geol. Soc. Lond.* **136,** 471-488.

Grocott, J. 1979b: Controls of metamorphic grade in shear belts. *Rapp. Grønlands geol. Unders.* **89,** 47-62.

Grocott, J. 1981: Fracture geometry of pseudotachylyte generation zones: a study of shear fractions formed during seismic events. *J. struct. Geol.* **3,** 169-178.

Grocott, J. & Pulvertaft, T. C. R. 1990: The Early Proterozoic Rinkian belt of central West Greenland. *In* Lewry, J. F. & Stauffer, M. R. (ed.) The Early Proterozoic Trans-Hudson Orogen of North America. *Spec. Pap. Geol. Ass. Can.* **37,** 443-463.

Grocott, J. & Watterson, J. 1980: Strain profile of a boundary within a large ductile shear zone. *J. struct. Geol.* **2,** 111-117.

Hansen, B. 1989: En petrografisk og geokemisk undersøgelse af Kangamiutgangene, Vestgrønland. Unpublished cand. scient. thesis. Univ. Aarhus.

Hansen, B. F. 1977: En charnockitisk suite i Agto området, Vestgrønland. Unpublished cand. scient. thesis. Univ. Aarhus.

Hansen, B. F. 1979: Some charnockitic rocks in the Nagssugtoqidian of West Greenland. *Rapp. Grønlands geol. Unders.* **89,** 85-96.

Hansen, B. F. 1981: Thermodynamiske og experimentelle studier af høj metamorphosegrad i det Nagssugtoqidiske mobile bælte, Vestgrønland. Unpublished lic. scient. thesis. Univ. Aarhus.

Hansen, B. F. 1981: The transition from granulite facies to garnet clinopyroxene granulite facies. Experiments in the system CaO-MgO-Al_2O_3-SiO_2. *Contrib. Mineral. Petrol.* **76,** 234-242.

Henderson, G. 1966: Field mapping in the Egedesminde-Christianshåb area (sheets 68 V.1 and 68 V.2). *Rapp. Grønlands geol. Unders.* **11,** 17-19.

Henderson, G. 1969: The Precambrian rocks of the Egedesminde-Christianshåb area, West Greenland. *Rapp. Grønlands geol. Unders.* **23,** 37 pp.

Hickman, M. H. 1979: A Rb-Sr age and isotope study of the Ikertôq, Nordre Strømfjord, and Evighedsfjord shear belts, West Greenland - outline and preliminary results. *Rapp. Grønlands geol. Unders.* **89,** 125-128.

Hickman, M. H. 1981: Contrasting responses of Rb-Sr isotope systematics to shear belt formation in three Precambrian fault zones, West Greenland. *Eos* **62,** 429 only.

Hickman, M. H. & Glassley, W. 1982: Relationships between chemical and Rb-Sr isotope reequilibration in a granulite facies shear belt, West Greenland. *Eos* **63,** 458 only.

Hickman, M. H. & Glassley, W. 1984: The role of metamorphic fluid transport in the Rb-Sr isotopic resetting of shear zones: evidence from Nordre Strømfjord, West Greenland. *Contrib. Mineral. Petrol.* **87,** 265-281.

Hickman, M. H. & Grant, N. K. 1980: Rb-Sr age and isotope study of three major shear belts, West Greenland. *Abstr. 26 Congr. Geol. Int. Paris* 1980, Vol. **2,** 592 only.

Jack, S. M. B. 1978: The North Atlantic Proterozoic dyke swarm. Unpublished Ph.D. thesis, Univ. Liverpool.

Jensen, N. R. 1971: Geologisk beskrivelse af Rifkol - Nunarssuaq skærgården, Vest-grønland. Unpublished cand. scient. thesis. Univ. Aarhus.

Jensen, V. 1968: Pseudotachylite in the Agto area. *Rapp. Grønlands geol. Unders.* **15,** 22-23.

Jensen, V. 1971: Early Precambrian impact structure and associated hyalomylonites near Agto, West Greenland. *Nature* **233,** 188-190.

Kalsbeek, F. 1979: Rb-Sr isotope evidence on the age of the Nagssugtoqidian orogeny in West Greenland, with remarks on the term 'Nagssugtoqidian'. *Rapp. Grønlands geol. Unders.* **89,** 129-131.

