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Accretion and evolution of an Archaean high-grade grey gneiss – amphibolite complex: the Fiskefjord area, southern West Greenland

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Cover
Coastal exposure of purplish grey orthogneiss retrogressed from granulite facies, with angular fragments of homogeneous amphibolite. The purplish grey orthogneiss displays indistinct foliation and migmatisation fabrics, which have been blurred during recrystallisation under granulite facies *P-T* conditions and subsequent static hydrous retrogression in amphibolite facies. Outer coast north of Fiskefjord, point west of Pâtôq. The island Talerulik is visible in the far distance.

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Contents

Abstract

Garde, A. A. 1997: Accretion and evolution of an Archaean high-grade grey gneiss – amphibolite complex: the Fiskefjord area, southern West Greenland. *Geology of Greenland Survey Bulletin* 177, 115 pp.

The Fiskefjord area in southern West Greenland, part of the Akia tectono-stratigraphic terrane, comprises a supracrustal association and two groups of grey quartzo-feldspathic orthogneises *c.* 3200 and 3000 Ma old. The supracrustal association forms layers and enclaves in grey gneiss and may comprise two or more age groups. Homogeneous amphibolite with MORB-like but LIL element enriched tholeiitic composition predominates; part, associated with cumulate noritic and dunitic rocks, represents fragments of layered complexes. Heterogeneous amphibolite of likely submarine volcanic origin, (basaltic) andesitic amphibolite, leucogabbro-anorthosite, and minor pelitic metasediment occur. Disruption by magmatic and tectonic events and geochemical alteration have obscured primary origin: the supracrustal association may represent oceanic crust.

Grey orthogneiss of the tonalite-trondhjemite-granodiorite (TTG) association was generated during continental accretion at *c.* 3000 Ma, most likely by partial melting of wet and hot tholeiitic basaltic rocks subducted in a convergent plate setting. Most dioritic gneiss is *c.* 220 Ma older. A 3040 Ma dioritic to tonalitic phase, enriched in P_2O_5, Ba, Sr, K, Pb, Rb and LREE, probably was derived from metasomatised mantle.

Intense deformation and metamorphism accompanied the 3000 Ma magmatic accretion. Thrusts along amphibolite-orthogneiss contacts were succeeded by large recumbent isoclines, upright to overturned folds, and local domes with granitic cores. Syntectonic granulite facies metamorphism is thought to be due to heat accumulation by repeated injection of tonalitic magma. Strong ductile deformation produced steep linear belts before the thermal maximum ceased, whereby folds were reorientated into upright south-plunging isoclines. Two large TTG complexes were then emplaced, followed by granodiorite and granite.

Post-kinematic diorite plugs with unusually high MgO, Cr and Ni, and low LIL and immobile incompatible element contents, terminated the 3000 Ma accretion. Hybrid border zones and orbicular textures suggest rapid crystallisation from superheated magma. The diorites most likely formed from ultramafic magma contaminated with continental crust.

Widespread high-grade retrogression preserved a granulite facies core in the south-west; to the east the retrogressed gneiss grades into amphibolite facies gneiss not affected by granulite facies metamorphism and retrogression. LIL elements were depleted during granulite facies metamorphism and reintroduced during retrogression, probably transported in anatectic silicate melts and in fluids. Rb-Sr isotope data, and relationships between retrogression, high-strain zones and granite emplacement, show that retrogression took place shortly after the granulite facies metamorphism, before terrane assembly at *c.* 2720 Ma, probably by movement of melts and fluids into the upper, marginal zone of granulite facies rocks from deeper crust still being dehydrated. Retrogression during Late Archaean terrane assembly was in narrow reactivated zones of ductile deformation; in the Proterozoic it occurred with faulting and dyke emplacement.

Geochemical data are presented for Early Proterozoic high-Mg and mafic dykes. A rare 2085 Ma microgranite dyke strongly enriched in incompatible trace elements was formed by partial anatexis of Archaean continental crust.

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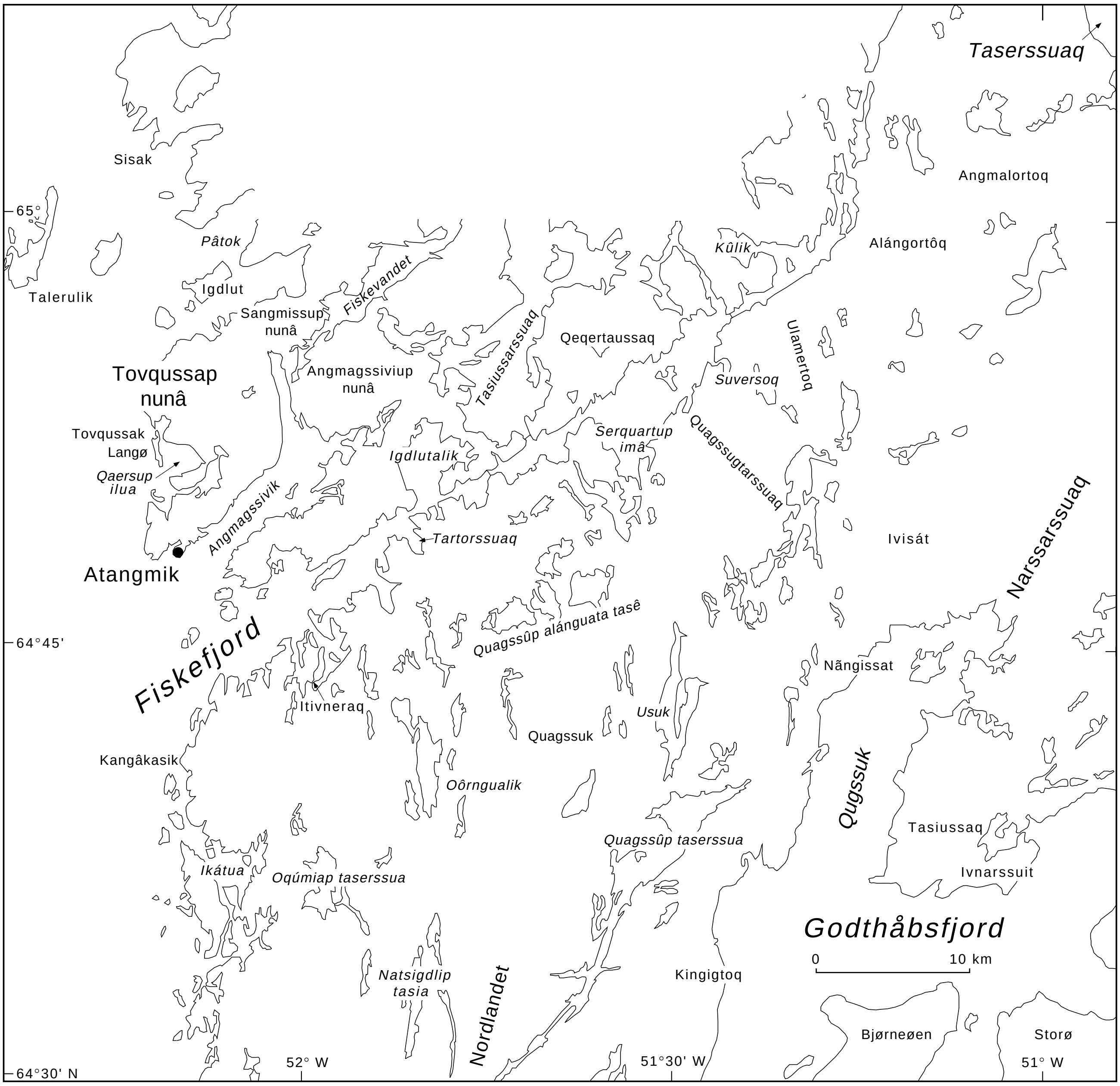


Fig. 1. Outline map of the Fiskefjord area showing place names used in the text. Finnefjeld lies 15 km to the north of the map, and Qôrqût 30 km to the south in Godthåbsfjord.

Introduction

Much of the Archaean crust presently exposed on Earth is traditionally considered to belong to either of two major associations: low-grade granite–greenstone terrains and high-grade grey gneiss – amphibolite terrains (e.g. Windley, 1984; Passchier, 1995). There is growing evidence from both types of associations that 'plate tectonics' in some form was important at least as early as the middle Archaean. Granite–greenstone terrains can provide detailed information about volcanic and sedimentary environments and upper crustal structure, but they may represent specific geotectonic settings where only rather thin continental crust was developed (e.g. Shackleton, 1995), and arguably they do not contain any remnants of oceanic crust (Bickle *et al.*, 1994). There is also new evidence from geophysical studies that most greenstone belts do not extend deep into the underlying continental crust (de Wit & Ashwal, 1995). By contrast, high-grade grey gneiss – amphibolite terrains represent environments where thick Archaean continental crust was rapidly accreted, and the uppermost crust therefore quickly removed by isostatic uplift and erosion. These terrains display the results of mid-crustal metamorphic and tectonic processes, but their supracrustal rock associations are commonly rather poorly preserved. The grey gneiss – amphibolite terrains are sometimes interpreted as the root zones of granite–greenstone terrains, and it is as yet uncertain if they comprise fragments of oceanic crust.

The Fiskefjord area examined in this paper is a type example of a middle Archaean high grade grey gneiss – amphibolite terrain. An early development of supracrustal rocks was followed by magmatic accretion of quartzo-feldspathic rocks in two separate episodes, the first of which took place at around 3200 Ma. A second major episode at *c.* 3000 Ma was short-lived but resulted in the establishment of thick continental crust and subsequent mid-crustal differentiation, and was accompanied by major metamorphic and tectonic activity.

The Fiskefjord area (Figs 1, 2) is located in the northern part of the Archaean block, southern West Greenland (Bridgwater *et al.*, 1976; Kalsbeek & Garde, 1989), which is bounded by the Proterozoic Nagssugtoqidian and Ketilidian orogens to the north and south, respectively. The Fiskefjord area forms a large part of the Akia terrane (Friend *et al.*, 1988a), see Fig. 2, which is juxtaposed to the south-east against the Akulleq terrane

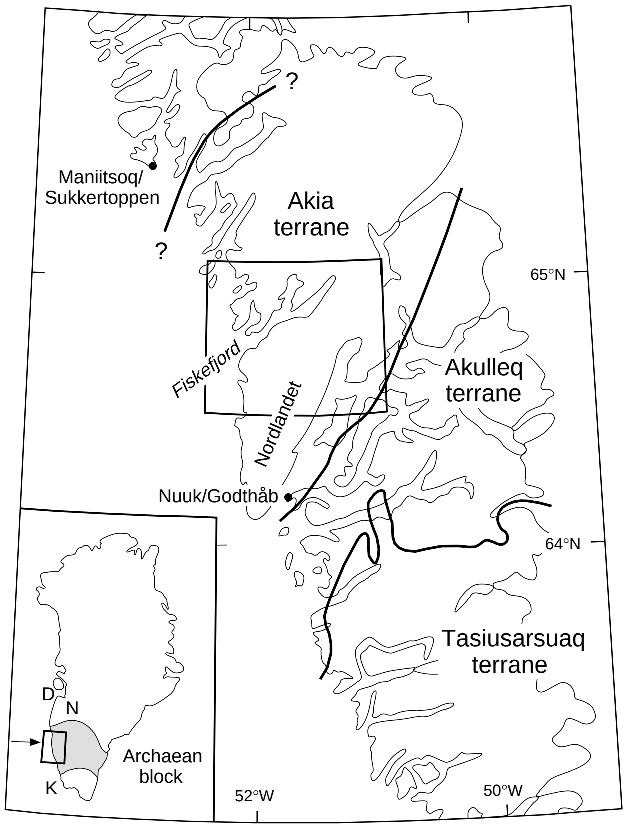


Fig. 2. Positions of three Archaean tectono-stratigraphic terranes: Akia, Akulleq and Tasiusarsuaq in the northern part of the Archaean block of southern West Greenland (inset map), with frame showing location of the Fiskefjord area in the southern part of the Akia terrane. The terranes were assembled around 2750–2650 Ma. D = Disko Bugt. N and K mark the position of the Proterozoic Nagssugtoqidian and Ketilidian orogens, respectively. See the main text for discussion and references.

in Godthåbsfjord (McGregor *et al.*, 1991). The northern boundary of the Akia terrane has not been identified in the field, but recent isotope work suggests that it is located south-east of Maniitsoq (Friend & Nutman, 1994). Plate 1 shows a simplified geological map of the Fiskefjord area, and Fig. 1 shows place names.

