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GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 111

SAND ANALYSIS AS A METHOD OF ESTIMATING BEDROCK COMPOSITIONS IN GREENLAND,

ILLUSTRATED BY FLUVIAL SANDS FROM THE FISKENÆSSET REGION

BY

FEIKO KALSBEEK, MARTIN GHISLER
AND BRUNO THOMSEN

WITH 10 FIGURES AND 12 TABLES IN THE TEXT,
AND 1 PLATE

KØBENHAVN
1974

GRØNLANDS GEOLOGISKE UNDERSØGELSE

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Abstract

Mineralogical and chemical composition, heavy and opaque mineral content and grain size distribution of the sands show that they mainly consist of locally derived material. Glacially transported material has little influence on the composition of the sands. By comparing sands of various grain sizes it is shown that the sedimentary processes do not appreciably change the composition of the sands, except that biotite is largely winnowed out. Thus the sands are suitable for a regional study of the composition of the country rocks and for prospecting. Estimates are made of the average mineralogical and chemical composition of the area and the abundance of the different rock types. The amount of hypersthene gives an impression of the metamorphic grade of the rocks, and the average chemical composition of the high-grade rocks in the northern part of the area is the same as that of the lower grade rocks in the southern part.

CONTENTS

1. Introduction

The Fiskenæsset region belongs to the Archaean gneiss block of South-West Greenland (PULVERTAFT, 1968) which consists mainly of gneisses with bands and lenses of amphibolite. Metamorphosed anorthositic and leucogabbroic rocks (the so-called 'Fiskenæsset complex') occur both as minor inclusions in the gneisses and as persistent layers and major outcrops up to 5 km across. The anorthositic and leucogabbroic rocks are often associated with minor amounts of meta-gabbros and ultramafic rocks.

The metamorphic grade of the rocks in the area decreases from north to south. Around the base Midgård of the Geological Survey of Greenland (GGU) in the northern part of the area (plate 1), most rocks belong to the granulite facies, while south of Fiskenæsfjorden amphibolite facies rocks prevail, but locally granulite facies rocks have also been found. In the extreme southern part of the area epidote locally becomes common in the gneisses and the rocks may belong to the epidote-amphibolite facies.

For more information on the bedrock geology of the Fiskenæsset district the reader is referred to KALSBEEK & MYERS (1973).

The area has been extensively glaciated and erratic boulders are found everywhere. Sand and gravel terraces occur commonly along the valley sides, and it is generally not clear in the field whether this material is glacial in origin or not.

In the hope that an investigation of sand samples would give information on the overall composition of the rocks in the area, a number of sand samples were collected from river beds and the shores of lakes. A preliminary report on the bulk composition of the sands has been published by KALSBEEK (1971); the present paper reports in more detail upon the mineralogical and chemical composition of the sands and upon the control of grain size on composition (sections 2 to 4). Furthermore, both the non-opaque and the opaque minerals of the heavy fractions of the sands have been studied (sections 5 and 6) by B. THOMSEN and M. GHISLER.

The validity of the use of sand samples as a method of obtaining a quick impression of the composition of the bedrock in an area depends upon whether the sands found in the river beds represent material

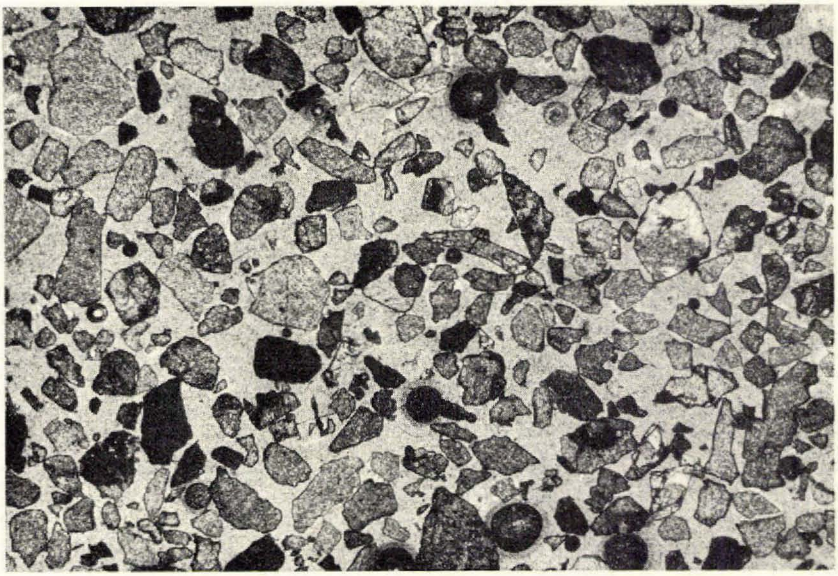

Fig. 1. Thin section of sand from the Fiskenæsset area. Note the angularity of the grains. The thin section is uncovered and the relief of the grains is therefore high. The largest grains are approximately 0.5 mm in size.

derived locally or material imported by glacial transport from distant areas. This question, which is also of interest for other parts of Greenland, is discussed in section 7. In section 8 the results of the foregoing sections are used to make estimates of the average composition of the rocks in the Fiskenæsset district and of the abundance of the different rock types.

Inspection of thin sections of the sands shows that the grains generally are poorly rounded (fig. 1); since in this investigation the sands are mainly used to study the bedrock composition of the area, the grain shapes are of minor importance and have not been studied further.

The 86 samples studied were collected at 47 localities spread over an area of approximately 3500 km² (plate 1). At most localities two samples were taken at distances up to a few hundreds of metres apart. Several of the samples were taken from terraces. The weight of the samples was generally 500–1000 gm. One sample from each of the 47 localities was fully investigated; of the remaining samples only the bulk composition and the grain size distribution were studied.

A further collection of 30 sand samples was taken at 15 localities along a river running through a major body of anorthositic rocks. These samples were investigated to obtain more information about the correspondence between the composition of the rocks outcropping along the river and the sands in the river bed. The results of this study are described in section 7 b.

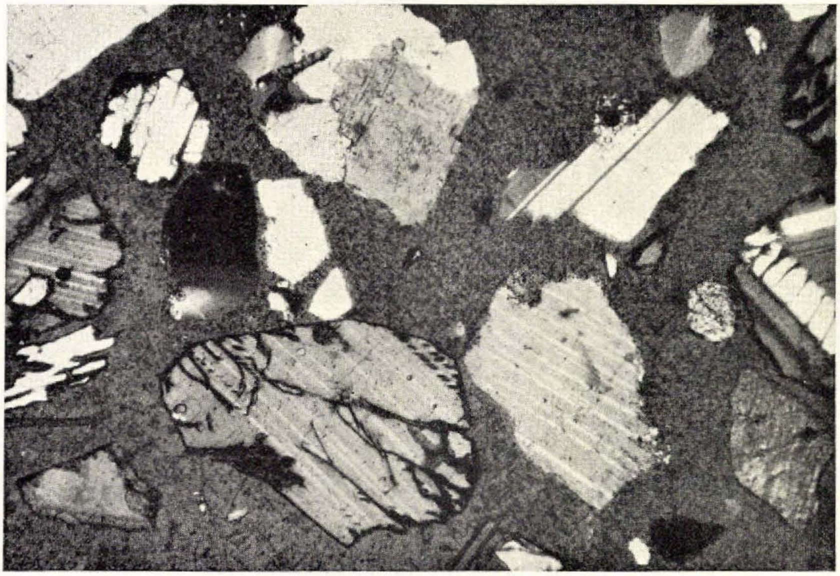

Fig. 2. Calcic (anorthosite-) plagioclase and sodic plagioclase with some quartz. The very calcic plagioclase has a high relief and is strongly etched by the HF vapours. The largest grain is 1.5 mm in size. Crossed polars.

Tables with the results of the various point and grain counts, the chemical and the granulometric analyses of the sand samples, as well as the details of the different methods of study have been collected in an internal GGU report (Kalsbeek, Ghisler & Thomsen, 1973), copies of which will be sent to interested readers on request.