Kalsbeek, F. 1981: The northward extent of the Archaean basement of Greenland - a review of Rb-Sr whole-rock ages. *Precambrian Res.* **14,** 203-219.

Kalsbeek, F. 1982: The evolution of the Precambrian shield of Greenland. *Geol. Rundschau* **71,** 38-60.

Kalsbeek, F. 1986: The tectonic framework of the Precambrian shield of Greenland. A review of new isotopic evidence. *Rapp. Grønlands geol. Unders.* **128,** 55-64.

Kalsbeek, F. 1993: Use of Rb-Sr isotope data to constrain the time of deposition of Precambrian metasediments: an example from Hamborgerland, West Greenland. *Rapp. Grønlands geol. Unders.* **159,** 95-100.

Kalsbeek, F. & Taylor, P. N. 1985: Pb-isotopic studies of Proterozoic igneous rocks, West Greenland, with implications on the evolution of the Greenland shield. *In* Tobi, A. C. & Touret, J. L. R. (ed.) *The deep Proterozoic crust in the North Atlantic provinces*, 237-245. Dordrecht: Reidel.

Kalsbeek, F. & Zeck, H. P. 1978a: Preliminary Rb-Sr whole-rock data for Archaean and Nagssugtoqidian rocks from the Søndre Strømfjord area, West Greenland. *Rapp. Grønlands geol. Unders.* **90,** 129-134.

Kalsbeek, F. & Zeck, H. P. 1978b: Nagssugtoqidian deformation and Kangâmiut dyke intrusion in the Søndre Strømfjord area, West Greenland. *Rapp. Grønlands geol. Unders.* **90,** 42-45.

Kalsbeek, F. & Zeck, H. P. 1985: Dykes and deformation in the Ikertôq zone of the Nagssugtoqidian at Søndre Strømfjord Airport - a discussion. *Bull. geol. Soc. Denmark* **34,** 213-217.

Kalsbeek, F., Bridgwater, D. & Zeck, H. P. 1978: A 1950 $\pm$ 60 Ma Rb-Sr whole-rock isochron age from two Kangâmiut dykes and the timing of the Nagssugtoqidian (Hudsonian) orogeny in West Greenland. *Can. J. Earth Sci.* **15,** 1122-1128.

Kalsbeek, F., Taylor, P. N. & Henriksen, N. 1984: Age of rocks, structures, and metamorphism in the Nagssugtoqidian mobile belt, West Greenland - field and Pb-isotope evidence. *Can. J. Earth Sci.* **21,** 1126-1131.

Kalsbeek, F., Pidgeon, R. T. & Taylor, P. N. 1987: Nagssugtoqidian mobile belt of West Greenland: cryptic 1850 Ma suture between two Archaean continents - chemical and isotopic evidence. *Earth Planet. Sci. Lett.* **85,** 365-385.

Kalsbeek, F., Taylor, P. N. & Pidgeon, R. T. 1988: Unreworked Archaean basement and Proterozoic supracrustal rocks from northeastern Disko Bugt, West Greenland: implications for the nature of Proterozoic mobile belts in Greenland. *Can. J. Earth Sci.* **25,** 773-782.

Kalsbeek, F., Austrheim, H., Bridgwater, D., Hansen, B. T., Pedersen, S. & Taylor, P. N. 1993: Geochronology of Archaean and Proterozoic events in the Ammassalik area, South-East Greenland, and comparisons with the Lewisian of Scotland and the Nagssugtoqidian of West Greenland. *Precambrian Res.* **62,** 239-270.

Keto, L., Morthorst, J. & Hansen, P. S. 1987: Undersøgelser af grafitforekomsten ved Akuliaruseq 1982-1986. Internal report, Kryolitselskabet Øresund A/S, 15 pp.

Korstgård, J. A. 1972: Grundfjeldsgeologi i Inugsuk-området samt en zirkonunder-søgelse af områdets bjergarter. Unpublished cand. scient. thesis. Univ. Aarhus.

Korstgård, J. A. 1974: Zirkonundersøgelser af prækambriske granulitfacies gnejser fra Inugsuk-området, Agto, Vestgrønland. *Årsskrift dansk geol. Foren.* 1973, 100-107.

