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RAPPORT Nr. 113

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Report No. 113

Petrography and geochemistry of amphibolites from the Nordre Strømfjord area in the central part of the Nagssugtoqidian of West Greenland

by

Flemming C. Mengel

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Petrography and geochemistry of amphibolites from the Nordre Strømfjord area in the central part of the Nagssugtoqidian of West Greenland

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Abstract

The microstructures and general occurrence of orthopyroxene in the investigated amphibolites indicate that the rocks have been strongly deformed under granulite facies conditions. Microstructural features also suggest that high grade metamorphism in some cases outlasted deformation. The amphibolites show chemical resemblance to tholeiites from tectonic settings around active plate margins. Since chemical differentiation trends are not obvious, the results are insufficient to show that all the Nordre Strømfjord amphibolites originated in the same magmatic environment. The Nordre Strømfjord amphibolites may be Archaean or Proterozoic in age.

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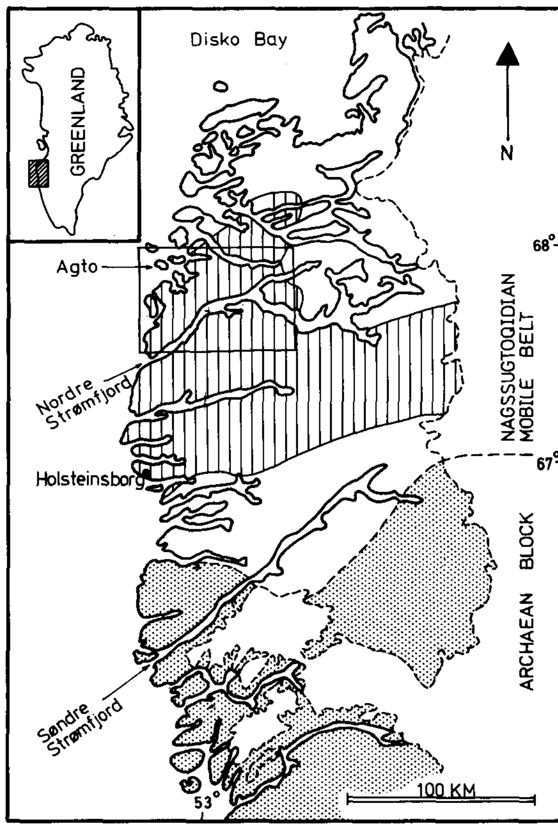

Fig. 1. The central and southern part of the Nagssugtoqidian mobile belt of West Greenland. The ruled area is the granulite facies 'Isortoq complex', bordered to the north and south by the 'Egedesminde' and 'Ikertoq' amphibolite facies complexes respectively (Ramberg, 1948); the stippled area is the Archaean block. The boxed area is the map sheet Agto 67 V.1 Nord.

INTRODUCTION

The amphibolites described in this study are from the Nordre Strømfjord area (map sheet Agto 67 V.1 Nord – 1:100 000), situated in the central part of the Nagssugtoqidian mobile belt of West Greenland (fig. 1). The area belongs to the granulite facies 'Isortoq complex' bordered to the north and south by the 'Egedesminde' and 'Ikertoq' amphibolite facies complexes respectively (Ramberg, 1948).

Lithologically the area covered by the Agto map sheet consists of alternating orthopyroxene-bearing and orthopyroxene-free tonalitic to granodioritic gneisses. Rocks of presumed supracrustal origin occur intensely folded with the gneisses throughout the area. These supracrustal rocks consist of garnet-biotite gneisses (±sillimanite, ±cordierite), various schists (±orthopyroxene, ±graphite), quartzitic and leucocratic gneisses, and marbles and associated calc-silicate rocks. Metabasics, ultrabasics, charnockites, and granites of various types occur in both the tonalitic to granodioritic gneisses and the supracrustal rocks. This study concentrates on the metabasic rocks. A summary of lithology and structures in the Nordre Strømfjord area is given by Olesen *et al.* (1979).

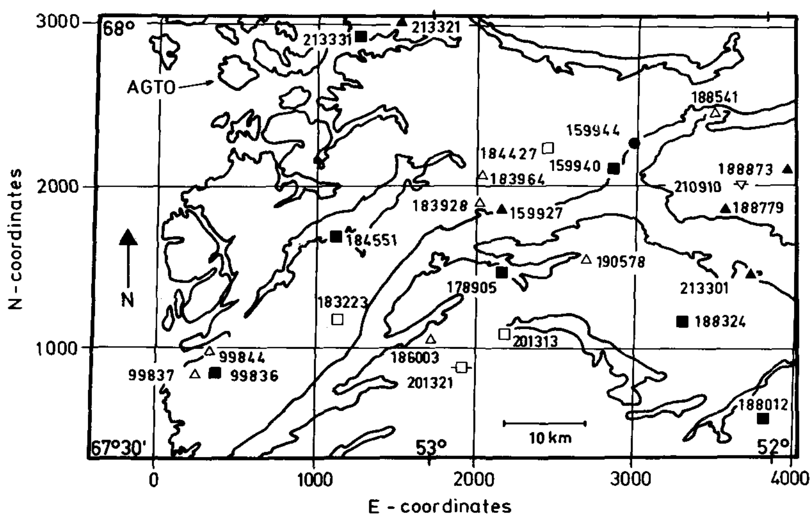

Fig. 2. The Agto 67 V.1 Nord map sheet showing the locations of the samples investigated. Filled symbols represent amphibolites found within tonalitic/granodioritic gneisses; open symbols indicate amphibolites associated with supracrustals. Symbols are further explained in fig. 10. In the text and figures localities are referred to by the E and N coordinates in the format (E coordinate/N coordinate).