The geological history of the Fiskefjord area, summarised in Table 1 together with pertinent isotopic age data, comprises the following main stages: (1) formation of mafic, ultrabasic to ultramafic and minor pelitic supracrustal rocks, perhaps in an oceanic environment; (2) magmatic accretion of large volumes of first dioritic and then dioritic, tonalitic, trondhjemitic and grano-

Table 1. Magmatic, tectonic and metamorphic events in the Fiskefjord area, southern West Greenland

Igneous activity	Tectonic events	Metamorphism	Isotopic age data	Reference
Middle Archaean				
Oceanic? supracrustal association				
Accretion of Nordlandet dioritic gneiss precursors (number of phases unknown)	Early deformation of supracrustal association and dioritic gneiss		3221 ±13 Ma, SHRIMP zircon U-Pb Nordlandet dioritic gneiss	This paper
Second (oceanic?) supracrustal association?	Folding and thrusting within the supracrustal package	Early thermal event (?granulite facies)	*c.* 3180 Ma, SHRIMP zircon U-Pb, Nordlandet dioritic gneiss	This paper
Accretion of Qeqertaussaq diorite precursors (number of intrusive phases unknown) Accretion of main grey gneiss precursors (numerous intrusive phases)	Assembly of Nordlandet dioritic gneiss, dioritic-tonalitic-trondhjemitic gneiss (each with supracrustal enclaves), and possibly larger supracrustal bodies		3112 ±40 Ma?, w.r. Pb-Pb (composite from several units) 3044 ±7 Ma, SHRIMP zircon U-Pb Qeqertaussaq diorite	Garde (1989a, 1990), This paper
	Thrusting at high crustal levels along amphibolite – grey gneiss contacts (e.g. on Angmagssiviup nunâ)	Prograde metamorphism		
Continued magmatic crustal accretion	Midterhøj phase of deformation (recumbent isoclinal folds) in central Fiskefjord area and possibly on Tovqussap nunâ	Granulite facies conditions possibly reached in the southern and western parts of the Fiskefjord area	2954 ±120 Ma, w. r. Rb-Sr Amphibolite facies grey gneiss, Qugssuk	Garde (1989a, 1990)
	Smalledal phase of deformation (widespread recumbent, E–W trending isoclinal folds)			
Intrusion of mesoperthite granite sheets	Pâkitsoq phase of deformation (widespread upright to overturned, S-plunging folds)	Granulite facies metamorphism outlasting Pâkitsoq phase of deformation		
Intrusion of trondhjemitic and granitic rocks	Early doming, e.g. on Tovqussap nunâ and south of Fiskefjord			
	Ductile deformation in linear N–S trending high strain zones	Late stage of granulite facies metamorphism		
		Widespread high-grade (regional) retrogression	3137 ±172 Ma, w. r. Rb-Sr Grey gneiss, inner Fiskefjord	This paper
Intrusion of Finnefjeld gneiss complex (few large intrusive phases, four of which identified)	Ductile deformation along the south-eastern margin of the Finnefjeld gneiss complex		3067 $^{+62}_{-42}$ Ma, zircon U-Pb 3058 ±123 Ma, w. r. Rb-Sr 3034 ±134 Ma, w. r. Rb-Sr Finnefjeld gneiss complex	Garde (1990) This paper
Middle to Late Archaean				
Intrusion of Taserssuaq tonalite complex (few and large intrusive phases)	Doming	Local granulite facies conditions reached in western Taserssuaq tonalite complex	2982 ±7 Ma, zircon U-Pb 2882 ±36 Ma, w. r. Rb-Sr 2930 ±100 Ma, w.r. Rb-Sr Taserssuaq tonalite complex	Garde *et al.* (1986) This paper
Intrusion of Igánánguit granodiorite	Formation of Igánánguit dome		2935 ± 240 Ma, w. r. Rb-Sr 3092 ±48 Ma (?), w. r. Pb-Pb Igánánguit granodiorite	Garde *et al.* (1986) This paper
Intrusion of Qugssuk granite and related granite sheets, e.g. in northern Nordlandet	Localised doming Localised ductile deformation along N–S trending zones	Local retrogression caused by granite emplacement	2969 ±32 Ma, w. r. Rb-Sr 2842 ±85 Ma, w. r. Rb-Sr Qugssuk granite	Garde *et al.* (1986) This paper
Intrusion of post-kinematic diorite plugs, mainly in the north-western part of the area	End of regional deformation	Auto-retrogression in diorites; possibly also affected by regional retrogression	3017 $^{+12}_{-10}$ Ma, zircon U-Pb (zircons interpreted as cogenetic). Rb-Sr data, Post-kinematic diorite	Garde (1991) This paper

Table 1. Magmatic, tectonic and metamorphic events in the Fiskefjord area (continued)

Igneous activity	Tectonic events	Metamorphism	Isotopic age data	Reference
Late Archaean				
Pegmatite intrusion?	Terrane assembly Reactivation of high-strain zones	Renewed local retrogression along reactivated zones	*c.* 2720 Ma	McGregor *et al.* (1991), Friend *et al.* (1996)
Pegmatite intrusion? (Intrusion of Qôrqut granite complex in Akulleq terrane)		Thermal event	*c.* 2500 Ma, plagioclase, titanite, apatite, Rb-Sr Taserssuaq tonalite complex	Garde *et al.* (1986)
Proterozoic				
Intrusion of N–S trending high-Mg and related dykes, followed by mafic dykes in other directions	Faulting along the Fiskefjord fault and a related conjugate system of NE- and WNW-trending faults	Localised retrogression along dykes and faults	*c.* 2200 Ma, w. r. Rb-Sr SHRIMP zircon U-Pb High-Mg and mafic dykes	Bridgwater *et al.* (1995) Nutman *et al.* (1995)
Intrusion of microgranite dyke at Qugssuk		Weak thermal event	2085^{+55}_{-65} Ma, zircon U-Pb Microgranite dyke at Qugssuk	This paper
		Weak thermal event	*c.* 1690 Ma, epidote and biotite Rb-Sr Taserssuaq tonalite complex	Garde *et al.* (1986)

Note the concentration of events at *c.* 3000 Ma, with overlapping ages. Specific listed events need not be synchronous over the entire area. w. r. = whole rock.

dioritic grey orthogneiss and related rocks at *c.* 3225 and *c.* 3040–2980 Ma, probably in convergent plate-tectonic environments, and culmination of associated ductile deformation and high-grade metamorphism (Garde, 1989a, 1990); (3) partial remobilisation of newly formed grey gneiss, leading to the emplacement of sheets and domes of younger granitoid rocks (Garde *et al.*, 1986); (4) emplacement of local post-kinematic diorite plugs (probably at *c.* 3000 Ma, Garde, 1991), which mark the end of regional Archaean deformation and metamorphism in the Akia terrane. (5) Towards the end of the Archaean (at around 2720 Ma) the Akia terrane was amalgamated with other terranes in the Godthåbsfjord region (Nutman *et al.*, 1989; McGregor *et al.*, 1991; Friend *et al.*, 1996) and became part of the Archaean craton of southern West Greenland. (6) In the Early Proterozoic, contemporaneously with Nagssugtoqidian and Ketilidian orogenic activity north and south of the Archaean craton, block faulting occurred along the NE–SW trending Fiskefjord fault and related faults. Mafic dykes were emplaced, and thermal episodes resulted in injection of rare acid dykes of crustal anatectic origin (Kalsbeek & Taylor, 1983; this paper) and resetting of Rb-Sr biotite ages (Garde *et al.*, 1986).

The present study is based on investigations in the Fiskefjord map area (Garde, 1989b) with its predominant grey orthogneiss and amphibolite, and in two adjacent areas: an inland area to the north-east within the Isukasia map area (Garde, 1987) that includes a younger granitic dome, and a coastal area to the north-west (Marker & Garde, 1988). In the latter area the border zone is exposed between the orthogneiss–amphibolite terrain and the Finnefjeld gneiss complex, a large composite tonalitic pluton that also post-dates the formation of the grey gneisses. The field work was carried out in the period 1980–1987 during a systematic mapping project by the Geological Survey of Greenland (Garde & McGregor, 1982; Garde, 1984, 1986; Garde *et al.*, 1983, 1987; Marker & Garde, 1988).

Previous geological investigations include an early coastal reconnaissance of West Greenland by Noe-Nygaard & Ramberg (1961) and – within the Fiskefjord map area – detailed studies of Tovqussap nunâ and adjacent areas (Berthelsen, 1951, 1960, 1962), and the area west of Qugssuk (Lauerma, 1964). Besides, Sørensen (1953) carried out a detailed petrographic study of ultrabasic rocks at Tovqussap nunâ. In the 1970s B. F. Windley undertook a coastal reconnaissance survey along Fiskefjord and adjacent fjords in preparation for the 1:500 000 map sheet Frederikshåb Isblink – Søndre Strømfjord (Allaart, 1982), and the exploration company Kryolitselskabet Øresund A/S carried out an extensive geological and geophysical mineral exploration programme. Dymek (1978, 1984) and Pillar (1985) studied metamorphism at Langø west of Tovqussap nunâ and in the southern part of the Fiskefjord area, respectively (and elsewhere in the region), and Riciputi *et al.* (1990) determined peak metamorphic conditions in Nordlandet.

Supracrustal rock association: field characteristics and petrography

Amphibolite of presumed volcanic origin and related basic and ultrabasic intrusive rocks, besides very minor pelitic metasediments, form an important component of the Fiskefjord area and constitute about 10 per cent of the outcrop. For convenience these lithologies are collectively referred to as the supracrustal rocks in the following, although this is not strictly correct. The supracrustal rocks form both layers and enclaves of very variable size in most parts of the dioritic, tonalitic and trondhjemitic orthogneiss, and the intrusive relationships of the latter rocks (described later) show that the supracrustal rocks as a whole are older than the grey gneiss, although they may well consist of originally independent sequences of different age.