Korstgård, J. A. 1978: Petrography and geochemistry of Nagssugtoqidian granulite-facies gneisses from the Inugsuk area, Nordre Strømfjord region, West Greenland. Unpublished lic. scient. thesis. Univ. Aarhus.

Korstgård, J. A. 1978: Kontrol af bjergarternes totalkemi over mineralparageneser i Prækambriske granulit-facies gnejser i Vestgrønland. *Abstr. 13. Nordiske geol. Vintermøde, København,* 1978, 34 only.

Korstgård, J. A. (ed.) 1979a: Nagssugtoqidian geology. *Rapp. Grønlands geol. Unders.* **89,** 146 pp.

Korstgård, J. A. 1979b: Compositional controls on mineral assemblages in quartzo-feldspathic granulite-facies gneisses. *Neues Jb. Miner. Abh.* **135,** 113-131.

Korstgård, J. A. 1979c: Metamorphism of the Kangâmiut dykes and the metamorphic and structural evolution of the southern Nagssugtoqidian boundary in the Itivdleq-Ikertôq region, West Greenland. *Rapp. Grønlands geol. Unders.* **89,** 63-75.

Korstgård, J. A. 1979d: Seminar on Nagssugtoqidian geology - an introduction. *Rapp. Grønlands geol. Unders.* **89,** 5-7.

Korstgård, J. A. 1980: Metamorphism, deformation and chemical evolution of the Kangâmiut dykes and their host gneisses across the Ikertoq complex, the Nagssugtoqidian mobile belt, West Greenland. Unpublished Ph.D. thesis, Univ. Liverpool, 340 pp.

Korstgård, J. A. & Olesen, N. Ø. 1978: Field work in the Precambrian of the Agto-Nordre Strømfjord area, central West Greenland. *Rapp. Grønlands geol. Unders.* **90,** 36-38.

Korstgård, J. A. & Sørensen, K. 1981: Tectonic-metamorphic evolution of the southern part of the Nagssugtoqidian mobile belt in central West Greenland (abstract). *Proc. 3rd int. Conf. Basement Tectonics* **3,** 271 only.

Korstgård, J., Ryan, B. & Wardle, R. 1987: The boundary between Proterozoic and Archaean crustal blocks in central West Greenland and northern Labrador. *In* Park, R. G. & Tarney, J. (ed.) Evolution of the Lewisian and comparable Precambrian high grade terrains. *Spec. Publ. geol. Soc. Lond.* **27,** 247-259.

Larsen, L. M. 1991: Registration of kimberlites and other potentially diamond-bearing rocks in Greenland. *Rapp. Grønlands geol. Unders.* **152,** 61-65.

Larsen, L. M. 1991: Occurrences of Kimberlite, lamproite and ultramafic lamprophyre in Greenland. *Open File Ser. Grønlands geol. Unders.* **91/2,** 36 pp.

Larsen, L. M., Rex, D. C. & Secher, K. 1983: The age of carbonatites, kimberlites and lamprophyres from southern West Greenland: recurrent alkaline magmatism during 2500 million years. *Lithos* **16,** 215-221.

Larsen, L. M. & Rex, D. C. 1992: A review of the 2500 Ma span of alkaline-ultramafic potassic and carbonatitic magmatism in West Greenland. *Lithos* **28,** 367-402.

Larsen, O. & Møller, J. 1968a: Potassium-Argon age studies in West Greenland. *Can. J. Earth Sci.* **5,** 683-691.

Larsen, O. & Møller, J. 1968b: K/Ar age determinations from western Greenland, I. Reconnaissance programme. *Rapp. Grønlands geol. Unders.* **15,** 82-86.

Linderoth, V. 1972: En grundfjeldsgeologisk beskrivelse af Kingigtoq SW området. Unpublished cand. scient. thesis, Univ. Aarhus.

Mengel, F. C. 1981: Amfibolitter i Nordre Strømfjord-området, den centrale del af de Vestgrønlandske Nagssugtoqider: geokemi og mineralkemi. Unpublished cand. scient. thesis. Univ. Aarhus.

Mengel, F. C. 1983a: Petrography and geochemistry of amphibolites from the Nordre Strømfjord area in the central part of the Nagssugtoqidian of West Greenland. *Rapp. Grønlands geol. Unders.* **113,** 20 pp.