Sørensen (1970) distinguished between two types of metabasic rocks on Agto and surrounding islands:

(a) (older) concordant metabasites (commonly migmatitic and agmatitic), and

(b) (younger) discordant metadolerites (often showing relict ophitic microstructures, and commonly cross-cutting the older concordant metabasites).

The discordant metadolerites were the subject of a study by Glassley & Sørensen (1980), who investigated the paragenetic changes associated with the transition from amphibolite to granulite facies mineral assemblages within individual dykes.

Skjernaa (1973) likewise reported the existence of two generations of metabasic rocks from an area immediately south-east of Agto island. Older concordant metabasics are here folded together with the gneisses in a complex manner, yielding a dome and basin interference pattern, and these folded successions are cut by younger metadolerites.

Similar observations have been made in the north-west corner of the Agto map sheet by Bek (1970), Bondesen (1970) and Jensen (1971).

The aim of this study is to investigate the petrographic and geochemical variations among metabasic rocks (i.e. amphibolites *sensu lato*) from the remaining part of the Agto map sheet on both sides of Nordre Strømfjord and to see whether a general chronology, similar to that mentioned above, can be established for the Nordre Strømfjord area, which covers approximately 3500 km^2.

As a member of the 'Agto II group' at the Department of Geology, Aarhus University, the author participated in mapping the Agto map sheet. Most of the 25 samples investigated in this study (fig. 2) were collected during the summers 1975 to 1978.

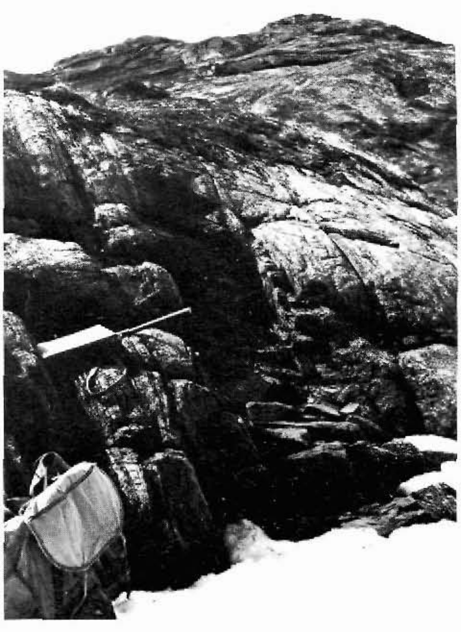

Fig. 3. Concordant amphibolite (metadolerite) in orthopyroxene gneiss. Note the sharp boundaries. Locality (2153/1829).

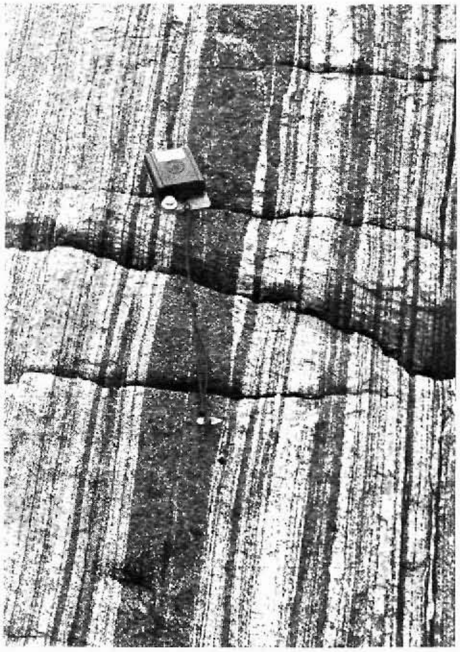

Fig. 4. Concordant mafic layers in orthopyroxene gneiss. Locality (1290/2845).

FIELD OCCURRENCE

On the basis of field occurrence the Nordre Strømfjord amphibolites can be divided into the following types:

(1) Concordant layers and lenses (fig. 3). These vary in width from a few centimetres to 20–30 m. Along the strike these amphibolites can be traced for a few metres to several kilometres, and are valuable structural marker horizons, especially in the area around Agto.

(2) Minor lenses and schlieren in the gneisses (fig. 4). These can locally depict complex structures in the gneisses, and a gradual change from amphibolites to mafic layers in the gneisses can often be seen.

(3) Discordant meta-dykes (fig. 5). These are rarely observed in the Nordre Strømfjord area. Their widths vary from 10 cm to 1 m, and the angle between the dyke contacts and the foliation in the gneisses is up to 20°. In contrast, the discordant meta-dykes in the north-west corner of the Agto map sheet can be up to 25 m wide (Sørensen, 1970; Glassley & Sørensen, 1980). From an area between Agto and Nordre Strømfjord Jensen (1968) reports an 8 m wide meta-dyke.