Supracrustal rocks in the Fiskefjord area have been referred to in previous papers as equivalent to Malene supracrustal rocks in the adjacent Godthåbsfjord region. All supracrustal rocks of supposed Middle Archaean age in the latter region were originally called the Malene supracrustal rocks by McGregor (1969), although he realised that they might belong to more than one group. Subsequent dating of Malene metasedimentary rocks (Hamilton *et al.*, 1983; Schiøtte *et al.*, 1988) showed that they comprise several Middle to Late Archaean age populations. At about the same time it was discovered that the Godthåbsfjord region consists of several terranes with different histories and different ages, and the term 'Malene supracrustal rocks' is no longer used.

None of the supracrustal rocks in the Fiskefjord area have been dated, and their preservation as scattered, fragmented layers and rafts in younger rocks complicates an assessment of their mutual relationships and stratigraphy. In addition, the post-magmatic history of the supracrustal rocks with repeated deformation and metamorphism as enclaves in the grey gneiss has obliterated most primary structures and hindered geochemical identification of their origin due to likely element mobility (see p. 21). Besides, some supracrustal rocks were not surveyed in detail due to limited time available in the field. Therefore this account is not entirely comprehensive.

For descriptive purposes the supracrustal rocks of the Fiskefjord area can be divided into two main groups. Homogeneous, in places porphyroblastic amphibolite forms the bulk of the supracrustal rocks with additional leuco-amphibolite, heterogeneous calc-silicate-bearing amphibolite and minor pelitic metasediment. The second group comprises various ultrabasic rocks. Some ultrabasic bodies have outcrop dimensions of 2–3 km and occur as ovoid or lens-shaped mega-enclaves in either amphibolite or orthogneiss. They predominantly consist of dunite and peridotite and locally display rhythmic magmatic layering. Other ultrabasic and noritic rocks form stratiform, up to a few hundred metres thick bodies overlain by thick sequences of homogeneous amphibolite. Collectively the latter rocks outline at least two layered intrusive complexes, the largest of which is more than 25 km long in its present deformed state.

Homogeneous amphibolite

The most common amphibolite forms homogeneous, fine- to medium-grained, granulite facies rocks with plagioclase, hornblende, ortho- and clinopyroxene (the pyribolites of Berthelsen, 1960), and equivalent plagioclase-hornblende rocks in amphibolite facies in the easternmost part of the Fiskefjord area. Accessory biotite and magnetite-ilmenite intergrowths may occur in rocks of both facies, and titanite is present in some amphibolite facies rocks. Finely disseminated iron sulphide (less than one per cent) is common, and chalcopyrite has occasionally been observed. The amphibolite commonly has a moderate to strong tectono-metamorphic schistosity, combined with distinct rodding and hornblende lineation in hinge zones of larger folds. Mineral textures observed in thin section may be equigranular, but hornblende commonly developed a preferred planar or linear orientation during regional deformation. Pyroxene-bearing amphibolite may be variably retrogressed, whereby hypersthene is partially altered to fibrous orthoamphibole or replaced by symplectitic hornblende-quartz aggregates, and clinopyroxene replaced by epidote-clinozoisite. In some samples the latter mineral also forms coronas around, or completely replaces hornblende. Chemical aspects of this retrogression are examined in a later section.

The homogeneous amphibolite forms layers up to several hundreds of metres thick (rarely up to *c.* 2 km)

Fig. 3. Homogeneous amphibolite cut by numerous thin quartzo-feldspathic sheets. 10 km east of the head of Fiskefjord.

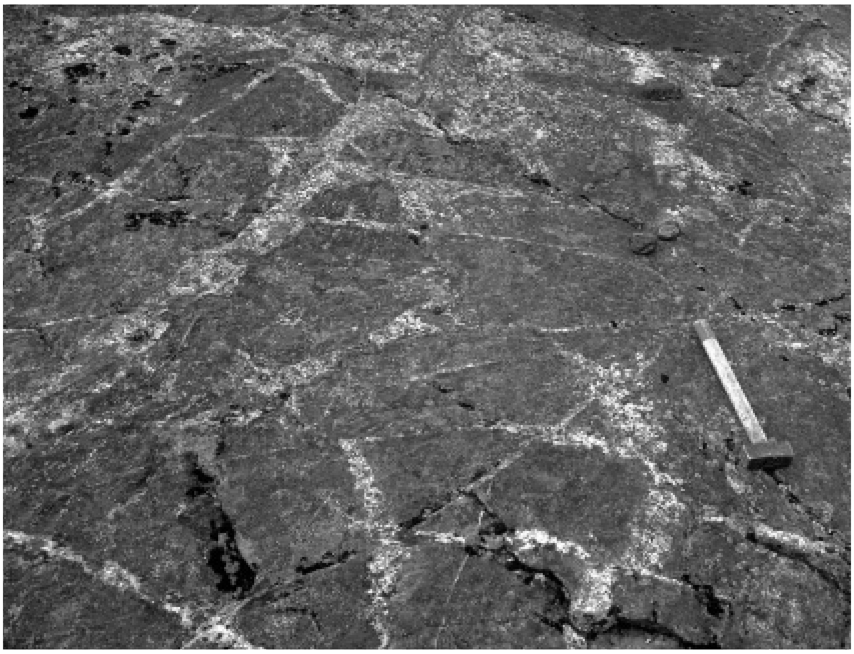
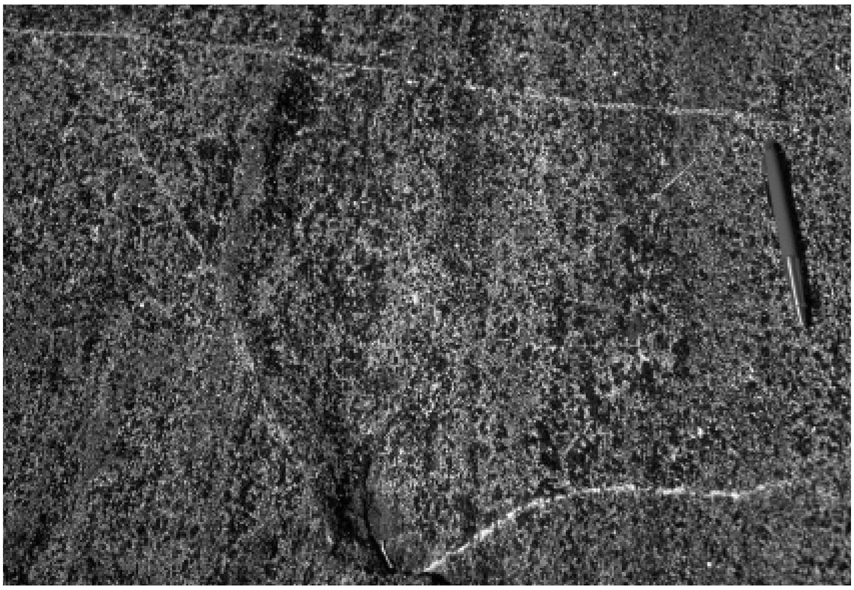


Fig. 4. Homogeneous medium-grained amphibolite with hornblende-blastic texture. East coast of Qugssuk, *c.* 5 km from the head of the fjord.



in the orthogneiss, and in its present state of preservation it generally appears to be very uniform, without lithological variations that can be ascribed to origin or mode of emplacement (Fig. 3). However, particularly in the lower grade, eastern part of the area there are local porphyroblastic varieties (Fig. 4) characterised by scattered hornblende or plagioclase crystals up to *c.* 1 cm, which may be pseudomorphs of porphyritic magmatic precursors. In this area a *c.* 500 m thick horizon of homogeneous, leucocratic, grey, fine-grained amphibolite also occurs adjacent to a more mafic amphibolite layer. The homogeneous and porphyroblastic amphibolites may have originated as volcanic flows or, more likely, as subvolcanic intrusive rocks (see p. 15).

Heterogeneous amphibolite

Thin horizons of heterogeneous, commonly calc-silicate-bearing amphibolite as well as pelitic metasediment alternate with homogeneous amphibolite in some parts of the Fiskefjord area. Such rocks occur in the western part of the peninsula east of Qugssuk, at the head of Qugssuk, east of the ridge Ulamertoq north of Qugssuk,

Fig. 5. Heterogeneous amphibolite with a *c.* 1 m thick calc-silicate horizon rich in diopside and garnet. The competent calc-silicate horizon is broken up into *c.* 50–80 cm large, in places folded, boudins and thinner slabs, which show anticlockwise rotation. 10 km north-east of Ulamertoq.

Fig. 6. Heterogeneous, thinly banded amphibolite cut by successive phases of diorite (right of the hammer) and tonalite, and subsequently folded. 8 km east of Ulamertoq.

on both sides of central Fiskefjord in the vicinity of the embayment Suversoq, at Tovqussaq (west of Tovqussap nunâ), and north of Tovqussap nunâ. The heterogeneous amphibolite mainly forms horizons up to a few metres thick with decimetre-sized lenses and irregular patches or, in strongly deformed varieties, distinct centimetre-thick bands of diopside, calcic plagioclase, hornblende, garnet and epidote besides local scapolite or calcite (Fig. 5). Other varieties of heterogeneous amphibolite consist of alternating layers a few centimetres to decimetres thick with variable proportions of hornblende, pyroxene and plagioclase (Figs 6, 7). Some of the heterogeneous, commonly calc-silicate-bearing amphibolite resembles strongly deformed varieties of pillowed lava sequences described from other parts of West Greenland (e.g. Hall & Hughes, 1982; Chadwick, 1990; McGregor, 1993). Besides, the common occurrence of heterogeneous amphibolite interlayered with pelitic metasediment also indicates a submarine extrusive, rather than subaerial or intrusive origin. Other units such as shown in Fig. 7 may originally have been tuffs or tuffites.

A different type of heterogeneous, banded amphibolite contains thin seams of quartz and pyrrhotite and forms rusty-weathering zones a few metres thick within homogeneous or calc-silicate-bearing amphibolite.

Bengaard (1988) described rare matrix-supported amphibolitic conglomerate or agglomerate, poor in calc-silicate minerals, in the Suversoq area south of inner Fiskefjord. Also calc-silicate-banded amphibolite and micaceous metasediment are present in this area. South of outer Fiskefjord there are local occurrences of another type of strongly deformed fragmental amphibolite consisting of closely packed, up to *c.* 1 m long, cigar-shaped or flattened lenses with diffuse margins to an indistinct quartzo-feldspathic matrix (Fig. 8). This type of fragmental amphibolite may represent strongly deformed pillow lava, or it could be an unusual type of agmatite.