Mengel, F. C. 1983b: Chemistry of coexisting mafic minerals in granulite facies amphibolites from West Greenland: clues to conditions of metamorphism. *Neues Jb. Miner. Abh.* **147,** 315-340.

Molen, I. van der 1984: Dykes and deformation in the Ikertôq zone of the Nagssugtoqidian at Søndre Strømfjord Airport, West Greenland. *Bull. geol. Soc. Denmark* **32,** 101-106.

Molen, I. van der 1985: Interlayer material transport during layer-normal shortening.
Part 1. The model. *Tectonophysics* **115,** 275-295.
Part 2. Boudinage, pinch-and swell and migmatite at Søndre Strømfjord airport, West Greenland. *Tectonophysics* **115,** 297-313.

Morgan, G. E. 1975: Palaeomagnetism and thermal history of an area of Precambrian terrain in West Greenland (abstract). *Eos* **56,** 167 only.

Morgan, G. E. 1976a: Palaeomagnetism of a slowly cooled plutonic terrain in western Greenland. *Nature* **259,** 382-385.

Morgan, G. E. 1976b: The palaeomagnetism of some Precambrian rocks from the Itivdleq shear zone, West Greenland. Ph. D. thesis, Univ. of London, 356 pp.

Morgan, G. E. & Smith, P. K. 1981: Transmission electron microscope and rock magnetic investigations of remanence carriers in a Precambrian metadolerite. *Earth Planet. Sci. Lett.* **53,** 226-240.

Morthorst, J. & Keto, L. 1984: Report on the graphite exploration in the Akuliaruseq area, 1983. Vol. 1, 29 pp. + Vol. 2 (drilling statistics and core logs).

Myers, J. S. 1984: The Nagssugtoqidian mobile belt of Greenland. *In* Krøner, A. & Greiling, R. (ed.) *Precambrian tectonics illustrated,* 237-250. Stuttgart: Schweitzer-bart'sche Verlagsbuchhandlung.

Nash, D. 1979a: An interpretation of irregular dyke forms in the Itivdleq shear zone, West Greenland. *Rapp. Grønlands geol. Unders.* **89,** 71-84.

Nash, D. 1979b: Nagssugtoqidian tectonics at the western end of the Itivdleq shear zone, West Greenland. *Rapp. Grønlands geol. Unders.* **89,** 43-46.

Nielsen, B. L. 1976: Economic minerals. *In* Escher, A. & Watt, W. S. (ed.) *Geology of Greenland,* 461-486. Copenhagen: Geol. Surv. Greenland.

Noe-Nygaard, A. 1948: A new orogenic epoch in the Precambrian of Greenland (abstract). *18th int. geol. Congr., G. B.* 1948, Vol. Titles & Abstr., 100 only.

Noe-Nygaard, A. 1952: A new orogenic epoch in the Pre-Cambrian of Greenland. *Rep. 18th int. geol. Congr. G. B.* 1948, Part 13, 199-204.

Noe-Nygaard A. & Berthelsen, A. 1952: On the structure of a high-metamorphic gneiss complex in West Greenland, with a general discussion on related problems. *Meddr dansk geol. Foren.* **12,** 250-265.

Noe-Nygaard, A. & Ramberg, H. 1961: Geological reconnaissance map of the country between latitudes 69°N and 63°45'N, West Greenland. *Meddr Grønland* **124**(5), 9 pp.

Nelson, D. R., 1989: Isotopic characteristics and petrogenesis of the lamproites and kimberlites of central west Greenland. *Lithos* **22,** 265-274.

Norton, M. G. 1984: Comment on 'Growth and dynamics of the Nordre Strømfjord shear zone' by Kai Sørensen. *J. geophys. Res.* **89,** 9471 only.

Olesen, N. Ø. 1984: Geologisk kort over Grønland 1:100 000, Agto 67 V.1 Nord. Copenhagen: Grønlands Geologiske Undersøgelse.

Olesen, N. Ø. & Sørensen, K. 1976: Studies of the Precambrian basement in the Agto - Nordre Strømfjord area, central West Greenland. *Rapp. Grønlands geol. Unders.* **80,** 68-69.