(4) 'Agmatite zones'. These are irregular concordant zones in the gneisses (fig. 6), where basic and ultrabasic fragments are mixed in a leucosome of likely anatectic origin. Strong deformation of these zones can lead to the formation of coarsely banded amphibolites.

(1), (2), and (4) occur in both the tonalitic-granodioritic gneisses and in the supracrustals, whereas (3) are only observed in the tonalitic-granodioritic gneisses. In the north-west corner of the Nordre Strømfjord area, however, discordant meta-dykes occur in both the

Fig. 5. Discordant metadolerite in orthopyroxene gneiss. Locality (2262/1407).

gneisses and supracrustal rocks (Escher *et al.,* 1976). In the area around Agto, Sørensen (1970) reported discordant relations between (3) and (4), but in the Nordre Strømfjord area no discordant relations between any of the four amphibolite types mentioned above have been observed.

The discordant meta-dykes and the concordant amphibolites in the tonalitic-granodioritic gneisses typically are hardly or not banded, but show a well-developed planar fabric defined by the parallel alignment of mainly hornblende and plagioclase.

Fig. 6. Amphibolitic and ultramafic lenses and boudins in a concordant zone in orthopyroxene gneiss (dark grey) and biotite gneiss (light grey). Map case shows scale. Locality (2153/1829).

In contrast the amphibolites associated with supracrustal rocks often have both a good planar fabric (defined as above) and a centimetre scale banding defined by alternating mafic (hornblende + pyroxenes) and felsic (plagioclase) layers.

Many of the concordant amphibolites have structural features similar to the discordant meta-dykes. These features include homogeneously developed foliation, weak or no banding, and sharp contact to the country rocks. These concordant amphibolites may originally have been discordant intrusives which have been reoriented parallel with the gneissic foliation by strong deformation. Reorientation is presumed to have been especially active in the supracrustal rocks since these are expected to have been less competent than the tonalitic-granodioritic gneisses during deformation.

Summarizing the lithological description, it can be concluded that field observations do not permit a divison of the Nordre Strømfjord amphibolites into different generations of basic magmatic rocks. Due to the heterogeneity of the Nagssugtoqidian deformation (Escher *et al.,* 1976) discordant and concordant amphibolites may well belong to the same magmatic episode.

MAJOR ELEMENT CHEMISTRY

Analytical methods

Chemical analysis of 25 amphibolites (Table 1) was carried out at the geochemical

Table 1. Chemical and modal compositions of Nordre Strømfjord amphibolites

	99836	99837	99844	159927	159940	159944	178905	183223	183928	183964	184427	184551	186003
	■	△	△	▲	■	●	■	□	△	△	□	■	△
SiO_2	48.17	47.66	50.31	49.99	47.87	56.26	47.46	44.41	49.24	48.67	47.62	50.74	48.18
TiO_2	1.59	1.24	0.90	1.28	1.69	1.26	1.06	1.54	1.04	1.88	1.13	1.02	0.85
Al_2O_3	13.00	15.47	15.87	13.26	16.40	15.47	20.68	12.83	12.70	16.45	12.94	13.49	12.64
Fe_2O_3	3.67	1.39	0.90	4.49	3.88	3.23	3.34	1.79	1.95	1.03	0.51	2.93	1.77
FeO	11.26	10.12	9.44	8.41	6.00	5.91	6.12	9.70	9.90	11.64	7.85	5.19	9.38
MnO	0.21	0.15	0.13	0.18	0.11	0.10	0.14	0.16	0.16	0.18	0.25	0.12	0.15
MgO	6.43	8.97	8.40	6.09	7.12	3.95	3.68	6.12	8.82	6.86	7.74	9.61	10.19
CaO	9.97	12.06	12.26	10.06	9.95	7.08	11.96	17.66	11.33	10.46	16.42	10.12	16.17
Na_2O	2.84	1.21	0.91	2.99	3.62	4.15	2.97	1.79	1.84	1.52	0.47	3.16	1.48
K_2O	1.05	0.50	0.19	0.76	1.02	0.68	0.75	0.19	0.72	0.32	1.98	1.02	0.47
volat.	1.69	1.13	0.87	1.41	1.21	1.25	0.90	2.81	2.26	0.78	2.45	1.39	1.43
P_2O_5	0.13	0.06	0.07	0.12	0.26	0.07	0.31	0.10	0.24	0.16	0.08	0.38	0.10
Σ	100.01	99.96	100.78	99.04	99.13	99.41	99.37	99.10	100.20	99.95	99.44	99.17	99.82
Q	0.8		1.2	0.7				+				+	
PLAG	29.6	40.4	51.7	40.5	45.1	58.7	56.3	4.8	24.8	56.6	34.4	34.5	29.9
BIO	2.1	0.6	1.6	1.3	0.7	2.4	0.7		3.8	0.2	1.5	0.8	+
HBL	63.1	39.1	5.6	33.4	50.9	34.6	35.7	50.0	48.9	3.6	+	58.8	41.7
OPX		15.4	31.2	3.3					12.5	8.2			8.5
CPX	3.5	3.5	8.1	13.5	1.2		4.6	23.8	9.4	28.7	60.8	4.3	19.5
GNT			(+)							(+)			
ACC	+			0.5	+	0.1	0.4	1.7	0.5	0.2	0.8	+	+
OPAQUES	0.9	1.0	0.7	6.2	2.1	4.2	2.4	0.5	0.1	2.6	4.6	1.6	0.5
OTHER								19.5(1)					
N	1070	1110	1130	1061	1460	1363	1361	2072	1288	1174	1871	1531	1499
PPC	1.07	1.11	1.13	1.21	1.55	1.11	1.33	1.80	1.26	1.11	1.58	1.40	1.35
UP	1000	1000	1000	960	942	1228	1023	1151	1022	1058	1184	1094	1110

Table 1. cont.