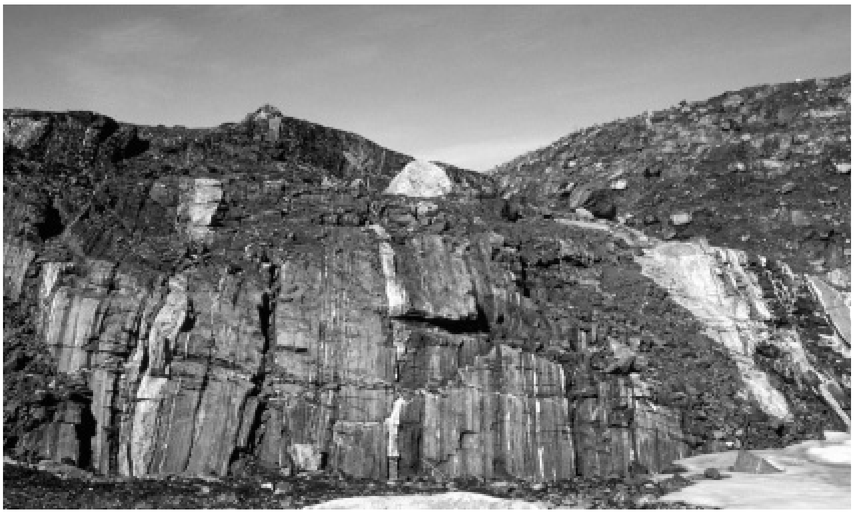


Fig. 7. Succession of strongly deformed, heterogeneous amphibolite with horizons of leuco-amphibolite, perhaps meta-andesitic tuff or tuffite. 7 km east of Ulamertoq.

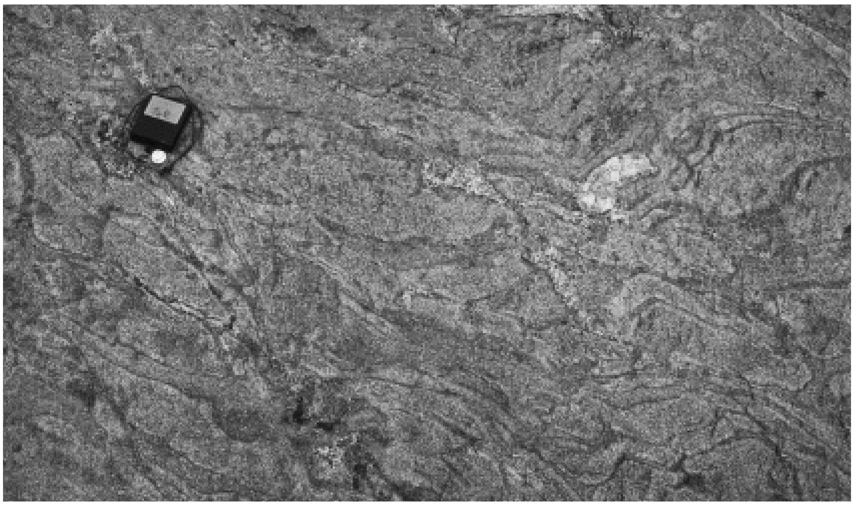


Fig. 8. Strongly deformed fragmental amphibolite consisting of closely packed, up to *c*. 1 m long, cigar-shaped or flattened lenses with diffuse margins to an indistinct quartzo-feldspathic matrix. South of outer Fiskefjord, *c*. 7 km north-east of Itivneraq.

Ultrabasic rocks

Large dunitic bodies

Several ovoid or lens-shaped ultrabasic bodies associated with amphibolite occur in the Fiskefjord area, the largest ones being 2–3 km long (Plate 1). Two of them, north-east of Fiskevandet and north-east of Tasiussarssuaq, are embedded in amphibolite and largely consist of granular, medium-grained dunite, olivine-rich peridotite and smaller irregular bodies of orthopyroxene-rich peridotite with a gradational transition into the dunitic rock. Well-developed rhythmic magmatic layering of olivine and orthopyroxene (locally of olivine and chromite) has been observed in both of these bodies. A third ultrabasic body occurs *c*. 5 km west of the head of Fiskefjord just north of 65°, at the boundary between amphibolite and leucocratic orthogneiss. It is in part covered by a lake and may be longer than the *c*. 1 km long outcrop. Like the two other ultrabasic bodies it consists predominantly of dunite, but its northernmost part adjacent to the amphibolite also contains noritic rocks. Irregular sheets of granite up to *c*. 100 m thick cut the ultrabasic bodies (see p. 14).

A fourth, large ultrabasic body is located 5 km east of Ulamertoq, forming a 1 by 1.5 km large enclave in grey orthogneiss (Fig. 9; Plate 1) at the northern tip of a *c*. 100 m thick amphibolite layer. This was investigated in some detail, and a sketch map is shown in Fig. 10. The ultrabasic body has a partial shell of biotite- and garnet-rich metasediment with thin bands of amphibolite and leuco-amphibolite. The orthogneiss host just south of the ultrabasic body contains numerous metre-sized and larger rafts of amphibolite, biotite schist and ultrabasic rock, which dip steeply inwards to the centre of the body and commonly outline tight N-plunging small scale folds. The ultrabasic body predominantly consists of granular, very uniform, medium-grained

Fig. 9. Large, pale brown ultrabasic body *c.* 5 km east of Ulamertoq, viewed towards the west. The ultrabasic body mostly consists of granular dunite and forms a mega-enclave in the orthogneiss. Part of the body is covered by many small lakes.

dunitic rock with pale brown weathering colours. Variable proportions of ortho- and clinopyroxene may be present and locally dark green spinel or chromite. Thin veins of hydrated phases such as anthophyllite, tremolite, chlorite and phlogopite are quite common (Fig. 11). In the southern, most olivine-rich part of the body there are small areas where centimetre-scale indistinct chromitite layering occurs in the dunite; the chromite occurrence was investigated in the 1970s by Kryolitselskabet Øresund A/S, but it was found to be of no economic interest.

The north-eastern part contains ultrabasic rocks which are less magnesian (Fig. 10). Red-brown weathering harzburgite and locally orthopyroxenite with *c.* 2 cm large pale brown equidimensional, poikilitic orthopyroxene covers an irregular area of *c.* 250 by 600 m. This is bounded to the north-east by a 150 by 500 m large sheet of grey-brown weathering, medium- to coarse-grained norite consisting of calcic plagioclase and magnesian orthopyroxene with accessory hornblende and phlogopite. There are also small pods of granular, medium-grained, greenish brown weathering clinopyroxene-rich rocks. These different rock types generally have gradational contacts; their orientations are difficult to determine due to their gradational nature and the flat topography, but moderately steep to subvertical contacts appear to be common.

Distinct magmatic layering with orientations varying from flat-lying to almost vertical has been observed locally along the contacts. A *c.* 40 m thick norite lens 300 m from the southern end of the ultrabasic body is separated from the dunite by a subvertical, metre-thick layer of coarse-grained orthopyroxenite, followed towards the norite by several parallel, few centimetres thick, alternating layers of orthopyroxenite and plagioclase-rich leuconorite (Fig. 12). The adjacent dunite contains several series of parallel, 0.5–2 cm thick, pale pyroxene-bearing horizons (Fig. 11), traceable over a few metres.

The ultrabasic body contains several irregular sheets and pods of white to pale pinkish granite, which are up to *c.* 150 m thick (Fig. 10). The granite sheets locally cut into the surrounding grey gneiss but are essentially confined to their ultrabasic host. The granites, which are probably of local anatectic origin, appear to have been emplaced along fractures in the competent ultrabasic body during regional deformation. Similar granites are also present in the other large ultrabasic bodies of the Fiskefjord area.

Layered complexes with stratiform ultrabasic and noritic rocks

Two large, layered complexes consisting of ultrabasic, noritic and metagabbroic rocks are embedded within supracrustal rocks. One complex extends for *c.* 25 km in N–S direction across central Fiskefjord, from west of

Quagssugtarssuaq through Suversoq and northwards to the embayment Kûlik. Another occurs at Sangmissup nunâ, north-east of Tovqussap nunâ (Plate 1). Their exact boundaries have not been located as it is not known how much of the overlying homogeneous amphibolite they comprise. These kilometre-sized bodies of ultrabasic rocks may be fragments of larger layered complexes.

The best preserved complex, that across Fiskefjord, consists of elongate lenses and layers of olivine-rich ultrabasic rocks which either pass laterally or grade upwards into norite which, in turn, is overlain by homogeneous amphibolite (see also Bengaard, 1988). The ultrabasic and noritic rocks together form discontinuous, 10–50 m (locally up to *c.* 150 m) thick sheets along the base of a major unit of massive, homogeneous amphibolite (Fig. 13). This amphibolite outlines an elongate, doubly-plunging synform with closures south-west of Quagssugtarssuaq and north of Kûlik. The ultrabasic and noritic rocks occur both along the flanks and in the two hinge zones of this fold; the longest norite sheet can be traced for at least 15 km.

Most of the exposed lower boundary of the layered complex comprises intrusive or tectonic contacts with grey orthogneiss, and both the orthogneiss and ultrabasic-noritic rocks are commonly appreciably deformed along them. In places a *c.* 10 m thick layer of flaggy, strongly schistose, biotite- and garnet-rich pelitic sed-

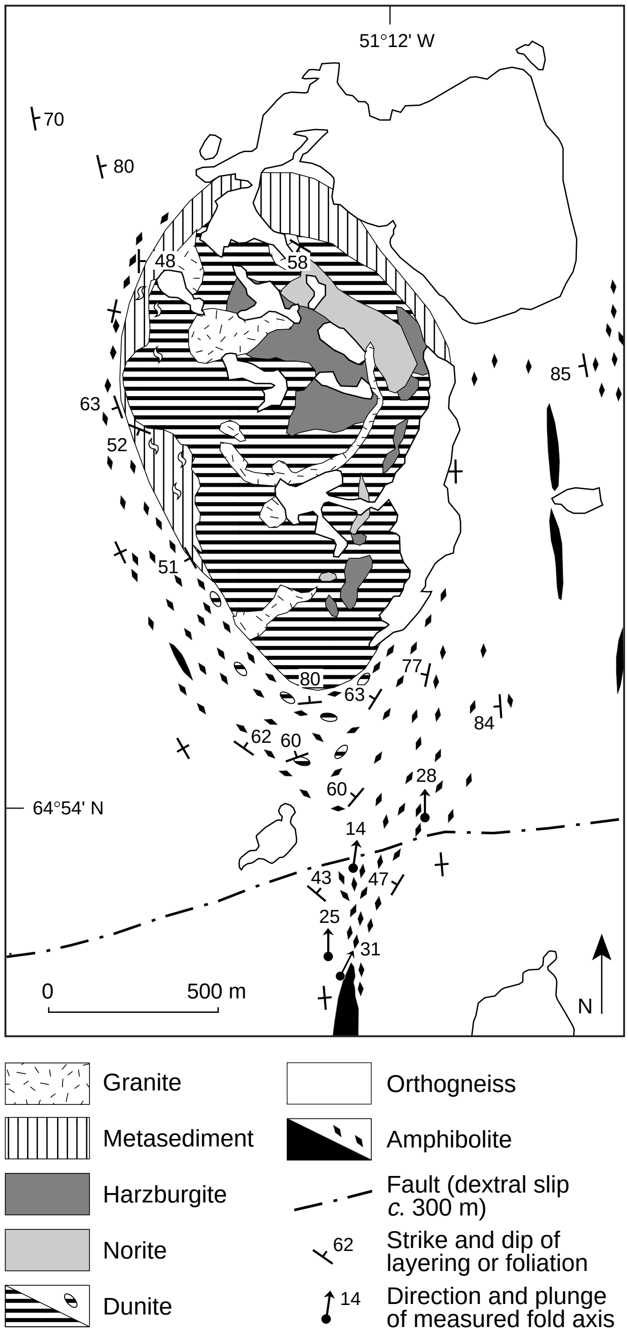


Fig. 10. Sketch map of the ultramafic body east of Ulamertoq.

iment occurs along the lower contact of the layered complex. At one locality Bengaard (1988) observed little-deformed norite cutting compositional banding in the metasediment, suggesting an intrusive relationship. At the mouth of Suversoq steep isoclinal folds occur in the layered complex and adjacent supracrustal rocks, including thin horizons of 'infolded' metasediment. These folds pre-date the emplacement of the surrounding orthogneiss.