2. The Bulk Mineralogical Composition of the Sands and the Composition of the Feldspars

a. Method of study

To determine the bulk composition of the sands, splits of approximately 15 gm were boiled in concentrated HCl, washed, dried, cemented with 'Araldite' and thin sections of the resulting mounts were point counted. Point counting was facilitated by selective staining of K-feldspar and plagioclase. The very calcic plagioclase (generally bytownite) of the anorthositic rocks can easily be recognized in the thin section, because of its high relief and the way it is etched by HF vapour (fig. 2). The percentage of this calcic plagioclase was also determined during the countings. Point counting of thin sections has the advantages that the mineralogical composition of the sands are obtained directly in percentages

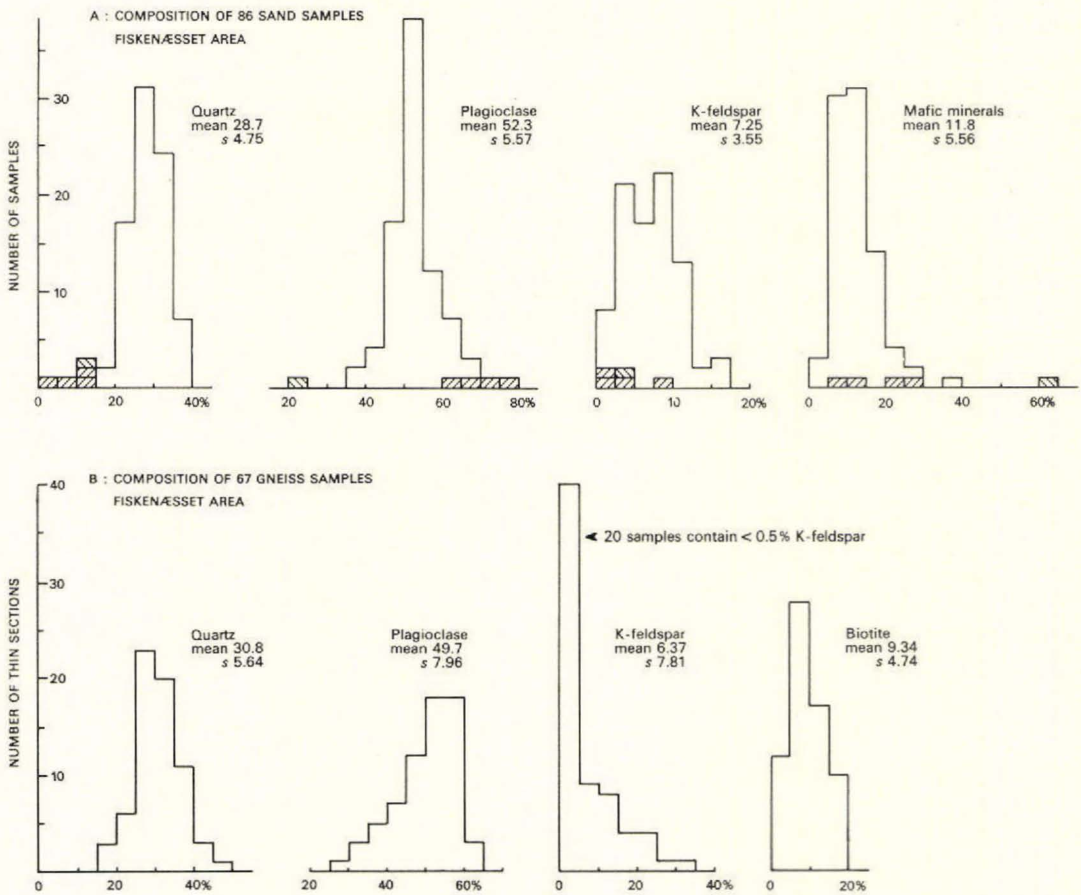

Fig. 3. The composition of 86 sand samples from the Fiskenæsset area (A) compared with 67 gneiss samples (B). One sample of black sand and 4 samples rich in very calcic plagioclase have been indicated by cross hatching. Modal analyses of the gneisses by J. R. TOMAS (1973) and L. S. ANDERSEN (pers. comm.). Volume per cent.

by volume and that the composition of the feldspars can be determined without difficulty.

Information on the accuracy of the point counter analyses is given in KALSBEEK, GHISLER & THOMSEN (1973).

b. Results of the point counter analyses

Most of the sands contain 45–60 $^0/_0$ (by volume) of plagioclase, 20–35 $^0/_0$ of quartz, 5–20 $^0/_0$ of mafic minerals and less than 15 $^0/_0$ of potash feldspar (fig. 3A). For comparison fig. 3B shows histograms of the amounts of the main minerals in a number of gneiss samples. The figures show that the composition of the sands compares well with the bedrock gneisses. The average amounts of quartz, plagioclase and potash feldspar are more or less equal, but the spread is larger for the gneisses than for the sands. Differences in composition between the sands and the gneisses are partly due to the presence of amphibolite material in the sands and partly to the absence of much of the biotite derived from the gneisses.

In the preliminary report (KALSBEEK, 1971) on the composition of the sands a comparison was made between sands from the northern, the central and the southern parts of the area, i.e. areas with different grades of metamorphism. It could be shown that only small differences in the average mineralogical composition of these sands exist. This will be discussed further in section 3.

c. The composition of the feldspars

In every thin section the anorthite content of several plagioclase grains was measured using extinction angles $X'\Lambda$ 010 in sections normal to the crystallographic *a* axis. The anorthite content of the very calcic anorthosite plagioclase was not determined. The anorthite content measured is rather variable because in every sand sample plagioclase from different rock types may be present (fig. 4). The anorthite contents

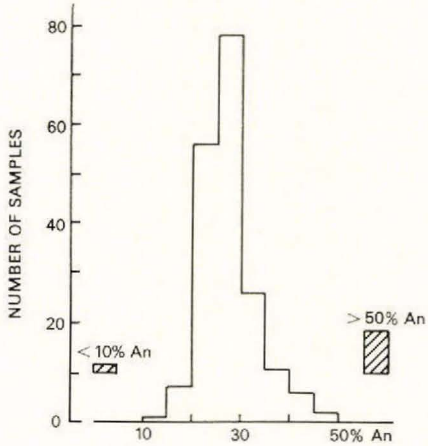

Fig. 4. Histogram of the An contents of 197 plagioclase grains from the Fiskenæsset sands. The composition of the very calcic plagioclase from the anorthositic rocks is not shown in the diagram.

of the plagioclase are slightly higher when the sands contain hypersthene (table 1); the differences are small but statistically significant.

Presence or absence of antiperthite was recorded (KALSBEEK, GHISLER & THOMSEN, 1973) since it was supposed that antiperthite might indicate the presence of high-grade metamorphic rocks. Anti-

Table 1. *Anorthite contents of plagioclase grains in sands of the Fiskenæsset area*

	Mean An	*S*	Number of measurements
Hypersthene-rich sands	28.6 %	5.09	60
Hypersthene-poor sands	27.3 %	6.45	82
Sands without hypersthene.	26.5 %	4.13	45

The anorthite contents of the very calcic anorthosite plagioclase are excluded.

perthite is encountered more frequently in hypersthene-rich sands than in hypersthene-poor sands but the association is rather loose.

The K-feldspar present in the sands is invariably microcline.