Olesen, N. Ø., Korstgård, J. A. & Sørensen, K. 1979: A summary of lithology and structure within the Agto map sheet (67 V.1 Nord), Nagssugtoqidian mobile belt, West Greenland. *Rapp. Grønlands geol. Unders.* **89,** 19-22.

Olsen, T. S. 1978: Prækambrisk grundfjeldsgeologi i Qeqertaussaq W-området ved Nordre Strømfjord, den centrale del af de vest-grønlandske Nagssugtoqider. Unpublished cand. scient. thesis. Univ. Aarhus.

Olsen, T. S. 1979: Chemical controls on the occurrence of orthopyroxene in granulite-facies hornblende gneisses. Neues *Jb. Miner. Mh.* **10,** 448-452.

Olsen, T. S. & Kohlstedt, D. L. 1981: Dislocations in some naturally deformed plagioclase feldspars. *Eos* **62,** 395 only.

Olsen, T. S. & Kohlstedt, D. L. 1984: Analysis of dislocations in some naturally deformed plagioclase feldspars. *Phys. Chem. Minerals* **11,** 153-160.

Olsen, T. S. & Kohlstedt, D. L. 1985: Natural deformation and recrystallization of some intermediate plagioclase feldspars. *Tectonophysics* **111,** 107-131.

Paul, D. K. & Potts, P. J. 1976: Rare-earth abundances in kimberlites from Greenland and Zambia. *Chem. Geol.* **18,** 161-167.

Paul, D. K., Buckley, F. & Nixon, P. H. 1976: Fluorine and chlorine geochemistry of Kimberlites. *Chem. Geol.* **17,** 125-133.

Pauly, H. 1949: Calcite and skarn minerals in the gneisses of the Holsteinsborg district, West Greenland. *Meddr dansk geol. Foren.* **11,** 328-350.

Piper, J. D. A. 1981a: The altitude dependence of magnetic remanence in the slowly-cooled Precambrian plutonic terrain of West Greenland. *Earth Planet. Sci. Lett.* **54,** 449-466.

Piper, J. D. A. 1981b: Palaeomagnetic study of the (late Precambrian) West Greenland kimberlite-lamprophyre suite: definition of the Hadrynian track. *Phys. Earth Planet. Inter.* **27,** 164-186.

Piper, J. D. A. 1981c: Palaeomagnetism of pseudotachylites from the Ikertoq shear belt, and their relationship to the kimberlite-lamprophyre province, central-west Greenland. *Bull. geol. Soc. Denmark* **30,** 51-61.

Piper, J. D. A. 1985: Palaeomagnetic study of the Nagssugtoqidian mobile belt in central-west Greenland. *Precambrian Res.* **28,** 75-110.

Pulvertaft, T. C. R. 1968: The Precambrian stratigraphy of Western Greenland. *Rep. 23th int. geol. Congr., Czechoslovakia,* 1968, Vol. **4**, 89-107.

Ramberg, H. 1949: On the petrogenesis of the gneiss complexes between Sukkertoppen and Christianshaab, West Greenland. *Meddr dansk geol. Foren.* **11,** 312-327.

Ramberg, H. 1951: Remarks on the average chemical composition of granulite facies and amphibolite to epidote amphibolite facies gneisses in West Greenland. *Meddr dansk geol. Foren.* **12,** 27-34.

Rehkopff, A. 1981: Grundfjeldsgeologien i Marranguit-Kangilerssua området, Nordre Strømfjord, den centrale del af de vestgrønlandske Nagssugtoqider. Del 2b: De kvarts-feldspat-rige suprakrustalers geokemi. Unpublished cand. scient. thesis. Univ. Aarhus.

Rehkopff, A. 1984: Origin of quartzo-feldspathic supracrustal rocks from the central part of the Nagssugtoqidian mobile belt of West Greenland. *Rapp. Grønlands geol. Unders.* **117,** 26 pp.

Scott, B. H. 1977: Petrogenesis of kimberlites and associated potassic lamprophyres from central West Greenland. Unpublished Ph.D. thesis, Univ. Edinburgh, 133 pp.