Fig. 11. Magmatic layering in olivine-rich ultrabasic rock, and a tremolite-phlogopite-diopside vein. Ultrabasic body east of Ulamertoq.

Fig. 12. Layered orthopyroxenite and plagioclase-rich leuconorite. Ultrabasic body east of Ulamertoq.

In the field the norite typically appears as a sugary, grey, very homogeneous rock, not unlike homogeneous tonalitic-dioritic granulite facies orthogneiss, but rare igneous layering consisting of metre-thick orthopyroxene-rich horizons alternating with norite has also been noted. Whereas contacts between dunitic and noritic rocks are sharp or gradational over less than *c.* 5 m, the boundaries between the noritic rocks and overlying homogeneous amphibolite is typically very gradual, with transitions over several tens of metres marked by increasing hornblende.

The norite has metamorphic textures. Orthopyroxene mostly forms equidimensional, *c.* 2–5 mm large anhedral grains, commonly replaced by up to 1–2 mm green hornblende in rounded embayments. Matrix calcic plagioclase (about An_{75}) forms large anhedral grains (up to 10 mm) with frequent tiny hornblende inclusions. Metamorphic equilibrium is suggested by common triple junctions between plagioclase, orthopyroxene or hornblende, and by the absence of mineral zoning.

The deformed margins of the norite bodies contain a distinct schistosity. Elongate, poikiloblastic orthopyroxene crystals up to 10 mm, intergrown with hornblende and subordinate pale brown phlogopite, are orientated parallel to schistosity and surrounded by a mosaic of equant to elongate plagioclase grains. The orthopyroxene grains are commonly composite, consisting of smaller lensoid domains with slightly different optical orientations.

Fig. 13. Dunitic ultrabasic rock (left, marked u) overlain by grey norite (at the lake, marked n) and homogeneous amphibolite in the far distance (marked a). West of Quagssugtarssuaq, 5 km south-east of Serquartup imâ.

Origin of the ultrabasic and noritic rocks

Komatiites in the sense of Arndt (1994) – volcanic, commonly spinifex-textured rocks of picritic to ultrabasic composition, crystallised from previously superheated magmas, have so far not been identified within the Archaean block of southern West Greenland, although Hall (1980) described ultrabasic pillow lavas from the Ivisârtoq area in southern West Greenland. However, komatiites are common constituents of many Mid Archaean supracrustal sequences and may also comprise cumulate rocks. For instance, in the generally well preserved Late Archaean Norseman–Wiluna Greenstone Belt, Yilgarn Block, Western Australia (Hill *et al.*, 1990), the thickest komatiitic flows can commonly be demonstrated to have differentiated, and they may contain cumulate dunitic rocks at their bases, which may rarely reach thicknesses up to a couple of hundred metres. The ultrabasic volcanic units very commonly alternate with basaltic units of similar thickness.

All the larger ultrabasic bodies in the Fiskefjord area predominantly consist of granular, medium-grained, olivine-rich, locally chromite-bearing dunitic rocks, in which magmatic layering and orthocumulus textures are fairly common features. There is a common association with noritic cumulates and, west of Quagssugtarssuaq there is a thick overlying sequence of homogeneous amphibolite. In spite of strong deformation and flattening which has resulted in disruption of the ultrabasic bodies (e.g. south of Quagssugtarssuaq) rather than tectonic repetition, some of them retain thicknesses in the order of 1 km. The available observations from the Fiskefjord area thus suggest that the large ultrabasic bodies are cumulate rocks which were formed at the bases of large magma chambers. This is also supported by geochemical data (see p. 24) but is difficult to substantiate because the apparent absence of spinifex-textured rocks or pillowed lavas in the ultrabasic rocks is not positive evidence that there are no volcanic components among them: former spinifex textures might have been destroyed by high-grade metamorphism and strong penetrative deformation. On the other hand olivine-rich ultrabasic rocks are very competent and resistant to deformation if not hydrated, and do not readily recrystallise even at granulite facies metamorphic conditions.

Fig. 14. Coastal exposure of leucogabbroic to gabbroic enclave in granulite facies orthogneiss, on a small island 5 km south-south-west of Atangmik.

Anorthosite and leucogabbro

Anorthosite and leucogabbro are commonly associated with Archaean supracrustal sequences in West Greenland (e.g. Myers, 1985) and also occur in the relatively poorly exposed south-western part of the Fiskefjord area, forming the continuation of a larger unit in Nordlandet (see McGregor, 1993). At the outer coast south-east of Íkátua, leucogabbro is associated with a large body of amphibolite in the core of a major refolded fold. Along both flanks of this fold the unit continues as several parallel, up to about 1 km wide tracts of closely packed leucogabbroic and gabbroic enclaves in dioritic and tonalitic gneiss, and similar enclaves occur sporadically e.g. around outer Fiskefjord (Plate 1; Fig. 14). The leucogabbro is mostly a medium-grained, pale, homogeneous rock consisting of calcic plagioclase and hornblende with granoblastic metamorphic texture. Smaller units of medium- to coarse grained anorthosite and leucogabbro associated with amphibolite were described by Berthelsen (1960) from Tovqussap nunâ and also occur on a small island north-west of this peninsula.

The anorthosite and leucogabbro occurrences in the Fiskefjord area may be members of disrupted layered complexes, but it has not been possible to demonstrate this in the field.

Fig. 15. Biotite-garnet-sillimanite schist with flattened, up to *c.* 50 cm long calc-silicate lenses, and cut by thin sheets of garnet-bearing granite which is presumably of local anatectic origin (see the main text). North coast of the island Igdlut, *c.* 5 km south of Pâtok.

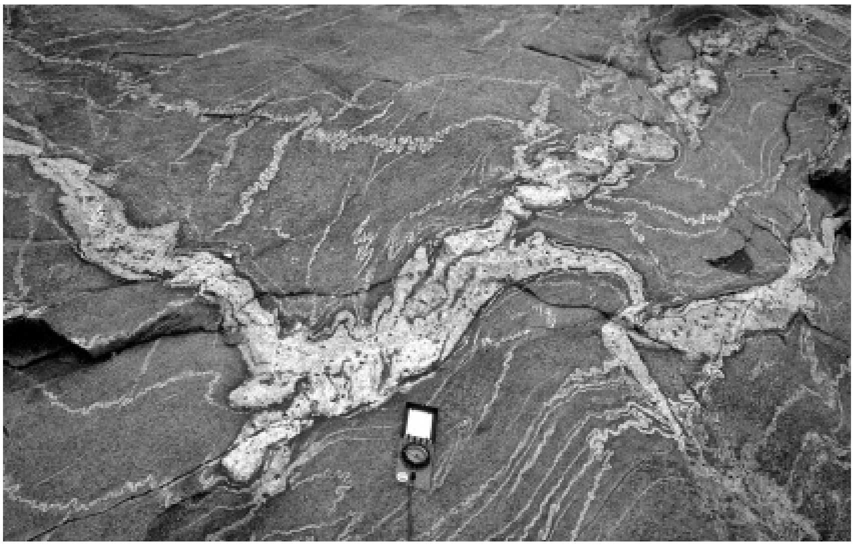


Fig. 16. Folded biotite schist with local anatectic vein of garnet-bearing granite; note the dark selvage rims. East coast of Qugssuk, *c.* 3 km from the head of the fjord.

Metasediments and altered felsic volcanic rocks

Metasediments are volumetrically very insignificant among the supracrustal rocks. They form thin, discontinuous horizons of fine- to medium-grained rocks, commonly strongly schistose with characteristic rusty brown weathering colours (Fig. 15). They exclusively occur within or along the margins of amphibolite, or along ultrabasic bodies. Pelitic schists are most common and consist of plagioclase, quartz, biotite, commonly garnet, and in places additional sillimanite or cordierite. Thin anatectic sheets of garnet-bearing granite (granulite *s.s.*, Berthelsen, 1960), are commonly associated with the pelitic schists (Figs 15, 16). Fine-grained, brownish-grey, quartzo-feldspathic rocks of intermediate composition are locally intercalated with biotite-garnet schist or occur adjacent to amphibolite and ultrabasic rocks. These rocks may be closely related to leuco-amphibolite as suggested by their composition (see p. 24) and are probably of volcano-sedimentary origin. Quartzite or quartz-rich clastic rocks are almost absent from the metasediments of the Fiskefjord area.

On a small island off the outer coast *c.* 2 km north of Kangâkasik, less than 1 m thick horizons of garnet- and magnetite-rich siliceous rocks are intercalated with biotite-garnet-cordierite schist. Berthelsen (1960) and Dymek (1984) described magnetite-diopside-quartz rocks from Langø west of Tovqussap nunâ, associated with calc-silicate rocks and biotite-garnet schist. These rare rock types are interpreted as chemical metasediments (silicate facies iron formation).

Cordierite- and anthophyllite-cummingtonite-rich siliceous rocks form a significant proportion of the thin supracrustal horizons in the south-western part of the Fiskefjord area (between Íkátua and Oqúmiap taserssua and west of Natsigdlip tasia), which also include impure quartzites. Sporadic cordierite-bearing supracrustal rocks also occur, e.g. at Tovqussap nunâ (Berthelsen, 1960). Similar rocks in the Godthåbsfjord region have been interpreted by Beech & Chadwick (1980) and Dymek & Smith (1990) as hydrothermally altered siliceous metavolcanic rocks.

