GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT Nr. 129

The Geological Survey of Greenland
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Occurrences of anorthositic rocks in the reworked Archaean basement in the Umanak area, central West Greenland

by

Morten C. Andersen and T. C. R. Pulvertaft

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Occurrences of anorthositic rocks in the reworked Archaean basement in the Umanak area, central West Greenland

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Abstract

The main occurrence of anorthositic rocks in the Umanak area is the Tunulik sheet, a body up to 300 m thick with an areal extent of about 80 km^2. The sheet is a composite body, consisting of blocks of crudely foliated anorthosite and leucogabbro 1–3 m in size in a granitic gneiss matrix. The blocks are jumbled together with no systematic distribution of blocks with different colour indices and no preferred orientation of the internal foliation within the blocks. The blocks are composed mainly of plagioclase, with small amounts of hornblende and biotite. The plagioclase shows patchy zoning; the composition is in the range An_{82-68}. The dark minerals tend to be clustered in parallel schlieren. Epidotisation has given many blocks a yellowish colour. Textures are metamorphic. Both quartz- and nepheline-normative compositions are represented in the anorthositic blocks; it is suspected that compositions were modified with respect to Si, and possibly also Na and K, during metamorphism and incorporation in the granitic host.

In addition to the Tunulik sheet, there are several small occurrences of anorthositic rocks in the Umanak area. These differ from the Tunulik sheet only in the fact that the anorthositic blocks in the minor occurrences are hosted in granodioritic-tonalitic gneiss no different from the country gneisses in the area, whereas in the Tunulik sheet the matrix gneiss is granitic.

Authors' addresses:
Morten C. Andersen
ASPRO Prospektering A/S
Gamle Ringeriksvei 14
N-1320 Stabekk, Norway

T. C. R. Pulvertaft
Geologisk Institut
Øster Voldgade 10
DK-1350 Copenhagen K, Denmark

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INTRODUCTION

Occurrences of anorthositic rocks are known from all over the Archaean of Greenland. The best known anorthositic bodies are those occurring within the Archaean craton (Bridgwater *et al.*, 1976), and of these the Fiskenæsset layered complex is the most important, not least because of the economic interest attached to the chromite-rich layers within the complex (Ghisler, 1976). However, there are also occurrences of anorthositic rocks in the reworked Archaean basement within the Proterozoic Nagssugtoqidian and Rinkian mobile belts of central and northern West Greenland (Ellitsgaard-Rasmussen & Mouritzen, 1954; Dawes, 1976; Nutman, 1984). This report describes an anorthositic sheet and other, minor,