	188012	188324	188541	188779	188873	190578	201313	201321	210910	213301	213321	213331
	■	■	△	■	▲	△	□	-□-	▽	▲	▲	■
SiO_2	46.73	49.70	49.62	47.37	48.92	48.47	46.32	47.54	45.72	51.11	49.22	45.36
TiO_2	0.88	1.28	1.87	0.92	0.88	1.16	1.29	1.71	1.05	0.79	0.61	1.46
Al_2O_3	14.19	13.33	17.12	14.65	14.37	13.14	11.75	11.89	19.12	13.66	13.42	15.01
Fe_2O_3	1.86	3.70	1.12	1.61	2.89	2.32	1.88	2.93	1.19	3.60	3.09	6.25
FeO	8.62	9.52	10.76	8.80	0.30	10.14	10.93	12.02	10.67	8.94	8.11	8.76
MnO	0.15	0.18	0.11	0.16	0.17	0.15	0.17	0.21	0.14	0.15	0.19	0.19
MgO	7.09	6.46	4.89	6.24	7.19	9.23	8.97	5.43	8.95	6.80	8.67	6.56
CaO	14.39	10.10	10.11	15.89	10.64	11.55	14.13	13.74	10.19	9.17	11.14	11.67
Na_2O	2.34	2.84	2.58	1.29	2.73	0.92	1.91	2.04	0.96	2.53	2.54	2.42
K_2O	0.40	1.25	0.49	0.38	1.02	0.50	0.58	0.33	0.84	0.97	0.83	0.59
volat.	2.88	1.51	0.97	2.06	1.80	2.27	1.38	1.88	1.12	1.48	1.70	1.54
P_2O_5	0.07	0.11	0.22	0.26	0.06	0.07	0.09	0.15	0.13	0.05	0.05	0.10
Σ	99.60	99.98	99.86	99.63	99.97	99.92	99.40	99.87	100.08	99.25	99.57	99.91
Q	+	+	0.4			+				+		
PLAG	30.4	32.8	60.1	44.6	40.6	29.5	10.7	30.3	48.0	37.0	26.6	35.1
BIO	+	+	1.7		+			0.1	5.8			+
HBL	50.2	55.5	3.0	2.3	44.1	51.5	55.3	11.7	31.8	54.8	50.8	53.1
OPX			12.6		1.7	4.0			12.9	6.8	1.1	
CPX	18.5	10.6	21.3	47.3	10.6	13.5	33.2	35.9	+	3.1	21.0	8.6
GNT			(+)					17.9	1.2			
ACC	0.6		+	0.5	0.2	+	0.2	1.3	0.1			0.2
OPAQUES	0.3	1.2	0.8	5.2	0.2	1.4	0.6	2.8	0.3	0.7	0.7	3.0
OTHER					2.7(2)							
N	1470	1310	1000	1001	1320	1250	1553	1624	1011	1590	1336	1512
PPC	1.33	1.07	1.86	1.56	1.18	1.49	1.60	1.30	1.25	1.29	1.29	1.33
UP	1106	1224	538	782	846	1059	1042	1012	778	1272	1036	1137

Chemical analyses: Symbols below sample numbers refer to parageneses: Filled symbols represent amphibolites found within tonalitic/granodioritic gneisses; open symbols indicate amphibolites associated with supracrustals. Symbols are further explained in fig. 7. All oxides in weight percent.

Modal analyses: '+' indicates that the mineral is present in the thin section, but not hit during point counting, whereas '(+)' shows that the mineral is present in the hand specimen, but not in the thin section.
'Other': (1) scapolite, and (2) alterations.
A 'Swift' point counter was used, and the spacing between individual points was 0.3 mm.
N = number of points counted, PPC = points per crystal, UP = number of uncorrelated points (i.e. N/PPC). The point counting method and the calculations of counting errors is described by Kalsbeek (1969, 1970). Modal analyses of GGU 99836, GGU 99837 and GGU 99844 from Korstgård (1972).

laboratory of the Geological Survey of Greenland. Na_2O was determined by atomic absorption spectrometry, FeO by titration and volatiles were calculated as

$$\%\text{volatiles} = (\%\text{FeO} \times 0.1113) + \%\text{loss on ignition}$$

The remaining major elements (inclusive total Fe) were determined by X-ray fluorescence spectrometry, using the technique described by Sørensen (1975, 1976, 1981) and Petersen & Sørensen (1979).