3. The Chemical Composition of the Sands

a. Method of study

To get an impression of the chemical composition of the sands, several composite sand samples were analysed. To obtain at the same

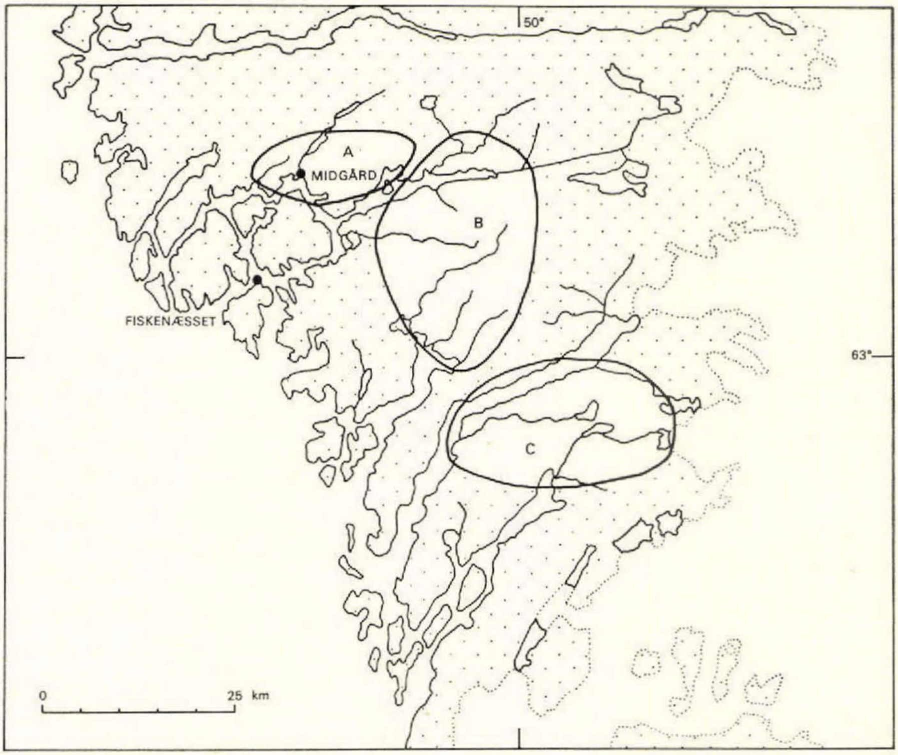

Fig. 5. Areas A, B and C from which mixtures of sands were analyzed. Sands from areas A, B and C differ in hypersthene contents, compare fig. 7.

time an idea of the relationship, if any, between the metamorphic grade and the composition of the rocks, large coherent subareas were chosen in the northern, central and southern parts of the area, i.e. across the metamorphic gradient, and splits of 20 gm of all the sands collected in these areas were used for the mixtures to be analysed (fig. 5).

At a few localities sand samples with widely divergent median grain sizes could be collected. To see whether the chemical composition of the sands depends on the grain sizes, coarser grained and finer grained sands were analysed from two localities, 6 and 47. The results of these analyses are given in table 4. All original analyses are listed in KALSBEEK, GHISLER & THOMSEN (1973) together with the C.I.P.W. weight norms.

b. Results of the analyses

The average chemical compositions for sands from the different parts of the area are almost identical (table 2). The only clear differences occur in the amounts of FeO and Fe_2O_3, indicating higher oxidation ratios for the rocks in the southern part of the area. The differences in amounts of FeO and Fe_2O_3 are clearly related to the distribution of hypersthene and epidote throughout the area, hypersthene being more

Table 2. *Average composition and C.I.P.W. norms for sands*

	Northern area A		Central area B		Southern area C	
SiO_2	69.7		69.3		69.6	
TiO_2	0.3		0.3		0.4	
Al_2O_3	15.2		15.3		15.1	
Fe_2O_3	0.8		1.0		2.2	
FeO	2.2		1.9		1.4	
MnO	0.0		0.0		0.0	
MgO	1.9		2.0		1.6	
CaO	4.1		4.5		3.9	
Na_2O	4.3		3.9		4.2	
K_2O	1.4		1.7		1.4	
P_2O_5	0.1		0.1		0.0	
q	27.3		27.3		29.0	
or	8.1		10.0		8.4	
ab	36.1	54.3	32.9	52.2	36.0	54.0
an	18.2		19.3		18.0	
di	1.3	10.2	2.1	10.4	1.1	8.7
hy	6.9		6.2		3.7	
mt	1.2		1.5		3.0	
il	0.6		0.5		0.8	
ap	0.2		0.1		0.1	

Recalculated to 100 % water free.

common in the northern part of the area and epidote in the southern part (section 5).

The fact that the sands from the different parts of the area have the same average compositions very probably implies that the average composition of the bedrock is the same in the different subareas. This means that the differences in (prograde or retrograde) metamorphism had hardly any or no influence at all on the bulk chemical composition of the rocks.

4. The Grain Sizes of the Sands

a. Grain size and sorting

Splits of all samples were sieved with mesh sizes of 1/8, 1/4, 1/2, 1 and 2 mm. The values for d_{75}, d_{50}, d_{25} and $S_0 = \sqrt{d_{75}/d_{25}}$ are given in KALSBEEK, GHISLER & THOMSEN (1973).

In general, the results of the grain size analyses are not representative for the river sediment as a whole. In many places the river bed is formed of coarse gravel and the sand was collected from local streaks of sand

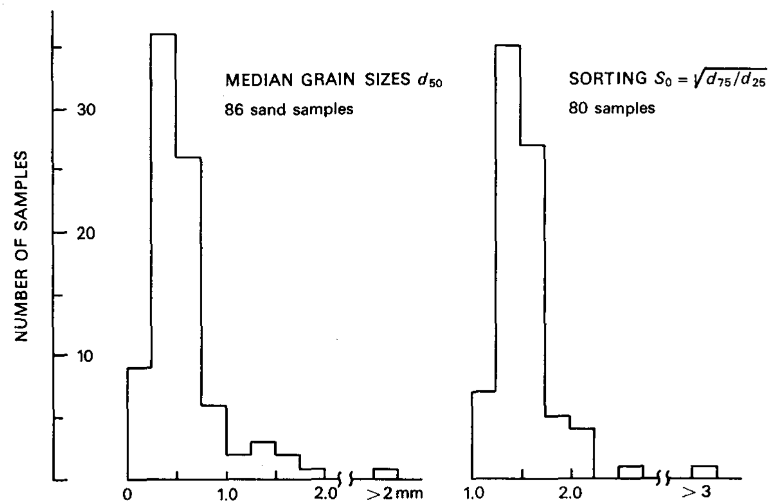

Fig. 6. Histogram of the median grain sizes d_{50} and the sorting coefficients $S_0 = \sqrt{d_{75}/d_{25}}$ of the Fiskenæsset sands.

occurring between the more coarse grained material. In a few cases even no streaks of sand were found and samples could only be collected with difficulty by scraping sand material together from in between the stones. In other places, however, very large amounts of sand are present. The major component of the sediment at each locality is given in the tables in KALSBEEK, GHISLER & THOMSEN (1973).

Most of the sands have median grain sizes < 1 mm, some have medians between 1 and 2 mm (fig. 6). Coarser sands are largely absent, which results in a size gap between sand and gravel with pebble sizes from several centimetres upwards. Possibly the smaller pebble fraction is broken up relatively easily into separate mineral grains. The grain size of the gneisses, amphibolites etc. in the area is in the order of 0.5–1 mm, which coincides with the most common grain sizes in the sands. In thin sections of the sands it can be seen that grains larger than 1.5–2 mm generally are composite. Such material, however, is relatively rare.

Most of the sands are moderately well sorted ($S_0 < 2$, fig. 6). The sands with sorting coefficient $S_0 > 2$ all come either from terraces or from localities where only minor amounts of sand occur in gravel deposits.

b. Influence of the grain size on the composition of the sands

If the study of sand samples is to be used as a tool to estimate the average composition of the bedrock in an area, it is of importance to know whether or not the composition of the sands is dependent on the grain size. A comparison between the 18 most fine grained samples ($d_{50} < 0.35$ mm) and the combined samples (table 3) shows that there is hardly any difference in average composition. The largest difference is found in K-feldspar, but even this difference is hardly of statistical significance.

Table 3. *Comparison of the mineralogical composition of the 18 most fine grained samples* ($d_{50} < 0.35$ mm) *with the average of all sands from the Fiskenæsset area*

	K-feldspar*	Plagioclase*	Quartz*	Mafics
All samples	8.2	59.3	32.5	11.8
18 most fine-grained samples	9.9	57.9	32.2	12.7

* The amounts of K-feldspar, plagioclase and quartz have been recalculated to a sum of 100 %. Volume per cent.

As a further test of the dependence of composition on grain size, chemical analyses (table 4) were made on material with widely diverging grain size from localities 6 and 47.