Supracrustal rock association: geochemistry

The analysed samples were collected from many different enclaves of supracrustal rocks mostly in the northern part of the Fiskefjord area (Plate 1; Fig. 17); the groups correspond to those introduced in the previous descriptions. The large geographical coverage is considered to provide a reasonable overview of rock compositions, although limited knowledge about primary relationships between various types of supracrustal rocks, uncertain correlation between geographically separate units, and absence of radiometric age deter-

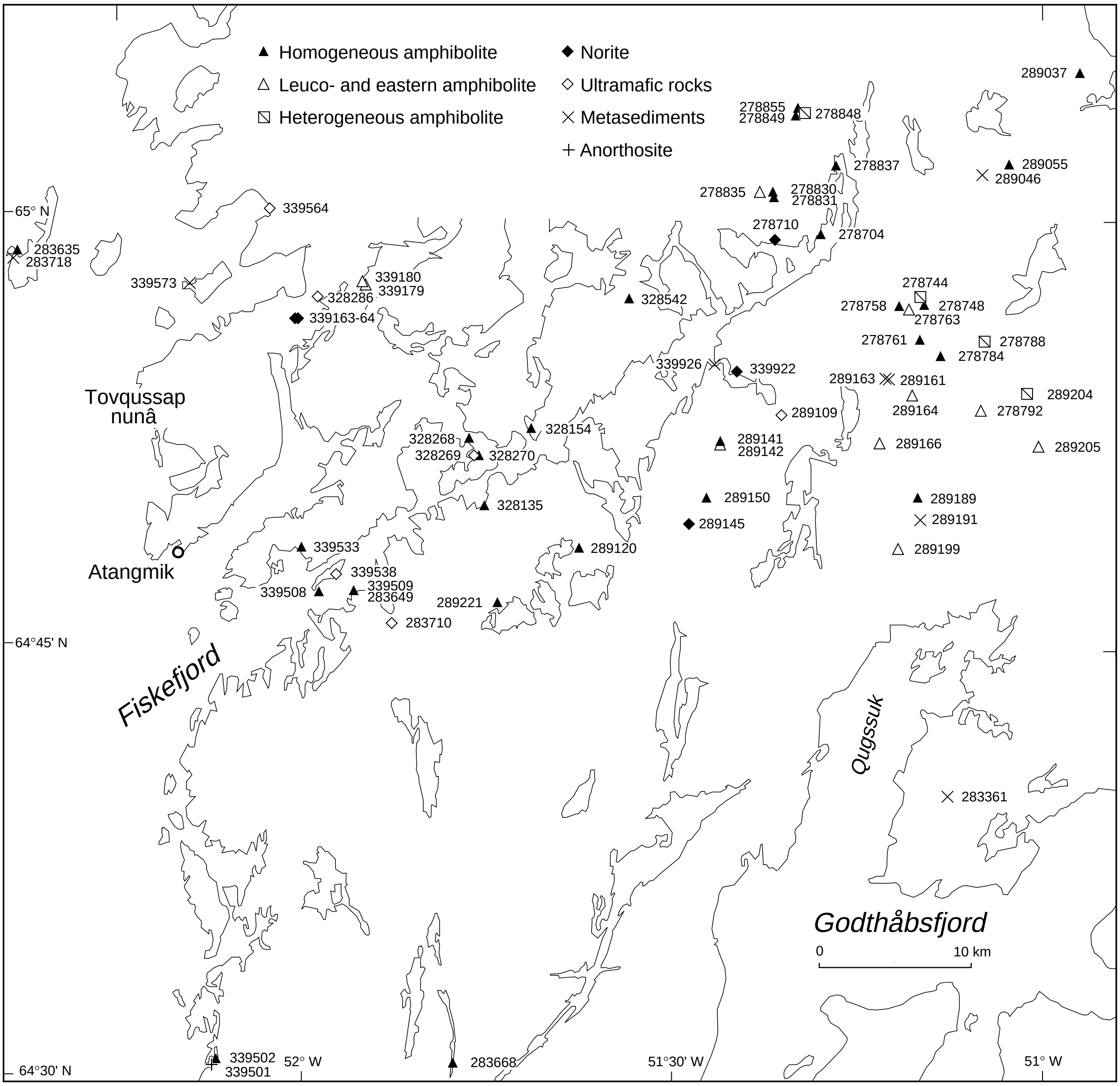


Fig. 17. Locations of analysed amphibolites, metasediments, norites, ultramafic rocks and anorthosite in the Fiskefjord area, with GGU sample numbers.

minations suggest that the analyses may well represent several originally independent sequences.

Modification of original compositions

The compositions of the supracrustal rocks are likely to have been modified from those of their original precursors at various stages of their geological history. Amphibolite precursor magmas may have been contaminated during their emplacement, e.g. by assimilation of crustal rocks, and their products affected by hydrous sea floor alteration. Subsequent metasomatism may have occurred during late diagenesis, during the emplacement of sialic magmas while the continental crust was building up around the supracrustal association, during prograde metamorphic dehydration reactions, and during localised retrogressive rehydration. Only the latest of possible alteration events can now be examined directly; obviously examples of pristine amphibolite precursors are not available for comparison. However, in contrast to the grey gneiss (Garde, 1990 and pp. 55-65), metasomatic changes associated with retrogressive hydration do not seem to have been significant in the case of the amphibolites. Geochemical data from homogeneous amphibolites (Appendix 1) include averages of 22 amphibolites with granulite facies parageneses and 9 similar rocks with textural evidence of partial rehydration. The two groups have almost identical compositions, except that the latter group has higher contents of trivalent iron and volatiles (about 1.0 and 0.5 per cent, respectively), and perhaps slightly different LREE (see below). Elements like K, Na, Rb, Sr, and Pb, which were mobile in intermediate and leucocratic orthogneisses in the Fiskefjord area during both the prograde granulite facies event and the subsequent retrogression (Garde, 1990; this paper), occur in similar concentrations in granulite facies and partially retrogressed amphibolites. A likely explanation is that whereas retrogression of intermediate orthogneisses was commonly complete and involved total replacement of pyroxene by secondary amphibole and biotite, retrogression in most amphibolites was incomplete, biotite was rarely involved, and a stable hydrated phase (mainly hornblende) that could accommodate LIL elements was present throughout the process.

Nevertheless, both the LIL elements and Ca show large variations in the amphibolites (see below), and several LIL elements occur in concentrations that are higher than in unaltered modern basaltic rocks of common geotectonic settings (see p. 25). Besides the LIL elements

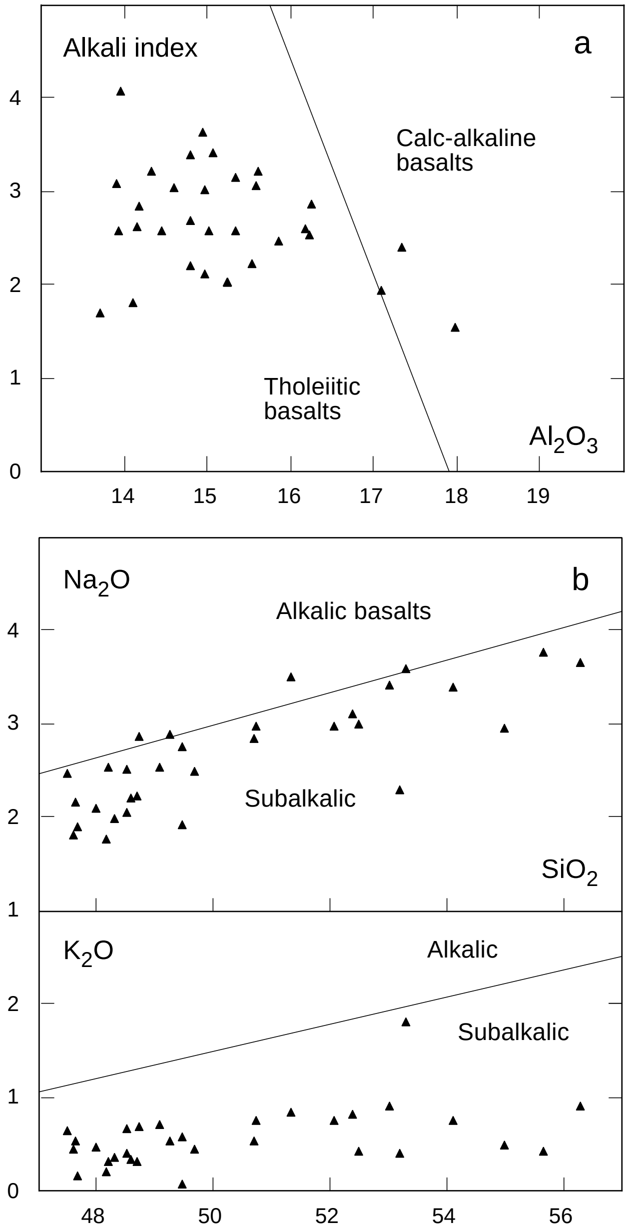


Fig. 18. (**a**) Alkali index *v.* Al_2O_3 (after Middlemost, 1975). (**b**) Variation diagrams of Na_2O and K_2O *v.* SiO_2 of homogeneous amphibolite, Fiskefjord area, illustrating its tholeiitic character. Locations of samples in Fig. 17; analytical details in Appendix.

Ca is also known to be mobile in many diagenetic environments (e.g. during interaction with sea water or carbonate rocks). In addition LIL element exchange may have occurred later between the supracrustal rocks and their orthogneiss hosts. It is therefore likely that amphibolite compositions have been modified by secondary processes, especially with regard to the high and variable concentrations of LIL elements and Ca presented below.

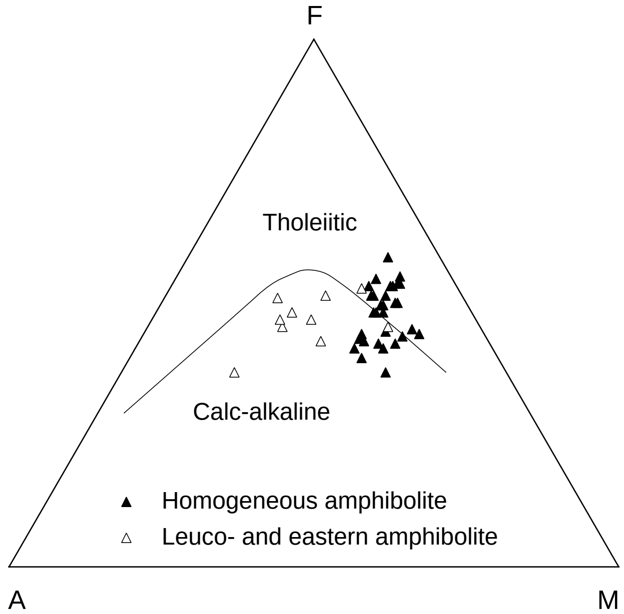


Fig. 19. AFM diagram (Na_2O + K_2O, FeO + Fe_2O_3, MgO) of amphibolites from the Fiskefjord area. Alkali element metasomatism may have shifted some samples of homogeneous amphibolite into the calc-alkaline field. See Fig. 17 for locations of samples and Appendix for analytical details.

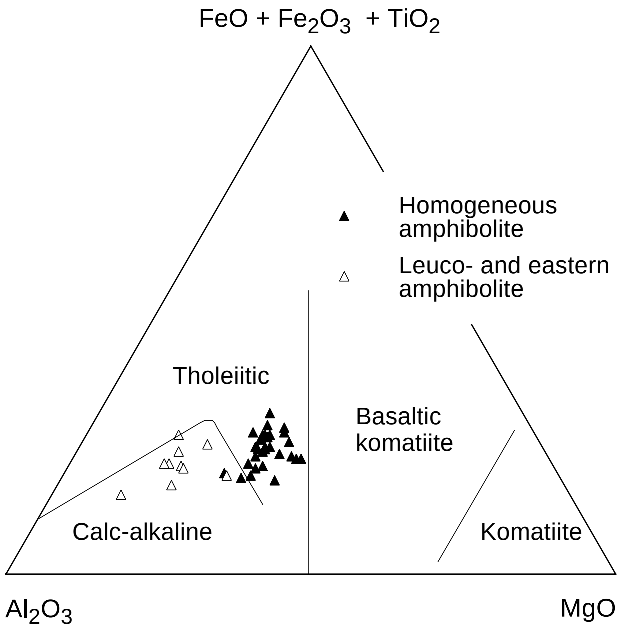


Fig. 20. Jensen diagram (Jensen, 1976) of amphibolites from the Fiskefjord area. Note the absence of samples in the field of basaltic komatiite. See Fig. 17 for locations of samples and Appendix for analytical details.