Scott, B. H. 1979: Petrogenesis of kimberlites and associated potassic lamprophyres from central West Greenland. *In* Boyd, F. R. & Myer, H. O. A. (ed.) Kimberlites, diatremes, and diamonds: their geology, petrology, and geochemistry. *Proc. 2nd int. kimberlite conf.* **1,** 190-205. Washington: Amer. Geophys. Union.

Scott, B. H. 1981: Kimberlite and lamproite dykes from Holsteinsborg, West Greenland. *Meddr Grønland Geosci.* **4,** 24 pp.

Scott-Smith, B. H. 1987: Greenland. *In* Nixon, P. H. (ed.) *Mantle xenoliths,* 23-32. New York: John Wiley.

Scott-Smith, B. H. & Skinner, E. M. W. 1984: Diamondiferous lamproites. *J. Geology* **92,** 433-438.

Secher, K. 1976: Airborne radiometric survey between 66° and 69°N, southern and central West Greenland. *Rapp. Grønlands geol. Unders.* **80,** 65-67.

Secher, K. 1980: Distribution of radioactive mimeralisation in central West Greenland. *Rapp. Grønlands geol. Unders.* **100,** 61-65.

Secher, K. 1986: Exploration of the Sarfartôq carbonatite complex, southern West Greenland. *Rapp. Grønlands geol. Unders.* **128,** 89-101.

Skjernaa, L. 1973: Precambrian structures of the Ikorfat peninsula, Agto region, West Greenland. *Rapp. Grønlands geol. Unders.* **52,** 22 pp.

Sørensen, K. 1970: Some observations on the structural and metamorphic chronology on Agto and surrounding islands, central West Greenland. *Rapp. Grønlands geol. Unders.* **27,** 32 pp.

Sørensen, K. 1972: Sampling of metadolerites in the Agto area, central West Greenland. *Rapp. Grønlands geol. Unders.* **45,** 21-22.

Sørensen, K. 1979: Are coronas cooling products? *Rapp. Grønlands geol. Unders.* **89,** 113-114.

Sørensen, K. 1981: A major shear zone in West Greenland treated as an experiment under natural conditions. *Geol. Fören. Stockh. Förh.* **103,** 132-133.

Sørensen, K. 1983: Growth and dynamics of the Nordre Strømfjord shear zone. *J. geophys. Res.* **88,** 3419-3437.

Sørensen, K. 1984: Reply (to a comment of M. G. Norton on K. Sørensens 1983 paper). *J. geophys. Res.* **89,** 9473-9474.

Sørensen, K. & Winter, J. 1981: Deformation and migration of material in the Nordre Strømfjord shear belt, West Greenland (abstract). *Symposium on Precambrian Problems, Copenhagen,* 28 only.

Sørensen, K. & Winter, J. D. 1989: Deformation and mass transport in the Nordre Strømfjord shear zone, central West Greenland. *In* Bridgwater, D. (ed.) *Fluid movements - element transport and the composition of the deep crust*, 171-185.

Sørensen, P. B. 1970: Field work on marble and calc-silicate rocks in the Nordre Strømfjord region. *Rapp. Grønlands geol. Unders.* **28,** 19-20.

Steenfelt, A. 1992: Gold, arsenic and antimomy in stream sediment related to supra-crustal units between Arfersiorfik and Qarajak Isfjord (68°N to 70°30′N), West Greenland. *Open File Ser. Grønlands geol. Unders.* **92/4,** 11 pp.

Steenfelt, A. & Dam, E. 1991: Reconnaissance geochemical exploration of map sheet 67 V.2 (67° to 68°N, 49°30′ to 52°W), West Greenland. *Open File Ser. Grønlands geol. Unders.* **91/8,** 13 pp.

Steenfelt, A., Dam, E. & Nielsen, J. P. 1992: Reconnaissance geochemical exploration of map sheet 68 V.2 (67°55′N to 68°45′N, 50°15′ to 52°45′W), West Greenland. *Open File Ser. Grønlands geol. Unders.* **92/7,** 20 pp.

Steenfelt, A., Dam, E. & Nielsen, J. P. 1993: Reconnaissance geochemical mapping of map sheets 67 V.1 and 68 V.1 (66° to 68°N, 51°40′ to 54°W), West Greenland. *Open File Ser. Grønlands geol. Unders.* **93/1,** 20 pp.