Since the material comes from the same source area, differences in the composition of the samples, if not fortuitous, must be due to the grain size. It is seen that these differences are quite small. In both examples the coarser grained sample is slightly richer in SiO_2 and slightly

Table 4. *Chemical composition and grain size distribution of fine grained and more coarse grained sands*

	Locality 6 GGU 131 155		Locality 47 GGU 131 196		
	b fine	*a* coarse	*b* fine	*a* + *c* coarse	
SiO_2	73.13	75.13	69.49	70.47	
TiO_2	0.21	0.11	0.22	0.22	
Al_2O_3	13.71	13.46	15.00	14.06	
Fe_2O_3	0.72	0.16	0.87	1.14	
FeO	0.97	0.89	1.57	1.61	
MnO	0.02	0.00	0.05	0.04	
MgO	0.78	0.55	1.68	1.68	
CaO	3.33	2.81	4.29	4.24	
Na_2O	4.02	4.04	3.99	3.68	
K_2O	1.44	1.54	1.75	1.39	
P_2O_5	0.11	0.03	0.06	0.07	
d_{75}	*b* 0.27mm	*a* 0.64	*b* 0.23	*a* 0.90	*c* 0.80
d_{50}	0.14	0.42	0.17	0.56	0.53
d_{25}	< 0.125	0.28	0.12	0.34	0.36

poorer in Al_2O_3. This may well be due to the differences in grain size of the samples.

5. The Composition of the Heavy Fraction

a. Method of study

The composition of the heavy fraction of one sample from each locality was studied in detail. The heavy minerals were separated with bromoform (specific gravity 2.9) from a 74–250 μ sieve fraction, and the amounts of each mineral were determined by grain counts according to the line count method. Although, theoretically, line counts do not give the amounts of the minerals in percentage by volume, it can be shown that the deviations from volumetric percentages probably are small (KALSBEEK, GHISLER & THOMSEN, 1973).

b. Properties of the heavy minerals

Most of the heavy minerals in the sands from the Fiskenæsset area are much the same as those described from the Holsteinsborg district (THOMSEN, 1957). The hypersthene, however, seems to be slightly less pleochroic than in the area north of Holsteinsborg. One mineral has only rarely been described from sand samples: a chromian epidote. This mineral occurs in irregular, almost colourless grains, light yellowish green in larger grains, and shows a faint pleochroism from yellow to yellowish green. In larger fragments, chromian epidote from rock samples shows a marked pleochroism from clear yellow to lighter green. The mineral is most easily recognised by its very marked anomalous dark blue and violet interference colours. The mineral commonly occurs in composite grains. The optical properties of the chromian epidote have not yet been studied in detail.

c. Results of the grain counts

On average, the samples contain 18.6 % by weight of heavy minerals in the 74–250 μ fractions. The point counter analyses gave an average of 11.8 % by volume in all samples, and 12.0 % in the samples in which the heavy minerals were investigated, i.e. some 15.5 % by weight for the mafic minerals. To this last figure should be added approximately 2 % for the amount of opaque minerals that appears in the grain counts but not in the thin sections because of the HCl treatment.

The heavy fractions are dominated by normal rock-forming minerals such as hornblende, epidote and pyroxenes, whereas heavy minerals that play an important role in more mature sediments, such as zircon, rutile and tourmaline, occur only in very small amounts (table 5).

Table 5. *The average composition of the non-opaque heavy fractions of sands from the Fiskenæsset area*

> 1 %		0.1–1 %		< 0.1 %
hornblende	65 %	garnet	0.9 %	rutile
epidote	13	enstatite	0.6	sillimanite
hypersthene	8	sphene	0.4	kyanite
clinopyroxene	7	zircon	0.3	spinel
olivine	5	others	0.3	chromian epidote

Percentages of the non-opaque heavy fraction exclusive biotite and chlorite.

The amounts of biotite are very low. Since biotite gneisses are by far the most common rocks in the area, most of the biotite must have been winnowed from the sands before or during deposition.* To obtain better control of the amount of biotite in the sands, the biotite of a few sand samples was carefully separated using heavy liquids and the magnetic separator. These samples (8) proved to contain 0.1–2.0 %, (average 0.7 %), of biotite by weight. This biotite content is not re-

* Recent investigations by D. Heling (personal communication, 1973) have shown that muds largely consisting of biotite are the major sediment in many fjords and lakes in the area.

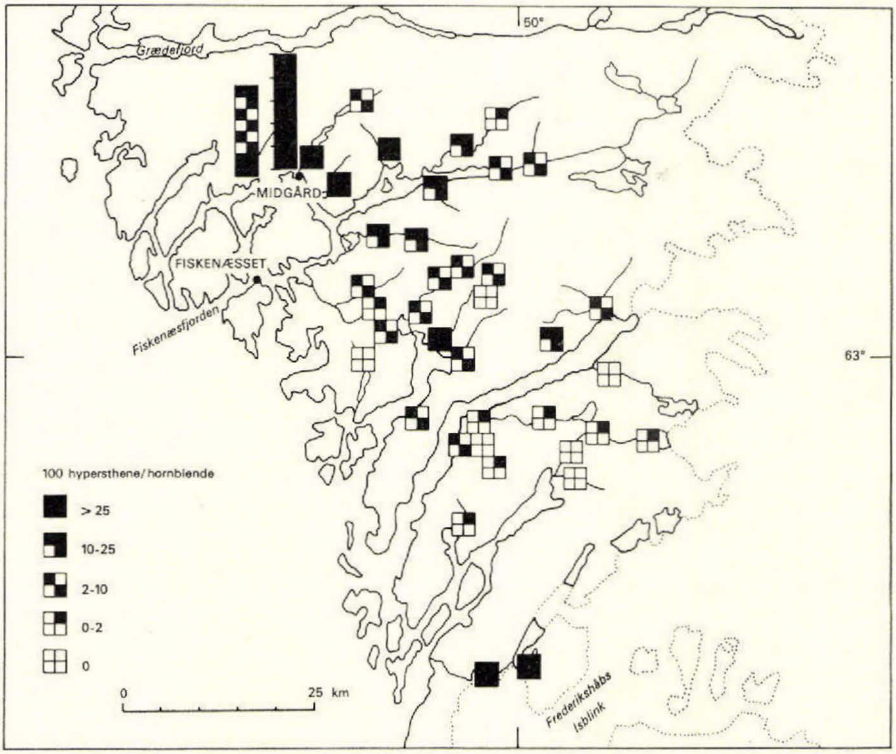

Fig. 7. Distribution of hypersthene in the sands from the Fiskenæsset area, expressed as 100 hypersthene/hornblende. The amounts of hypersthene and hornblende are given in Kalsbeek, Ghisler & Thomsen (1973).

produced in the heavy mineral counts, probably because part of the biotite does not sink in the bromoform.

Hornblende dominates among the other heavy non-opaque minerals. Most of the hornblende is derived from the amphibolites in the area, and a minor amount comes from the anorthositic rocks which also have hornblende as their most common mafic mineral. The gneisses more rarely contain hornblende.

Hypersthene occurs especially in the northern part of the area, where the rocks belong to the hornblende-granulite facies. Hypersthene occurs here both in the amphibolites and in the gneisses.

The distribution of hypersthene in the area is shown on fig. 7. The ratio 100 hypersthene/hornblende is generally > 25 in the area around Midgård in the northern part of the area, and decreases from here both eastwards and southwards. In the area between Fiskenæsfjorden and Bjørnesund the ratio 100 hy/hbl generally lies between 2 and 25 and south of Bjørnesund values < 2 are common. This picture compares well with the distribution of hypersthene arrived at by using thin sections in

Table 6. *Relationship between the average amounts of epidote, diopside and opaque minerals and the amounts of hypersthene in sands from the Fiskenæsset area*

(a) 100 hyp/hbl	epidote	diopside	opaque minerals
>25 (12)	9.6 (1–30)	12.2 (3–23)	14.6 (3–29)
8–25 (7)	8.1 (2–28)	10.3 (3–16)	6.3 (1–18)
2–8 (14)	13.4 (0–28)	4.6 (0–18)	2.7 (0–11)
<2 (14)	17.1 (6–35)	3.4 (0–10)	2.9 (1–6)
	epidote	diopside	opaque minerals
(b) A (12)	8.0 (1–21)	11.7 (2–23)	15.1 (3–31)
B (13)	12.1 (2–28)	8.4 (1–18)	3.2 (0–11)
C (9)	14.5 (5–29)	3.4 (0–10)	2.6 (1–6)

In the left column, the number of samples in each group is given between parantheses. In the other columns, the range in epidote, diopside and opaque mineral content is indicated between parantheses.