Amphibolites

Homogeneous amphibolite

The most widespread amphibolite group, homogeneous amphibolite, has a tholeiitic, basaltic major element composition (average *c.* 50.4 wt.% SiO_2, 15.2% Al_2O_3, 10.4% total FeO, 8.4% MgO, 9.9% CaO, 2.7% Na_2O and 0.6% K_2O; Appendix 1). Despite granulite facies metamorphism most samples are significantly hydrated (loss on ignition about 1%, compared to less than 0.5% in modern unaltered basaltic and gabbroic rocks). Most oxide compositions of homogeneous amphibolite are fairly uniform (Appendix 1), except CaO and K_2O which have relative standard deviations of *c.* 20 and 50%, respectively.

Variation diagrams of (a) alkali index *v.* Al_2O_3 and (b) Na_2O and K_2O *v.* SiO_2 (Fig. 18) illustrate the general subalkalic character of the homogeneous amphibolites, irrespective of whether some K_2O has been added or removed during diagenesis and metamorphism. On the AFM diagram (Fig. 19) a small majority of the homogeneous amphibolites plot in the tholeiitic field but do not show significant iron enrichment, whereas the leucocratic group (see section below) plots in the calc-alkaline field; in this plot the alkali content (i.e. possible alteration) is rather critical. The same division is more pronounced in the Jensen plot (Fig. 20), which is insensitive to mobile elements. None of the amphibolites are sufficiently magnesian to plot in the field of basaltic komatiite.

The trace element composition of homogeneous amphibolite (Appendix 1) is somewhat variable but generally basaltic: Cr, V and Ni are high (150–400 ppm), most lithophile elements low to moderate, and LIL elements low. Some elements like Y, Zn, V, Ga and Sc occur in very similar concentrations in most samples, whereas mobile elements like Rb, Ba and Sr show substantial variations, as noted above. Representative samples of homogeneous amphibolite have REE contents at about 10 times chondritic levels (Fig. 21a–b), with some variation in the LREE: most samples are unfractionated or weakly enriched in LREE, whereas a couple of granulite facies samples are weakly LREE depleted.

Leuco- and eastern amphibolite

Most rocks mapped as leuco-amphibolite are more felsic than the homogeneous amphibolite, with major element concentrations in the general range between basalt and andesite (Appendix 2). Their trace element compositions are broadly similar to those of homogeneous amphibolite. However, their variations in Rb, Ba and Th are larger, they have higher concentrations of LREE (Fig. 21c), Ta and Nb, and lower concentrations of compatible elements like Cr and Ni. The most acid leuco-amphibolite samples have strong geochemical similarities with some rocks mapped as metasediment and with the most basic members of dioritic orthogneiss (see p. 24; p. 51; Appendix 5).

Two samples placed in this group (GGU 289166 and 289205, Appendix 2; GGU = Grønlands Geologiske Undersøgelse) belong to amphibolite facies amphibolite from the easternmost part of the Fiskefjord area, which at the present erosion level has escaped granulite facies metamorphic conditions (Garde, 1990). Their compositions resemble leuco-amphibolite with regard to most trace elements. Although their SiO_2 contents of *c.* 50% are comparable to that in homogeneous amphibolite, they are more aluminous (Al_2O_3 above 17% compared to *c.* 15% in homogeneous amphibolite), less magnesian, and one of them considerably more sodic (4.4% Na_2O). The concentrations of most trace elements resemble those in leuco-amphibolite. Collectively these differences from homogeneous amphibolite are unlikely to stem from their different metamorphic histories, and the two eastern amphibolites are therefore tentatively correlated with the leuco-amphibolite in spite of the higher SiO_2 contents of the latter group.

Heterogeneous amphibolite

Four analyses (Appendix 2) of heterogeneous amphibolite with calc-silicate parageneses (formerly pillow lavas?) suggest that both major and trace element concentrations are highly variable in this group. Concentrations of some elements are outside the ranges found in homogeneous and leuco-amphibolite. Total FeO and especially MgO are low (averages of 9.19% and 3.8%), and two of the samples are also distinctly aluminous with 17.8 and 21.0% Al_2O_3. The CaO contents are very high (12.8–14.7%) and interpreted as due to exchange with carbonates on the sea floor or during diagenesis. Both field observations and the available geochemical data for the heterogeneous amphibolites suggest that they have been subject to much more severe alteration of their original compositions than the other amphibolite groups; these samples are therefore omitted from the geochemical plots.

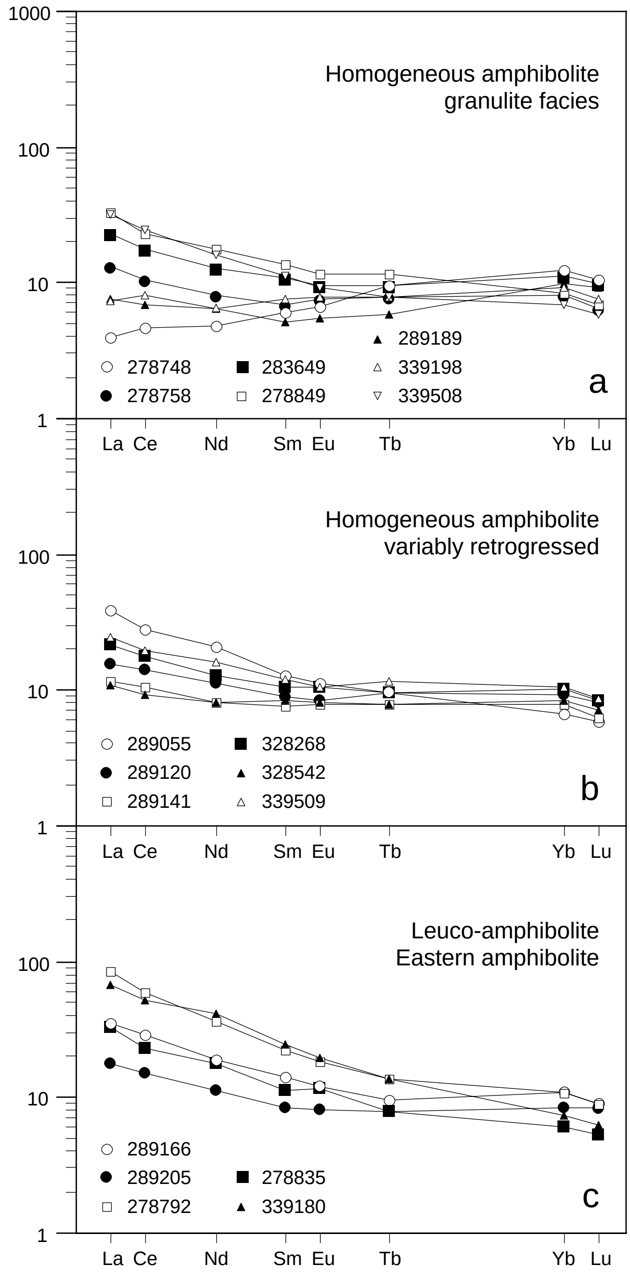


Fig. 21. Chondrite-normalised REE diagrams of three groups of amphibolites from the Fiskefjord area. Normalisation factors used for this and subsequent diagrams are from Nakamura (1974). All elements analysed by INNA; see Fig. 17 for sample localities and Appendix for analytical details.

Metasediments

The most common group of metasediments, biotite schist (± garnet, ± sillimanite) is represented by four typical samples from different parts of the Fiskefjord area (Fig. 17), which have a variable composition (Appendix 3). Two samples (GGU 289046 and 339926)

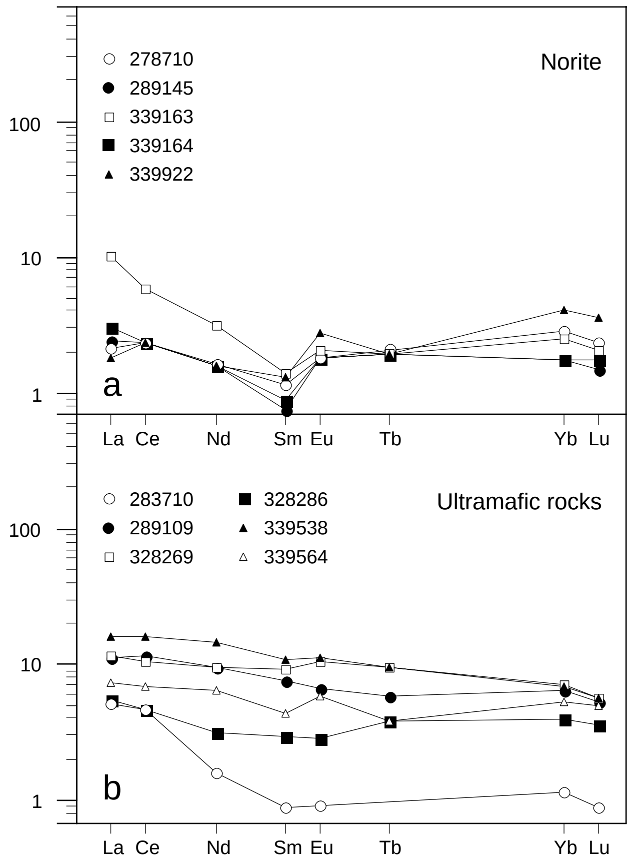


Fig. 22. Chondrite-normalised REE diagrams (Nakamura, 1974) of (**a**) norites and (**b**) ultramafic rocks from the Fiskefjord area. All elements analysed by INNA (see Appendix). See Fig. 17 for sample localities.

have FeO* concentrations above 13%, whereas two other samples are similar to leuco-amphibolite or mafic diorite. The rocks have very variable Al_2O_3 contents from *c.* 10.7 to 19.5%; none are siliceous or calcareous. Most trace elements occur in intermediate abundances; Rb, Zr, Zn, Cu and V are relatively high, and Sr, Ba, and the REE relatively low compared with mafic diorite or leuco-amphibolite.

Three of four analysed rocks in another group of supposed metasediments, fine-grained quartzo-feldspathic rocks associated with amphibolite, have a major element composition which resembles both the most felsic leuco-amphibolite and dioritic grey gneiss (compare Appendix 3 with Appendices 2 and 5). A fourth sample (283361) is more siliceous (68.1% SiO_2). The trace element composition of the quartzo-feldspathic metasediments is similar to that of leuco-amphibolite or diorite, except for lower Sr and higher Rb, Th and Zr contents. The fine-grained quartzo-feldspathic rocks are easily distinguished petrographically from dioritic orthogneiss, but their chemical compositions suggest that they may have been derived from andesitic igneous rocks without much alteration by physical or chemical surface processes, and they are therefore probably of volcanic or volcaniclastic origin.