Presentation of the analyses

The amphibolites are dealt with in two groups:

Group I: Amphibolites associated with tonalitic-granodioritic gneisses (filled symbols)

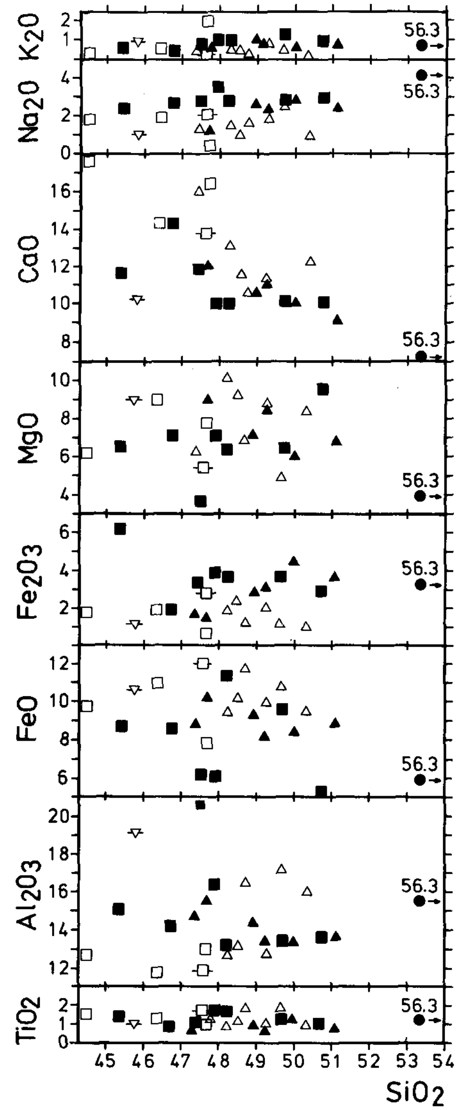

Fig. 7. Harker-type variation diagram for the Nordre Strømfjord amphibolites. Filled symbols: Group I amphibolites; open symbols: group II amphibolites. All oxides in weight percent. Symbols are further explained in fig. 10.

Group II: Amphibolites associated with the supracrustal rocks (open symbols).

Fig. 7 shows that the major chemical differences between groups I and II are Na_2O, K_2O, Fe_2O_3 (group I > group II), and FeO (group I < group II). To test whether these 'visual' differences are statistically significant, the non-parametric Mann-Whitney U-test (Siegel, 1956, p. 116) has been applied to all oxides (Table 2).

Table 2. Results of the application of the Mann-Whitney U-test

Oxide	$\alpha = 0.001$	$\alpha = 0.01$
Fe_2O_3	I > II	
FeO	I < II	
FeO^{tot}	I ≅ II	I ≅ II
Na_2O	I > II	
K_2O	I ≅ II	I > II

'α' is the significance level used in the test, FeO^{tot} is calculated as (FeO + o.9 x Fe_2O_3). Oxides not mentioned do not vary significantly from group I to group II. 'I' and 'II' indicate groups I and II respectively.

Chemical differences between group I and group II amphibolites

The differences shown by the Mann-Whitney U-test can also be seen from the average chemical analyses of group I and group II amphibolites (Table 3).

FeO-Fe_2O_3-FeO^{tot}. The oxidation ratios (see Table 3 for explanation) of the amphibolites are close to the oxidation ratios of their respective host rocks. Group I amphibolites and average orthopyroxene gneiss have nearly identical oxidation ratios, and the oxidation ratio of group II amphibolites compares well with those of the supracrustal rocks. It thus seems that the oxidation ratios of the amphibolites are governed by the oxygen fugacity in the host gneisses during metamorphism, a conclusion further substantiated by the fact that FeO^{tot} shows no significant variation from group I to group II.

Alkalies. There is no consistent pattern of alkali enrichment in the amphibolites relative to their respective host rocks (Na_2O: group I > group II, orthopyroxene-gneiss > most supracrustals; K_2O: group I > group II, orthopyroxene-gneiss ⩽ supracrustals (Table 3)). Thus the host rocks cannot have controlled the alkali contents of the amphibolites in a way similar to what was concluded for FeO-Fe_2O_3. The observed chemical differences must then be attributed to either metasomatic processes or to primary chemical differences in the original magma(s?).

Affinities to basaltic series and tectonic settings

Miyashiro (1974) – amongst others – has presented several diagrams in which calc-alkaline (CA) and tholeiitic (TH) basalts of various tectonic settings can be discriminated. His investigations were based on Tertiary and younger basalts, so in order to use these discrimination diagrams on Precambrian high-grade rocks, one has to assume that chemical changes during high-grade metamorphism and deformation have not significantly changed the bulk chemistry. This assumption has been discussed by many authors (e.g. Rivalenti, 1976; Büsch

Table 3. Mean composition of amphibolites, orthopyroxene-gneisses and supracrustal rocks from the Nordre Strømfjord area

	(1)	(2)	(3)	(4)	(5)	(6)
SiO_2	49.15	47.81	63.74	70.48	75.48	72.14
TiO_2	1.13	1.31	0.67	0.63	0.51	0.31
Al_2O_3	14.69	14.33	15.07	13.41	11.40	14.55
Fe_2O_3	3.43	1.57	1.47	0.61	0.36	0.24
FeO	8.07	10.26	3.54	4.25	3.48	1.83
MnO	0.16	0.16	0.06	0.07	0.06	0.04
MgO	6.61	7.88	2.60	2.32	1.62	0.84
CaO	10.93	12.76	4.85	1.68	1.40	2.27
Na_2O	2.80	1.47	3.62	2.41	2.36	3.95
K_2O	0.82	0.59	1.94	3.28	2.40	2.92
P_2O_5	0.15	0.12	0.21	0.08	0.07	0.09
volat.	1.60	1.61				
OX ratio	0.273	0.118	0.272	0.114	0.087	0.105