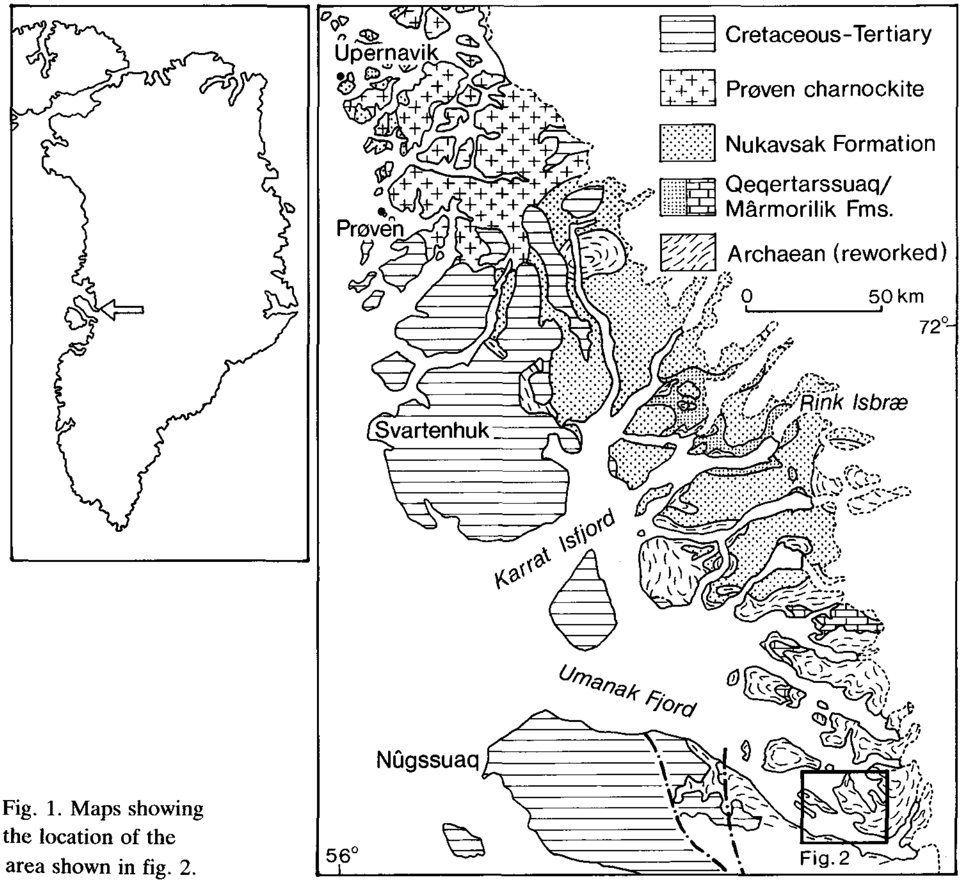

Fig. 1. Maps showing the location of the area shown in fig. 2.

occurrences of anorthositic rocks in the Umanak district in the southern part of the Rinkian mobile belt. These anorthositic rocks were discovered by the second author in 1965 (Pulvertaft, 1973) and mapped in greater detail by the first author during the mapping of the 1:100 000 sheet 70 V.2 N Agpat.

The Rinkian mobile belt in its type area is characterised by a thick supracrustal cover which overlies a reactivated gneiss basement. The supracrustal succession comprises two formations – the Qeqertarssuaq Formation (lower) which is up to 2 km thick and consists mainly of pelitic schist and quartzite, and the Nukavsak Formation (upper) which is an at least 4.5 km thick flysch formation (Henderson & Pulvertaft, 1967). Southwards the Qeqertarssuaq Formation gives way to a major carbonate formation – the Mârmorilik Formation. The only place where a primary unconformity between supracrustals and basement is preserved is at the base of the Mârmorilik Formation near Mârmorilik (Garde & Pulvertaft, 1976). However, as the Mârmorilik Formation is traced south from its type locality it becomes folded into the basement gneisses in a thin recumbent fold and subsequently refolded by younger tight to isoclinal folds. In the southern part of the Rinkian belt, where basement rocks dominate, the folds that are easiest recognised as Rinkian are those folding marble layers belonging to the Mârmorilik Formation.

The basement rocks in the Umanak district are mainly granodioritic to tonalitic gneisses, in addition to which there are horizons of banded amphibolite, anthophyllite-cordierite rocks and komatiitic ultrabasics (Knudsen, 1983). The anorthositic rocks that are the subject of this report occur within the gneisses. One of the anorthositic bodies is cut by representatives of a suite of basic-ultrabasic sheets that occur throughout the Umanak area. Since these sheets have been boudinaged and folded during the formation of Rinkian recumbent isoclines (Schiøtte, 1981), the pre-Rinkian age of the anorthositic bodies is not in doubt.

The age determinations carried out to date in the southern part of the Rinkian mobile belt indicate that the gneisses are at least 2500 Ma old, and that Rinkian metamorphism and deformation terminated about 1700 Ma ago (Larsen & Møller, 1968; Kalsbeek, 1981; Andersen & Pulvertaft, 1985).

THE TUNULIK ANORTHOSITIC SHEET

Field description

Outcrops of this anorthositic body are spread over an area of about 80 km^2 on Drygalski Halvø in the southern part of the Umanak area (figs 1 and 2). The body has an irregular sheet-like form, with a maximum thickness of 300 m. The shapes of the outcrops are determined by the way in which the topography follows the sheet (fig. 2). Although the western part of the sheet lies only about a kilometre in front of the closure of a large Rinkian recumbent fold (Escher & Pulvertaft, 1976, fig. 109), it has not been involved in this fold. Around Tunulik the sheet is involved in upright folds with steep southward-dipping axial planes. To the east, where the sheet is thinner, it has been folded by a number of southwards overturned folds (fig. 2), as well as by the broad E–W antiform that affects the whole area of outcrop.

The Tunulik anorthositic sheet is not a simple intrusion but a composite body, consisting of a more or less tightly packed aggregate of anorthosite and leucogabbro blocks in a granitic