Norite

The noritic rocks (Appendix 4; Fig. 17) contain *c.* 50% SiO_2, 17–21% Al_2O_3, and are both magnesian and calcic (*c.* 11–16% MgO and 7.5–11% CaO). Ni, V and Cr range from tens to several hundreds of parts per million. Total FeO is low, and Na_2O, K_2O and lithophile and LIL trace elements are very low (except for metasomatic? Rb in the range *c.* 10–30 ppm in three samples). A chondrite normalised REE plot (Fig. 22a) shows that REE abundances are close to chondrite or mantle values and that the patterns are generally unfractionated; the small positive Eu anomalies are interpreted as related to the large proportion of plagioclase in all norites. GGU 339163 which is enriched in LREE also has 31 ppm Rb, 9 ppm Pb and 139 ppm Ba (Appendix 4), indicative of mild metasomatism. The major and trace element compositions of the norites strongly suggest that they were formed as orthopyroxene-plagioclase cumulates which only trapped very small proportions of intercumulus melt.

Ultrabasic and ultramafic rocks

The geochemistry of units described in the field as ultrabasic rocks suggests that these are also cumulate rocks, like the norites (Appendix 4). They are calcic and highly magnesian (up to 28.3% MgO) and low in Al_2O_3 (1.2–9.9%). However, their major element geochemistry suggests some contamination or metasomatism, and some are not truly ultrabasic – SiO_2 ranges between 45.6 and 54.1% (unusually high for olivine-rich ultramafic rocks), and besides, Fe_2O_3 almost equals FeO in some samples. The Ni, V and Cr levels are high to very high, but most other trace elements occur in very low concentrations. Their REE patterns (Fig. 22b) resemble those of the norites but with slightly higher levels; the most siliceous (and metasomatised?) sample GGU 283710 has the lowest total REE content but a relative LREE enrichment.

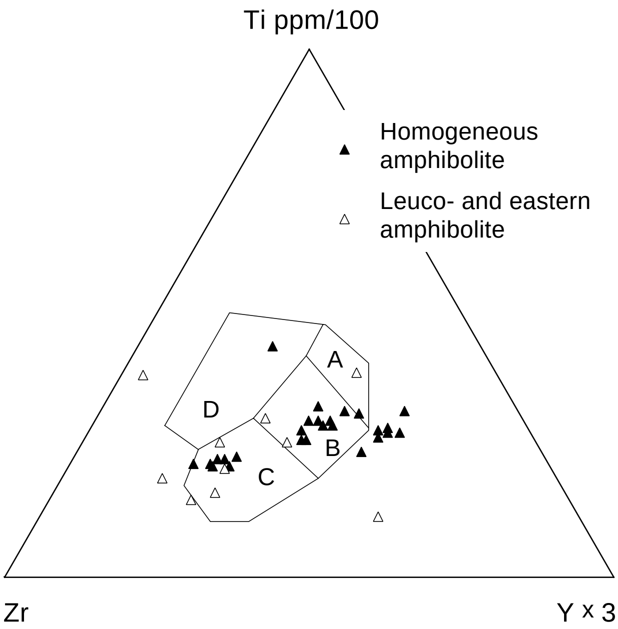


Fig. 23. Amphibolites from the Fiskefjord area plotted on the Ti–Zr–Y tectonomagmatic discrimination diagram (Pearce & Cann, 1973; A + B: low-K tholeiites, B: ocean floor basalts and island arc tholeiites, B + C: calc-alkaline basalts, D: within-plate basalts).

Anorthosite

One sample from the large leucogabbro-anorthosite association in the western part of Nordlandet, collected at the outer coast in the southern part of the Fiskefjord area (Fig. 17), was analysed (Appendix 4). Its composition, compared with a typical anorthosite from the Fiskenæsset complex, southern West Greenland (Appendix 4), shows that it clearly belongs to the calcic 'Archaean' anorthosite association (Ashwal & Myers, 1994), which occurs in most parts of the Archaean in West Greenland. Also the small occurrences of leucogabbro at Tovqussap nunâ belong to this association (Berthelsen, 1960).

Comparison of the amphibolites with modern basaltic rocks

A comparison of average homogeneous amphibolite geochemistry with compositions of modern basaltic rocks in various plate tectonic settings (using compilations of data from several sources published by Wilson, 1989) indicates that the homogeneous amphibolite most closely resembles tholeiitic ocean floor basalt or island arc tholeiite. The match with modern basalts from both settings is close for most major elements (SiO_2, Al_2O_3, total FeO, MgO and Na_2O), although the homogeneous amphibolite has lower TiO_2 and CaO and significantly higher K_2O contents. However, the latter two oxides were also shown above to be the most variable. Among the trace elements Rb, Ba and Sr (which are also very variable) are a poor match with both of the two modern basalt groups.

In terms of the Ti–Zr–Y discrimination diagram (Fig. 23) most samples of homogeneous amphibolite plot in the field of ocean floor basalts or island arc tholeiites, but a few samples plot outside any recognised field.

Spider diagrams of representative amphibolite samples normalised to normal, or N-type MORB (Fig. 24a–c) and REE diagrams (Fig. 21) can be used for a more specific comparison with modern normal, enriched and depleted MORB, island arc tholeiite, and ocean island alkali basalt (Fig. 24d). The homogeneous amphibolite plots show a clear pattern (irrespective of partial retrogression), except for the previously noted variations of mobile incompatible elements, in which they are variably enriched. Most samples are moderately depleted relative to MORB in immobile incompatible elements like P, Zr, Hf, Ti and Yb, whereas a few (represented by GGU 278849) are slightly enriched in some of the latter elements. There is no Nb anomaly, but a clear enrichment of Sc, Cr and Ni in some samples. Chondrite normalised REE diagrams of homogeneous amphibolite (Fig. 21a–b) show a general similarity to MORB with flat REE curves at *c.* 10 × chondrite values, and in some samples a weak LREE depletion as in modern N-type MORB (e.g. Schilling *et al.*, 1983).

Collectively the immobile incompatible, REE, and compatible element compositions of the homogeneous amphibolite are considered likely to reflect the original composition of their precursors to a large degree, and it may thus be argued that they have several general characteristics which resemble normal MORB (the horizontal line in Fig. 24d). In other respects they more resemble island arc tholeiites – namely in terms of their enrichment of LIL elements and depletion of immobile incompatible and moderately compatible elements, including Ti. However, these deviations from MORB are not as large as observed in modern island arc tholeiites. Besides, the homogeneous amphibolites differ noticeably from modern island arc tholeiites by their absence of a Nb anomaly and positive Cr and Ni anomalies. In addition the LIL element enrichment may be secondary as previously noted.

The composition of the homogeneous amphibolites does not preclude that they might be back-arc tholeiites, a favoured interpretation of some Phanerozoic ophiolite complexes preserved within the continents (e.g. Saunders *et al.*, 1979), but this is difficult to assess on the basis of geochemistry alone; due to very variable contamination back-arc tholeiites do not possess unique geochemical signatures (e.g. Wilson, 1989). Notwithstanding geochemical considerations, modern back-arc spreading seems to occur only where the subducting oceanic lithosphere is old, dense and cold (Furlong *et al.*, 1982) – an unlikely plate-tectonic scenario in the Archaean.

The leucocratic amphibolites have geochemical affinities to more evolved and aluminous recent basaltic rocks: their compositions resemble those of basaltic andesites and andesites from modern island arc settings, although they lack a distinct negative Nb anomaly. In the Ti–Zr–Y diagram (Fig. 23) they plot in the calc-alkaline basalt field, and representative samples show more variation on the MORB-normalised spider diagram (Fig. 24c) than the homogeneous amphibolites (Fig. 24a–b). Besides, the variation in LIL elements is more pronounced than in the homogeneous amphibolite, and there is an enrichment of several incompatible immobile elements but no Cr or Ni enrichment compared to MORB. Also the REE pattern (Fig. 21c) with its weak LREE enrichment indicates a calc-alkaline affinity.

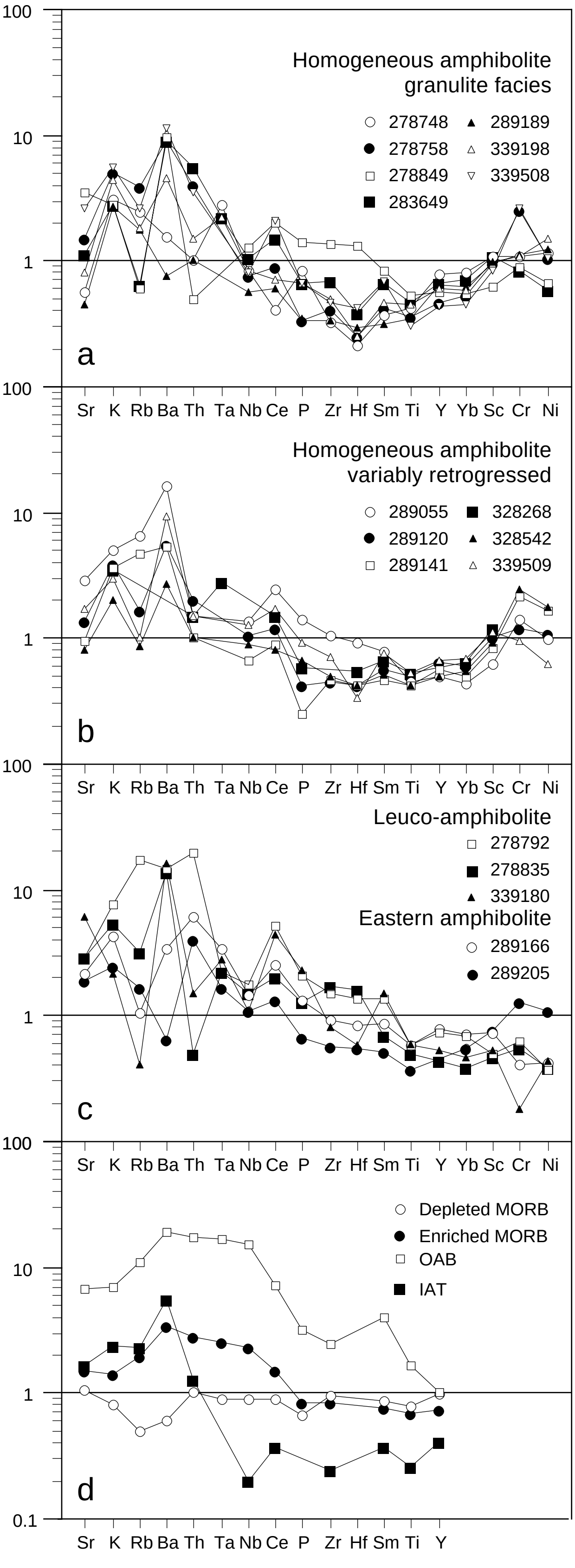


Fig. 24. MORB-normalised spider diagrams.
(**a–c**) Amphibolites from the Fiskefjord area. The samples have affinities both to MORB and island arc tholeiites; the large variation in LIL elements is interpreted as mainly due to metasomatism. Normalisation factors from Pearce (1983), except Sc, Cr and Ni from Taylor & McLennan (1985, p.274). Th, Ta, Ce, Hf, Sm, Yb and Sc analysed by INNA, other elements by XRF (see Appendix for details). Fig. 17 shows sample localities. (**d**) Modern volcanic rocks (Sun, 1980) for comparison with Fig. 24a–c. OAB = ocean island alkali basalt, IAT = island arc tholeiite.