Nordre Strømfjord amphibolites:

(1) Group I -amphibolites (n = 13)

(2) Group II-amphibolites (n = 12)

Nordre Strømfjord orthopyroxene gneiss:

(3) Orthopyroxene-gneiss (Korstgård,1979)(n = 25)

Nordre Strømfjord supracrustals:

(4) Garnet-(sillimanite)-biotite-gneiss (Korstgård, 1979)(n = 18)

(5) Garnet-sillimanite-biotite-gneiss (Rehkopff,1981) (n = 9)

(6) Garnet-biotite-gneiss (Rehkopff,1981)(n = 9)

All oxides in weight percent. 'OX-ratio' is the oxidation ratio, calculated as 2 x Fe_2O_3/(2 x Fe_2O_3 + FeO) (oxides in molecular proportions).

et al., 1979) and is generally found to be valid, except for alkalies. Due to potential mobility of alkalies, diagrams which incorporate these elements are not considered in the following.

Fig. 8 shows that the Nordre Strømfjord amphibolites have tholeiitic and not calc-alkaline affinities. It furthermore becomes evident that the samples investigated do not together define a single differentiation trend, and they only have slight Fe enrichment with increasing FeO^{tot}/MgO ratio in common. The diagrams also show that the Nordre Strømfjord amphibolites have chemical similarities with abyssal tholeiites and island arc tholeiites and not with ocean island basalts. The Nordre Strømfjord amphibolites thus show chemical resemblances with basalts from tectonic settings around active plate margins, rather than with basalts from 'within plate' areas.

Like field observations, major element chemistry thus cannot determine whether the Nordre Strømfjord amphibolites were emplaced by one or several magmatic episodes.

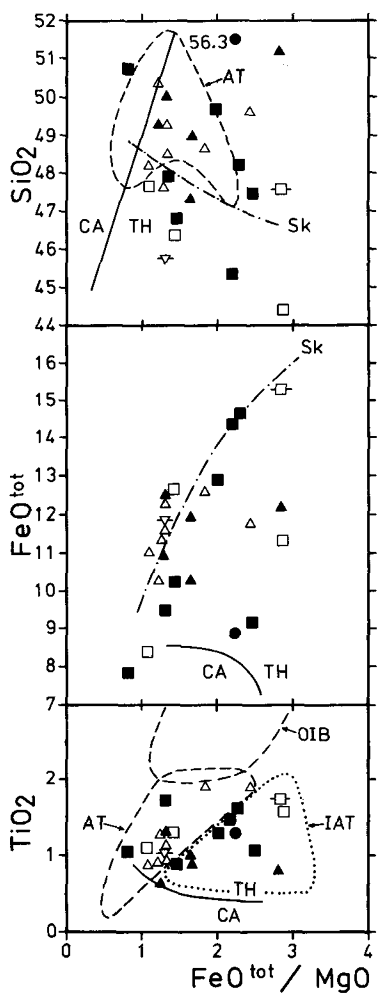

Fig. 8. FeO^{tot}/MgO vs. TiO_2, FeO^{tot}, and SiO_2 for the Nordre Strømfjord amphibolites. FeO^{tot}/MgO vs. TiO_2: AT = abyssal tholeiites, IAT = island arc tholeiites, OIB = ocean island basalts (Glassley, 1974). FeO^{tot}/MgO vs. SiO_2: AT = abyssal tholeiites (Bard & Moine, 1979). The remaining trends and fields are from Miyashiro (1974). All oxides in weight percent. Symbols are explained in fig. 10.

MINERALOGY AND PARAGENESES

Modal analyses have been carried out on all samples (Table 1) and brief microstructural descriptions of the individual minerals are given in the following.

Plagioclase. The grain size varies from 0.2 mm to 2.0 mm, averaging 0.5 mm in equant grains. The larger grains seem to have the better preferred shape orientation. In the banded amphibolites, plagioclase dominates the leucocratic layers. Recrystallization microstructures are often observed (i.e. new, small grains along the margins of older, larger grains, and polygonal aggregates). Growth and deformation twinning (following the albite and pericline twin laws) and zoning (normal and reverse) are common features. Plagioclase generally exhibits straight to curved grain boundaries towards the other minerals.

Hornblende. Hornblende grains often show a good preferred shape orientation, the dimensions ranging from 0.3 × 0.6 mm to 0.5 × 2.0 mm. Equant grains measure 0.5 to 1.0 mm. Hornblende generally exhibits straight to curved grain boundaries towards other minerals. A few observations of symplectic clinopyroxene-quartz intergrowths along hornblende-hornblende grain boundaries are interpreted as indicating initial breakdown of hornblende during prograde metamorphic conditions. The following observations point in the same direction (Wells, 1979):

ilmenite exsolution along hornblende cleavage planes and grain boundaries, and
irregular hornblende inclusions in clinopyroxene and orthopyroxene.