Per cent of the non-opaque heavy fraction exclusive biotite and chlorite.

A, B & C are the subareas indicated in fig. 5.

a more subjective way (Kalsbeek, 1971). In the two samples collected at the front of Frederikshåbs Isblink (localities 32 and 33), hypersthene is again common. It is not clear where this hypersthene comes from, since the rocks in the southern part of the area do not seem to contain hypersthene. Dawes (1970) has described hypersthene-bearing metadolerites from the nunataks and semi-nunataks in the Frederikshåbs Isblink, but also here the surrounding gneisses and amphibolites do not contain hypersthene.

The distribution of epidote is loosely correlated with the distribution of hypersthene (table 6a). Although the sands rich in hypersthene on average contain less epidote than the hypersthene-poor sands, large amounts of epidote may also occur in hypersthene-rich sands. This occurrence of epidote is evidently due to the partial retrogression of most of the granulite facies rocks in the area. Also the amount of opaque minerals and clinopyroxene (diopside) can be correlated with the amounts of hypersthene (table 6a).

To make sure that these mineralogical differences are not due to chemical differences, the average amounts of epidote, opaque minerals and clinopyroxene were calculated for the mixtures A, B and C that were chemically analysed and which proved to have almost identical compositions (table 6b). The same differences appear for these mixtures (which were chosen so that they contained different amounts of hypersthene) and therefore these differences in heavy mineral content of the sands must be due to differences in metamorphic grade of the source rock.

The clinopyroxene found in the sands is mainly diopside, but augitic pyroxenes also occur. Most of the diopside probably derives from amphibolitic and anorthositic rocks, the augite may come from basic dykes.

The fairly large amounts of olivine (on average 5 % of the non-opaque heavy fraction) are surprising. The olivine must come from ultramafic rocks which occur both in association with amphibolites in the gneisses and with anorthositic rocks. Olivine is also locally found in the basic dykes which occur in the area. Both the ultramafic rocks and the dykes, however, are relatively rare.

Other minerals that have been encountered in the heavy mineral concentrates are: rutile, spinel (colourless, brown and green varieties have been observed), sillimanite, kyanite, andalusite (?), tourmaline and corundum. The spinel minerals and the corundum, as well as the chromian epidote that has been found in several samples, derive from the rocks of the anorthosite complex.

6. The Composition of the Opaque Fraction

a. Method of study

The opaque minerals were studied in one sample from each locality. The amount of each mineral was determined by systematic grain counts in polished sections of the heavy fractions under reflected light. Generally the grain size range of 74–250 μ was used.

The opaque minerals show considerable grain size variation within each section, but on average are of smaller size than the translucent heavy minerals (fig. 8). As this applies to all of the opaque components, the number of grains is considered to represent the relative proportions of opaque minerals, whereas the calculated figure for the volume per cent for the whole sample must be regarded as a maximum value.

As the purpose of this paper is to discuss the general composition of the sands, for reasons of simplification only the major groups of opaque minerals have been determined separately. 'Magnetite' thus includes its different more or less advanced alteration products, and 'titanomagnetite' represents a group of primary as well as secondary minerals, for a description of which the reader is referred to STUMPFL (1958).

b. Results of the grain counts

On average the opaque minerals form 6.4 volume per cent of the heavy fraction, which amounts to 1.1 volume per cent or approximately 2.0 weight per cent of the whole sample.

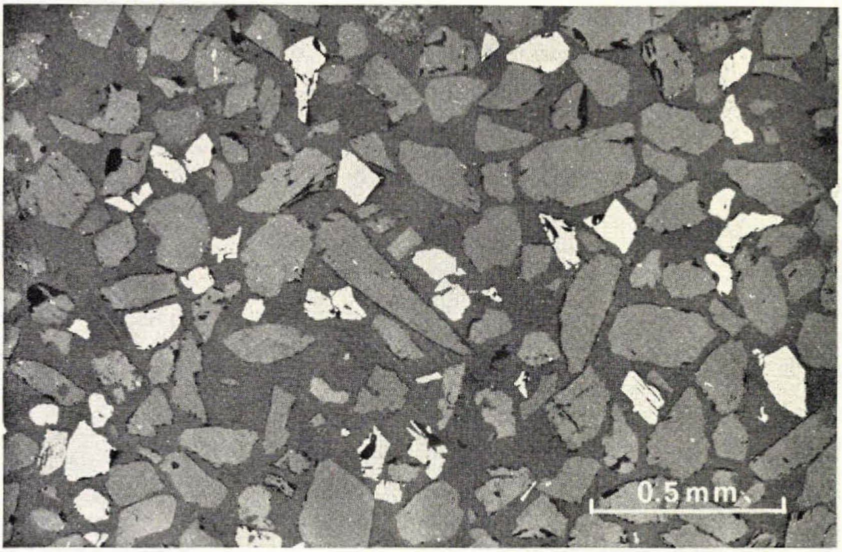

Fig. 8. Heavy fraction of sand from locality 10 under reflected light. Magnetite and ilmenite (white) and silicate minerals (grey) lying in 'Araldite'.

Table 7. *Average composition of the opaque fraction in sands from the Fiskenæsset area*

magnetite	56 %
ilmenite	27
titanomagnetite	6
ilmenite/haematite exsolutions	4
chromite	5
sulphides	2

The opaque fractions are dominated by magnetite and ilmenite, which form nearly 90 % of the total amount of opaque minerals (table 7). A brief study of a number of polished sections from the different rocks of the area has shown that most of the magnetite is derived from the gneisses and a minor amount from the ultramafics, whereas ilmenite originates from the amphibolites, and chromite from the anorthositic rocks. It has not yet been possible to correlate titanomagnetite and the sulphides with their respective source rocks; they both occur in amphibolites as well as in ultramafics. The occurrence of ilmenite with exsolutions of haematite is probably mainly derived from the dolerite dykes.

The amounts of magnetite and ilmenite vary throughout the area. This is shown for the subareas A, B and C of fig. 5 in table 8. Both the

Table 8. *Relationship between the composition of the opaque fraction and the hypersthene contents of the sands*

	total opaque	magnetite	ilmenite	sphene	TiO_2	total Fe as Fe_2O_3
A (12)	2.87 %	1.63	0.99	0.04	0.30	3.4
B (13)	0.50	0.32	0.08	0.07	0.26	3.1
C (9)	0.47	0.23	0.18	0.23	0.44	3.9

A, B & C are the subareas indicated in fig. 5.

amounts of magnetite and ilmenite decrease from north to south, but the amount of ilmenite is slightly higher in area C than in area B. The amount of sphene, however, increases from north to south. As the chemical values indicate a roughly constant amount of TiO_2 and total iron, the variations in the opaque mineral distributions are mainly due to differences in the metamorphic grade. Ilmenite is stable under granulite facies conditions in the area around Midgård, whereas sphene becomes the most common Ti-bearing mineral to the south. Similarly the iron occurring to some extent as magnetite in the northern area, is, under lower metamorphic conditions, bound mainly in the silicate minerals.

On the other hand, table 8 also reflects the variations in bedrock composition. Thus the slightly higher amounts of TiO_2 and total iron in area C compared to B, which show similar metamorphic conditions, are explained by the different amounts of amphibolite horizons in the two areas (section 8), which also is expressed by the volume per cent of ilmenite and sphene.

Chromite forms quantitatively a minor, but characteristic constituent of a large number of the sands. The poikilitic inclusions, which are known to occur in a certain portion of the chromite grains (GHISLER, 1970) are very helpful in the identification of this mineral.