Steenfelt, A., Kalsbeek, F. & Jepsen, H. F. 1993: Geochemical mapping and geological reconnaissance in the Nagssugtoqidian mobile belt, West Greenland. *Rapp. Grønlands geol. Unders.* **159,** 31-37.

Stevenson, R. K. & Patchett, P. J. 1990: Implications for the evolution of continental crust from Hf isotope systematics of Archaean detrital zircons. *Geochim. Cosmochim. Acta* **54,** 1683-1698.

Talbot, C. J. 1979: A klippe of Nagssugtoqidian supracrustal rocks at Sarfartûp nunâ, central West Greenland. *Rapp. Grønlands geol. Unders.* **89,** 23-42.

Taylor, P. N. & Kalsbeek, F. 1990: Dating the metamorphism of Precambrian marbles: Examples from Proterozoic mobile belts in Greenland. *Chem. Geol. (Isotope Geosc. Sect.)* **86,** 21-28.

Thorning, L. 1976: Aeromagnetic surveys in southern and central West Greenland between 63° and 71°N. *Rapp. Grønlands geol. Unders.* **80,** 61-65.

Thorning, L. 1977: Continuation of the aeromagneic surveys in southern and central West Greenland between 64° and 72°N. *Rapp. Grønlands geol. Unders.* **85,** 34-37.

Thorning, L. 1984: Aeromagnetic maps of parts of southern and central West Greenland: acquisition, compilation and general analysis of data. *Rapp. Grønlands geol. Unders.* **122,** 36 pp.

Thorning, L. 1993: Project AEROMAG-92: a new high resolution aeromagnetic survey of the Lersletten area, central West Greenland (68°15′ to 68°55′N, 50°25′ to 53°35′W). *Open File Ser. Grønlands geol. Unders.* **93/2,** 34 pp.

Thy, P., Stecher, O. & Korstgård, J. A. 1987: Mineral chemistry and crystallization sequences in kimberlite and lamproite dikes from the Sisimiut area, central West Greenland. *Lithos* **20,** 391-417.

Vaasjoki, O. 1965: Conclusions on the geology and ore mineralisations investigated in the Lersletten area, West Greenland, 1964. Internal report, Kryolitselskabet Øresund A/S, 22 pp.

Watterson, J. 1974: Investigations on the Nagssugtoqidian boundary in the Holsteinsborg district, central West Greenland. *Rapp. Grønlands geol. Unders.* **65,** 33-37.

Watterson, J. 1975: Mechanism for the persistence of tec tonic lineaments. *Nature* **253,** 520-522.

Watterson, J. 1978: Proterozoic intraplate deformation in the light of South-East Asian neotectonics. *Nature* **273,** 636-640.

Windley, B. F. 1970: Primary quartz ferro-dolerite/garnet amphibolite dykes in the Sukkertoppen region of West Greenland. *In* Newall, G. & Rast, N. (ed.) Mechanisms og igneous intrusion. *Geol. J. Spec. Issue* **2,** 79-92.

Winter, J. 1971: Geologisk beskrivelse af Tungarnit nunât området, Vestgrønland, samt en kemisk undersøgelse af en bjergart fra området. Unpublished cand. scient. thesis. Univ. Aarhus.

Winter, J. 1974: The Precambrian geology of the Túngarnit nunât area, outer Nordre Strømfjord, central West Greenland. *Rapp. Grønlands geol. Unders.* **61,** 17 pp.

Winter, J. 1974: The origin of a calcareous amphibolite from the Nagssugtoqidian, west Greenland. *Lithos* **7,** 235-238.

Zeck, H. P. & Kalsbeek, F. 1980: Geochemistry of amphibolite facies metamorphism of a suite of basic dykes, Precambrian basement, Greenland (abstract). *Abstr. 26th int. geol. Congr., Paris,* 1980, No. 26, vol. **2,** 805 only.

Zeck, H. P. & Kalsbeek, F. 1981: Geochemistry of amphibolite facies metamorphism of a suite of basic dykes, Precambrian basement, Greenland. *Chem. Erde* **40,** 1-22.

Zeck, H. P., Morthorst, J. R. & Kalsbeek, F. 1983: Metasomatic control of K/Rb ratios in amphibolites. *Chem. Geol.* **40,** 313-321.

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