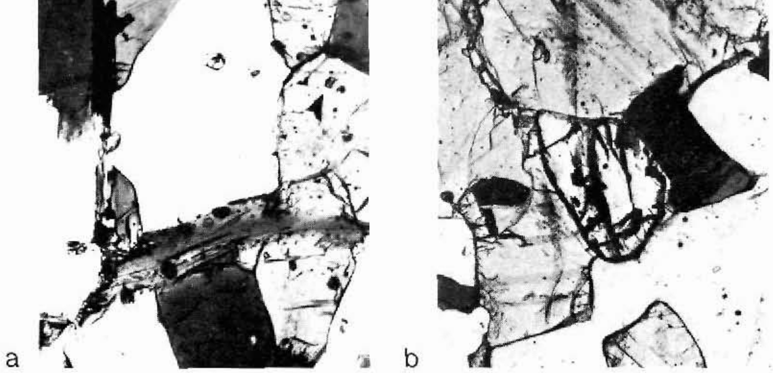

Fig. 9. Microstructural features in the Nordre Strømfjord amphibolites: a (left): Biotite (centre low) cross-cutting the foliation defined by hornblende (light and dark grey) and biotite (top right – black). Longest dimension of photograph corresponds to 1.1 mm and is oriented parallel to the foliation in the thin section. Sample GGU 99837. One nicol. b (right): Perfect microstructural equilibrium between hornblende (centre right – black), orthopyroxene (centre), clinopyroxene (light grey), and plagioclase (white). Longest dimension of photograph is 1.1 mm. Sample GGU 159927. One nicol.

MINERAL ASSEMBLAGES	symbols group I	symbols group II
plag-hbl	●	
plag-hbl-cpx	■	□
plag-hbl-cpx-gnt		-□-
plag-hbl-opx-gnt		-▽-
plag-hbl-opx-cpx	▲	△

Fig. 10. Parageneses found in the Nordre Strømfjord amphibolites and indications of their respective symbols. These symbols are used in all diagrams. Abbreviations: plag = plagioclase, hbl = hornblende, cpx = clinopyroxene, opx = orthopyroxene, gnt = garnet.

There is a general tendency for hornblende to occur in polygonal aggregates in the most deformed amphibolites, whereas a preferred shape orientation is best developed in the amphibolites that appear to have preserved some structural features similar to discordant dykes.

Orthopyroxene. This commonly occurs as equant grains, ranging from 0.1 mm to 1.5 mm. Grain boundaries are straight to curved, and orthopyroxene generally shows equilibrium microstructures together with the other phases. The grains are often altered to a 'brown alteration product', identified by Himmelberg & Phinney (1967) in similar rocks as a serpentine mineral.

Clinopyroxene. The average grain size is 0.5 to 1.0 mm and a prefered shape orientation is only sporadically developed. Clinopyroxene generally exhibits microstructural features similar to orthopyroxene.

Biotite. Biotite usually occurs as laths, measuring up to 2 mm in length. Some biotite grains overgrow the foliation defined by hornblende and (to a minor degree) pyroxene and biotite, although there are no microstructural indications of disequilibrium between these cross-cutting biotites and the other phases (fig. 9a). These biotites are therefore assumed to have grown post-kinematically, and high-grade metamorphism is believed to have outlasted the deformation phase that formed the foliation in the amphibolites.

This conclusion is supported by chemical studies of the minerals in the Nordre Strømfjord amphibolites (Mengel, 1981), where biotite, hornblende and pyroxenes are found to have equilibrated under granulite facies conditions.

Other minerals. Quartz is observed in approximately half the thin sections, but the grains are so small and few in number that the mineral is likely to occur in all samples. Calcite, scapolite and garnet occur sporadically, and opaque minerals (ilmenite, magnetite, pyrrhotite) and accessory minerals (apatite, zircon, sphene) are present in most samples.

The observed mineral assemblages are shown in fig. 10. Quartz, accessory minerals and opaque minerals may or may not be present. Biotite is present in all samples, but seems to belong to assemblages developed post-kinematically.

Using the nomenclature of Berthelsen (1960) (fig. 11), eighteen of the 25 samples are 'pyroxene amphibolites', five are 'hornblende pyriclasites', one is a 'pyriclasite' and one is an 'amphibolite'.

The minerals appear to be in perfect microstructural equilibrium (fig. 9b) in the vast