Chromite is found in 27 of the 47 samples investigated, of which 2/3 originate from the area north of Bjørnesund and east of the Midgård area. The major portion of the anorthosite complex actually occurs in this part (plate 1). There is a clear correlation between the occurrence of chromite and calcic plagioclase in the samples. Of the 27 samples where chromite was observed, 23 contain calcic plagioclase, and of the 30 samples with calcic plagioclase, 23 are chromite bearing. There is also a tendency indicating that the chromite-rich samples have high calcic plagioclase contents. Further it is worth noting that these samples are poor in total opaque material, indicating that resistant opaque minerals are relatively scarce in the anorthositic rocks. Of the 12 samples where chromian epidote has been observed nearly all are chromite bearing, and the few grains of rutile are also found within these samples.

The sulphides form only a very small portion of the opaque fractions, and are dominated by pyrite, often rimmed by a zone of limonite. Pyrrhotite, which is known to be the most important sulphide mineral throughout the area, only occurs in very few samples and is obviously decomposed very quickly and therefore less stable than pyrite. Single grains of chalcopyrite were found in eight samples.

7. The Provenance of the Sands

It is of importance to know whether the sands collected in the river beds are derived from nearby or represent material brought into the area over long distances by the ice. In the second case the sands could hardly be used to estimate the average composition of the bedrock in the area. Also the use of sands in prospecting would have a restricted value.

In the preliminary report (KALSBEEK, 1971) it was suggested that most of the sands come from a nearby source, because: (1) The distribution of hypersthene in the sands is clearly related to the known occurrence of granulite facies gneisses (indicated e.g. on GGU's Tectonic/geological map of Greenland 1970). (2) The distribution of very calcic plagioclase in the sands is related to the occurrence of meta-anorthosite and related rocks, and the few samples taken very near to anorthositic rocks contain large amounts of the calcic plagioclase.

To investigate this problem further, samples were collected in the area around Midgård and in the area just north of the head of Fiskenæsfjorden where a river runs through a large outcrop of metamorphosed anorthosites and leucogabbroic rocks. The results of these investigations are briefly described below.

a. Sands from the Midgård area

The high mountain to the north-west of Midgård (fig. 9) consists of a granitic gneiss with conspicuous K-feldspar megacrysts. The surrounding, often more or less clearly banded gneisses do not contain visible K-feldspar. The area has not yet been mapped in detail and the rocks have not been sufficiently investigated to know exactly how different the two rock types are.

At Midgård, a large river, draining mostly from the north-east runs into the fjord. In the north-eastern valley a large lake traps most of the bed-load, and the largest part of the sediment load of the river comes therefore presumably from the north-north-western branch of the

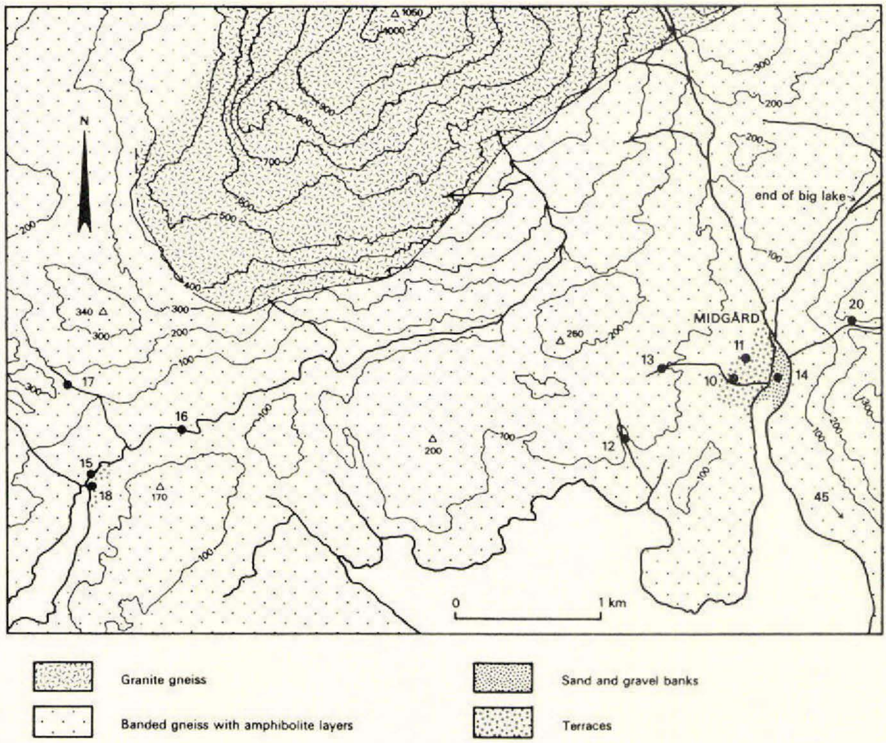

Fig. 9. Geological sketch map of the area around Midgård and the localities where sand samples were collected.

river which drains the granite gneiss terrain. The river has given rise to extensive gravel and sand banks at the head of the fjord. At an altitude of 20–30 m above sea level terraces are developed also consisting of gravel and sand in which many pebbles and boulders of granite gneiss material can be recognized.

A few kilometres to the west, another river comes from the granite gneiss terrain. This river has sand banks over much of its lower course and terraces are common along the sides of the valley.

Sand samples were collected (a) along the two rivers that come out of the granite gneiss area, both from the river beds and from the terraces, and (b) from minor rivers and streams where no direct influence of the granite gneiss material can be expected (fig. 9). The composition of the samples (table 9) shows that:

(1) The sands from the minor streams near Midgård (12, 13, 20 & 45) contain very little K-feldspar, much less than the sands of the terraces and the gravel and sand banks at the head of the fjord (10, 11 & 14).

Table 9. *Composition of the sands in the area around Midgård*

	Sands presumably containing granite gneiss material									
	10T		11T		14		15	16		18T
quartz	27 %	34	24	25_5	32	30	26	23	31	26
K-feldspar ...	11	7	10	5	9	12	5	6	3.9	3.0
plagioclase ...	53	51	52	50	47	51	59	57	58	53
mafics	9	8	15	20	12	6	10	14	7	18

	Sands presumably not containing granite gneiss material						
	12	13	20		45		17
quartz	19	22	24	24	21	25	21
K-feldspar ...	0.4	1.0	3.0	2.5	1.4	1.1	2.0
plagioclase ...	60	66_5	55	61	63_5	63	62
mafics	21	11	18	13	14	10_5	15

Samples marked with T come from terraces. Volume per cent.

(2) The samples collected from the gravel and sand banks (14) have the same composition as the samples taken from the terraces at Midgård (10 & 11).

(3) Of the samples collected farther to the west, the sample from the minor stream (17) is poorer in K-feldspar than the samples from the bed of the larger river (15 & 16) and from a terrace along the river (18).

(4) The samples taken from the western river (15, 16 & 18) contain less K-feldspar than the samples taken near Midgård (10, 11 & 14).

These results indicate that the rocks surrounding the granite gneiss are very poor in K-feldspar and that the presence of up to 10 % of K-feldspar in the sands taken along the larger rivers is due to the presence of granite gneiss material, originating a few kilometres away. This conclusion is supported by the fact that the sands from the larger rivers also contain more quartz and less plagioclase than the sands from the small streams. The results also suggest that the influence on the composition of the sands by material transported over long distances is restricted. The very low contents of K-feldspar in the sands from the minor streams (17, 12, 13, 20 & 45) cannot be explained if the sands contain large quantities of 'average material' coming from a long distance away.

b. Sands from the Majorqap qâva area

To obtain further information about the provenance of the sands, 30 samples were collected at 15 different localities in a valley running