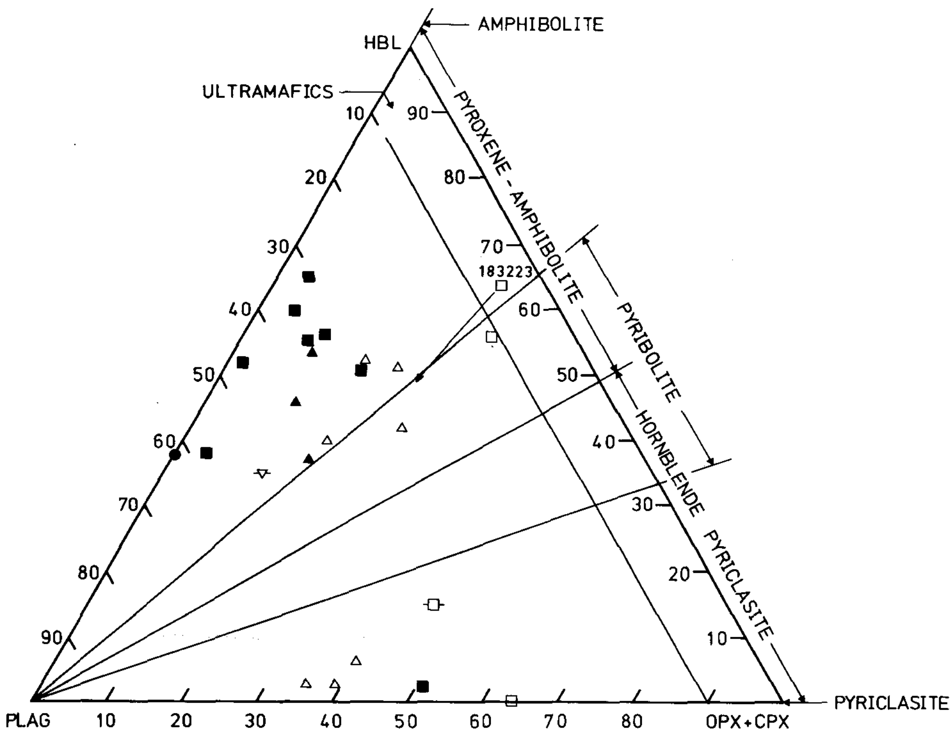

Fig. 11. Modal classification of the Nordre strømfjord amphibolites. Nomenclature from Berthelsen (1960). Symbols are explained in fig. 10.

majority of the samples investigated, the mineral assemblages thus constituting parageneses (Winkler, 1974; Vernon, 1976, 1977), the exceptions being the few cases where hornblende seems to be unstable (reacting to form e.g. pyroxenes). The frequently observed polygonal mineral aggregates composed of equant grains, and the observation of cross-cutting biotites (fig. 9) indicate that metamorphic conditions suitable for recrystallization and grain-growth in many cases outlasted the Nagssugtoqidian deformation.

P, *T* CONDITIONS

Orthopyroxene – the diagnostic mineral of granulite facies (e.g. De Waard, 1971; Winkler, 1974) – is found everywhere in the Nordre Strømfjord area where the rock chemistry is appropriate (e.g. Olesen *et al.,* 1979). The stable coexistence of garnet, cordierite and sillimanite in some of the supracrustal rocks, and of orthopyroxene, clinopyroxene and hornblende in the Nordre Strømfjord amphibolites indicate a metamorphic peak probably close to 800°C and 8–9 kbar (e.g. Winkler, 1974; Hensen, 1977; Bohlen & Essene, 1979).

CONCLUDING REMARKS

It has been shown that there are extensive chemical similarities between the investigated amphibolites. The observed Fe_2O_3/FeO differences can be explained as being due to varying oxygen fugacities in the host rock during metamorphism, and the alkali differences were attributed to either (1) primary magmatic differences, or (2) metasomatic activity. Metasomatism is considered to be the most likely cause, since primary alkali differences of the observed magnitude would be expected to be accompanied by significant variations in other elements (e.g. FeO/MgO, SiO_2 etc.).

The chemical homogeneity is striking in view of the wide variation with respect to the field occurrence of the amphibolites, and in view of the fact that the amphibolites may represent several episodes – separated in time – of basic magmatism. Similar observations were made by Walker *et al.* (1960) who attributed chemical similarities among some Australian amphibolites of different origins to chemical convergence during prograde metamorphism and metasomatism. A similar process cannot be ruled out but is difficult to verify for the Nordre Strømfjord amphibolites, since only high grade rocks are available for study rather than a prograde metamorphic suite.

Any primary magmatic microstructural differences that may have existed between the amphibolites have been completely obliterated by thorough deformation and recrystallization, and the rocks now have essentially uniform microstructures, formed under granulite facies conditions during and in the waning stages of the Nagssugtoqidian deformation.

The chemical homogeneity of the Nordre Strømfjord amphibolites does not prove that their protoliths were generated by the same magmatic episode, but rather that they originated in similar tectonic settings and/or via similar physical and chemical processes.

Comparisons of the Nordre Strømfjord amphibolites with recent basic rocks indicate formation in an oceanic plate tectonically active milieu, but the geotectonic validity of this comparison is limited since plate tectonics may not have been active in Precambrian times (e.g. Gill & Bridgwater, 1976). The majority of the rocks in the Nordre Strømfjord area are tonalitic to granodioritic gneisses, indicating continental rather than oceanic tectonic settings. Thus comparisons of the Nordre Strømfjord amphibolites with recent basaltic rocks can only yield credible information about physical and chemical conditions operative during magma formation and emplacement, and cannot determine the palaeo-tectonic setting of the Nordre Strømfjord amphibolites.

Basic rocks are widespread in the Archaean and Proterozoic (Nagssugtoqidian) of West Greenland (Escher *et al.,* 1976; Bridgwater *et al.,* 1976). The Archaean basic rocks occur either as inclusions of supracrustal rocks in the gneisses or as intrusives into these. The Proterozoic basic rocks comprises intrusive (e.g. the Kangâmiut dyke swarm) and later supracrustal rocks.

The Nordre Strømfjord amphibolites could belong to any of the above mentioned groups, since thorough deformation (the formation of the Nagssugtoqidian Mobile Belt) has obliterated most original structures and contact relations.

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