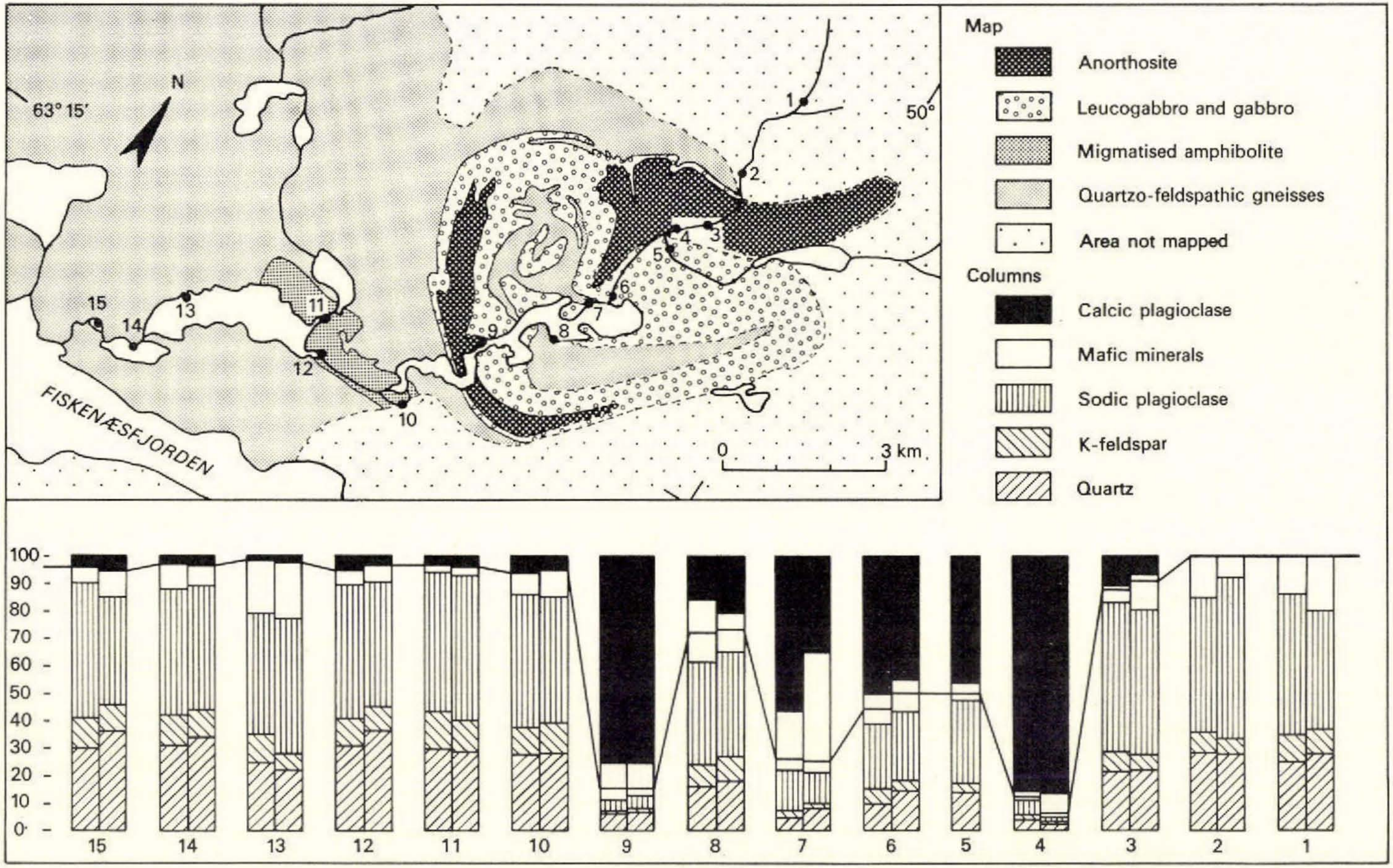

Fig. 10. Geological map of the Majorqap qâva area by JOHN MYERS (1973), and the localities where sand samples were collected. The columns show the mineralogical composition of the samples. There is a close agreement between the composition of the sands and the bedrock near the sample localities. The line between the columns divides anorthosite derived material (above) from gneiss/amphibolite derived material (below).

through one of the major outcrops of meta-anorthositic and leucogabbroic rocks, the Majorqap qâva outcrop just north of the head of Fiskenæsfjorden (MYERS, 1973). The samples were taken from the large river running through the valley and from the shores of several lakes. A study of the mineralogical composition of these samples (fig. 10) shows that the composition of the sands very closely reflects the composition of the rocks outcropping nearby. Soon after the river enters the anorthosite outcrop, the sands begin to contain large amounts of material derived from the anorthositic and leucogabbroic rocks. Calcic plagioclase occurs in these samples in large amounts, but also part of the mafic minerals is certainly derived from rocks of the anorthosite complex, since the sands deriving from gneiss terrains rarely contain more than 20 % of mafic minerals. The anorthositic rocks must also contain minor amounts of quartz since the quartz–sodic plagioclase ratios at a few localities (4 & 9) are much higher than in normal gneiss sands. This is confirmed by occasional finds of composite sand grains in which calcic plagioclase is intergrown with quartz. An estimate of the amount of material in each sample deriving from the anorthositic, leucogabbroic and associated rocks is also shown in fig. 10. To the west of the large anorthosite outcrop, the sands assume again the same composition as those taken to the north-east of it, although minor percentages of calcic plagioclase are present in all samples.

Also within the outcrop of the anorthosite complex, close correspondence exists between the composition of the sands and the composition of the rocks outcropping nearby. Samples from localities 4 and 9, where meta-anorthosites proper occur, are strongly dominated by calcic plagioclase. Sands from locality 8, where quartzo-feldspathic rocks outcrop within the anorthosite complex, contain large amounts of quartz and sodic feldspar again. Sands at one of the localities (7) where metamorphosed gabbroic and leucogabbroic rocks occur are rich in mafic minerals.

It can thus be concluded that the composition of the sands closely reflects the local geology. This implies that (a) the influence of glacial material incorporated in the sands must be small and (b) the transport of sand down the valley must be restricted.

The anorthositic rocks weather readily to a crumbly gravel, and it is therefore not surprising that the sands in the river bed are soon dominated by anorthositic material when a river reaches an anorthosite outcrop. However, the fact that the river sands lose their content of anorthosite material so soon after leaving the anorthosite area, can only mean that transport of sand material downstream is small in comparison with the addition into the river of new sand material coming from the mountain slopes.

That transport down the valley plays such a minor role in determining the composition of the sands, is probably due both to the presence of lakes, which act as traps for the sands (especially the long lake in the western part of the large anorthosite outcrop, which probably prevents the transport of anorthosite material downstream), and to the steepness of the valley slopes which facilitates the transport of locally derived material into the river.

Since the same conditions apply for most valleys in the Fiskenæsset district, it is probable that a large part of the sands in most of the rivers and streams consist of locally derived material. This does not rule out influence of glacial transport. The fact that, in spite of the presence of several lakes, up to 5 % of calcic plagioclase occurs even in the westernmost samples of this series, may well be due to glacial or fluvio-glacial transport in a westward direction.

8. Estimates of the Average Composition of the Bedrock in the Fiskenæsset Area

a. The abundance of the different rock types

The main rock types in the Fiskenæsset area are gneisses of variable composition, amphibolites and metamorphosed anorthositic, leucogabbroic and associated rocks. For various reasons it is difficult to make a reliable estimate of the abundances of these rock types. In the following an attempt is made to make such an estimate and the difficulties met with are outlined.

The sands contain on average 12 % of mafic minerals (fig. 3A) of which two-thirds, or approximately 8 % is hornblende (table 5). Assuming (as an approximation) that all the hornblende comes from amphibolitic rocks and that the amphibolites—as elsewhere in the Archaean gneiss block (KALSBEEK, 1970; KALSBEEK & LEAKE, 1970, see also GHISLER & SHARMA, 1969)—contain 60 % of hornblende, approximately 13 % of the area should be amphibolite. In reality a minor part (approximately 1 %) of the hornblende comes from the anorthositic and associated rocks, thus reducing the amount of amphibolite to approximately 12 %.

The sands contain on average 3.5 % of calcic plagioclase. Since the so-called anorthositic rocks for a large part consist of meta-leucogabbros, with 20–40 % of mafic minerals, an estimate of 5 % for these rocks seems reasonable, of which 1 % might be hornblende. South of Bjørnesund, the amounts of calcic plagioclase in the sands are very low; the samples collected north of Bjørnesund contain on average 4.6 % of calcic plagioclase. The estimate of the amount of anorthositic rocks is of

Table 10. *Estimates of the amounts of the different rock types in the Fiskenæsset area*

	a	b	c
gneiss	83 %	85 (82/87)	85
amphibolite	12	11 (9.5/12.6)	10
anorthosite complex	5	4 (8.5/0.4)	4

(a) based on the composition of the sands.
(b) based on the geological map. 1600 grid points were counted.
The values in parentheses are for the areas north and south respectively of Bjørnesund.
(c) based on a grid sample collection with 300 samples, collected at 150 localities. Volume per cent.

dubious value, since the amounts of calcic plagioclase are erratically distributed over the different sand samples.

Independent estimates of the amounts of amphibolite and anorthositic rocks were made (1) from the geological map with the help of a grid and (2) from a grid collection of rock samples. Since minor bands, streaks and lenses of amphibolite and anorthosite do not appear on the map, the first estimate may be too low, but this is partly cancelled because many amphibolites and anorthosites are veined by quartzo-feldspathic material. The second estimate is based on sampling at 150 localities only, and the statistical errors are therefore relatively large. Moreover, at many localities the rocks are so inhomogeneous that it is difficult to choose representative, let alone random, samples.

Although the accuracy of each of the three estimates can be doubted, the three estimates very nearly give the same results (table 10). That the estimate based on the composition of the sands agrees so well with the other estimates, is a strong indication that the study of sands really can be regarded as a valid tool for regional geochemical investigations.

b. The mineralogical composition of the rocks in the area

The average mineralogical composition of the sands in the area (fig. 3A, tables 5 & 7) is not the same as that of the bedrock. Biotite, the main mafic component of the gneisses, only occurs in minor amounts in the sands (p. 15); most of it has evidently been winnowed from the sands before or during deposition. The biotite content of the gneisses is variable; 67 point counted gneisses contain 1.0–19.8 % biotite, average 9.3 % (fig. 3B). Assuming that 85 % of the area consists of biotite gneiss, 8 % by volume of the average bedrock would be biotite. Correcting for this amount of biotite, the average mineralogical composition of the area would become as shown in table 11.

Table 11. *Average mineralogical composition of the rocks of the Fiskenæsset area estimated with the help of the sand samples*

main minerals		mafic minerals	
quartz	26.5 %	hornblende	6.5 %
plagioclase	48 (mean An 27 %)	epidote	1.3
K-feldspar	6.5	hypersthene	0.8
biotite	8	clinopyroxene	0.7
other mafics	11	olivine	0.5
		opaque minerals	1.1
		(0.6 % magnetite, 0.3 % ilmenite)	

per cent by volume.

c. The chemical composition of the rocks in the area

The average composition of the rocks in the area can be estimated from the estimated average mineralogical composition of the rocks (table 11) or from the chemical analyses of the sands (table 2).

(1) Taking the average mineralogical composition of the rocks as basis, the percentages by weight of the different minerals can be cal-

Table 12. *Average chemical composition of the rocks of the Fiskenæsset area estimated with the help of sand samples*

	a	b
SiO_2	66.3	65.6
TiO_2	0.6	0.5
Al_2O_3	15.0	15.2
Fe_2O_3	1.9	1.4
FeO	3.5	3.1
MgO	2.3_5	2.4
CaO	3.8	3.9
Na_2O	4.3	3.8
K_2O	1.8	2.1
H_2O	0.4_5	–
	100.0	98.0

(a) Calculated from the mineralogical composition of table 11.
The result of this estimate depends on the mineral compositions used for the calculations. This is especially the case for FeO and MgO.

(b) Calculated from the chemical composition of the sands (see table 2) correcting for the amount of biotite in the rocks. The low total is due to slightly low totals in the original analyses and to the fact that H_2O was not analysed.
Weight per cent.

culated with the known densities of the minerals. With the help of published analyses of these minerals in comparable rocks (analyses from DEER, HOWIE & ZUSSMAN (1962–63) have been used) the average chemical composition of the rocks in the area can be calculated (table 12a).

(2) Taking the average chemical composition of the sands, and correcting for the deficiency of biotite (of the same composition and density as the biotite used above), the chemical composition shown in table 12b is obtained.

9. Summary and Conclusions

Most of the sands in the Fiskenæsset area contain 40–60 % (by volume) of plagioclase, 20–35 % of quartz, 5–20 % of mafic minerals and less than 15 % of potash feldspar (section 2). Among the mafic minerals, hornblende is dominant. Epidote, hypersthene and diopside also occur in appreciable amounts. Garnet occurs in only very small amounts (section 5). Approximately 1 % of the sands consist of opaque minerals, among which magnetite and ilmenite together form nearly 90 % (section 6). This composition, together with the very irregular shapes of the sand grains (figs 1 and 8) illustrates the extremely immature nature of the sands, and results from the nature of the bedrock (mainly plagioclase gneisses), the high relief which causes strong erosion and the subarctic climate which almost completely prevents chemical weathering of the main rock minerals.

The aim of this study was particularly to learn something about the bedrock geology of the area through the study of the sands. To be able to use the sands in this way two conditions must be fulfilled: (1) the sands must be of local origin (and not reworked glacial material derived perhaps from far beneath the inland ice), and (2) there must be no appreciable change in the composition of the sands due to sedimentary processes. These conditions seem to be fulfilled. In section 7 it has been shown that in two test areas the composition of the sands is strongly related to the local geology; this indicates that material brought into the area from long distances by glacial transport only plays a minor role in the investigated sands. It could also be shown that no major transport of sand along the rivers occurs; this is evidently due to the presence of the numerous lakes which trap the sands. In section 4b it was shown that the grain size of the sands hardly influences their mineralogical and chemical compositions, indicating that sedimentary processes do not drastically change the composition of the sands. On the other hand, biotite is rare in the sands and evidently has been removed during sedimentation owing to its specific hydraulic properties.

Assuming that the composition of the sands (corrected for biotite) equals the average composition of the rocks in the area, estimates have been made for (1) the amounts of the different rock types in the area, (2) the average mineralogical composition, and (3) the average chemical composition of the rocks (section 8). Using sand samples it can be estimated that 83 % of the area consists of gneisses, 12 % of amphibolite and 5 % of rocks of the anorthosite complex. This estimate agrees very well with the results of the systematic mapping, which confirms the usefulness of the sands in determining the composition of the bedrock. The average chemical composition of the rocks in the area compares well with estimates of other shield areas (RONOV & YAROSHEVSKY, 1969, table 4).

The metamorphic grade of the bedrock can roughly be followed from the hypersthene content of the sands. Diopside and the opaque minerals magnetite and ilmenite are more common in the northern high-grade parts of the area, epidote and sphene in the southern more low grade part of the area (sections 5 & 6). The average chemical composition of the rocks, however, does not seem to change with the metamorphic grade (table 2, section 3).

Since it could be shown that the sands are largely of local origin, they can also be used in prospecting for economic minerals, and in fact chromite was found in some samples where in the immediate neighbourhood chromitite layers were not yet known. It must be emphasized, however, that a dense sampling grid must be adopted, as numerous lakes trap most of the sand material, and sample locations will have to be chosen with a strategic position.

Moreover, not all opaque minerals survive in the sands. Thus pyrrhotite, the most widely distributed sulphide mineral of the area, is hardly found in the sands, whereas pyrite and chalcopyrite because of the relatively short distances of transport are still found. On the other hand, a resistant mineral like molybdenite, occurring in very small amounts in all the rock units of the area, is (probably because of its flaky nature) completely lacking in the samples investigated. Preconcentration in the field by panning would probably make molybdenite appear.

The present study shows that collection of sand samples would be an important first step in prospecting glaciated areas in West Greenland with similar climatic and topographic conditions. The chemical and mineralogical compositions of such sands would give a first idea of the regional economic possibilities of the area. Panning of river sands on a small scale would be helpful to find concentrations of mineral deposits such as magnetite, ilmenite, rutile, chromite, as well as molybdenite and even chalcopyrite (associated with possible nickel deposits) and pathfinder minerals of kimberlites. All these minerals are known to occur in the Precambrian rocks along the coast of West Greenland.

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDDELELSER OM GRØNLAND BD. 201 NR. 1 (F. KALSBEEK, M. GHISLER & B. THOMSEN)

PLATE 1