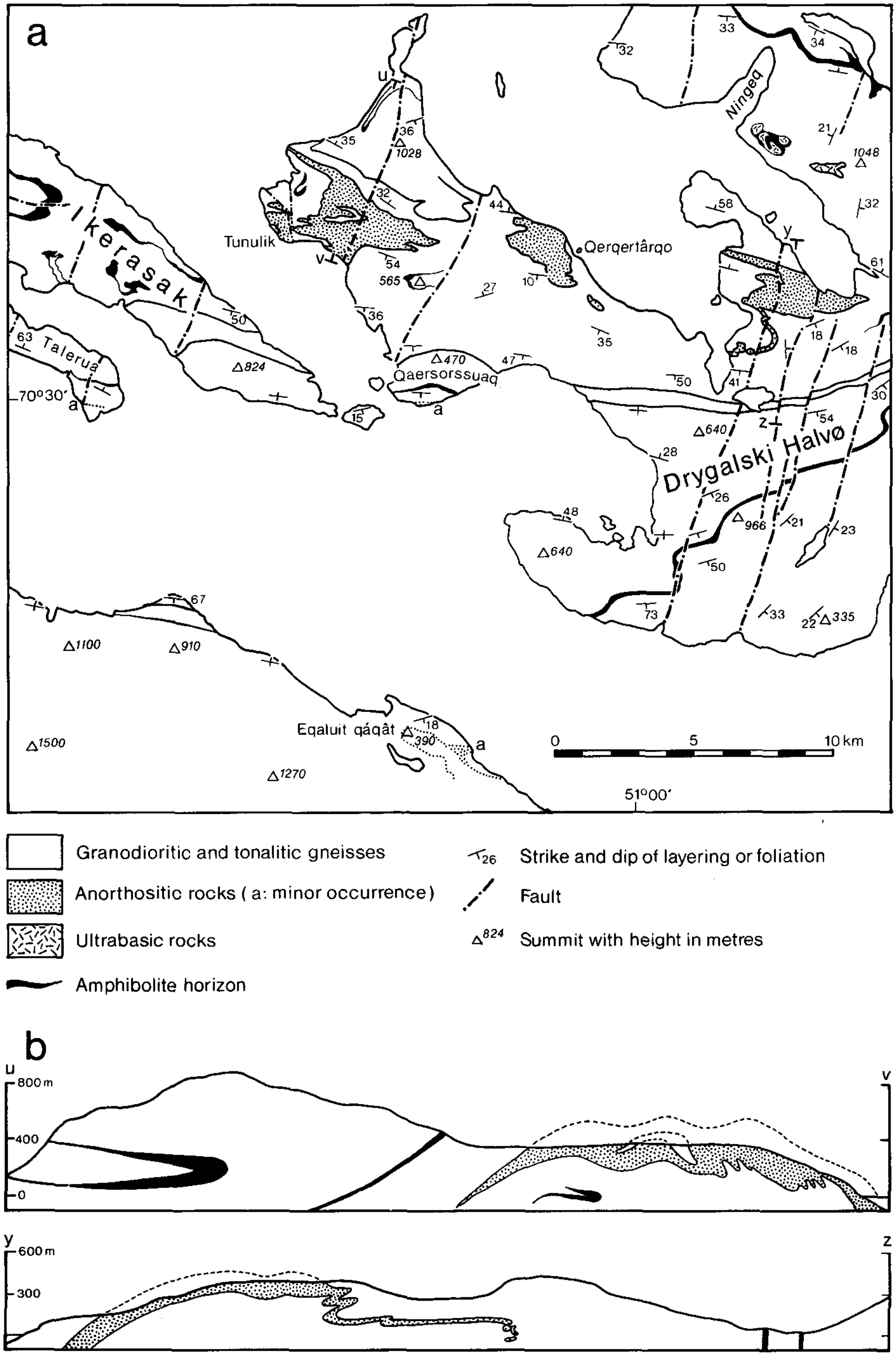

Fig. 2. (a) Map showing the distribution of anorthositic rocks in the Umanak area. (b) Two cross-sections (with no vertical exaggeration) illustrating the structure of the Tunulik anorthositic sheet.

Fig. 3. Typical outcrop of the Tunulik anorthositic sheet.

biotite gneiss matrix (fig. 3). The microcline : plagioclase ratio in the matrix gneiss is *c.* 1, which means that this gneiss is clearly different from the country granodioritic to tonalitic gneisses.

The anorthosite/leucograbbro blocks are from 0.1 to 10 m wide, but most blocks are 1–3 m in size. The blocks show no particular shape and only locally a weak shape orientation where the long axes of blocks are roughly parallel to the regional structure. The outlines of the blocks are subangular to subrounded. The blocks : matrix volume ratio varies but is generally ≤ 1. Towards the top of the sheet the blocks are less closely packed. Since the density of the anorthosite/leucogabbro is greater than that of granite, this reduction in the blocks : matrix ratio towards the top of the sheet implies that the sheet has not been inverted since the intrusion of the granite parent to the gneissic matrix. At the base of the sheet there is in many places a clear contrast between the pale rocks of the sheet and an underlying 1–10 m thick layer of relatively dark, slightly rusty-weathering biotite-hornblende augen gneiss or hornblende-biotite gneiss with many amphibolitic enclaves; there is locally interdigitation with this underlying gneiss.

The anorthosite/leucogabbro is a pale rock which gives rise to bare, almost pure white

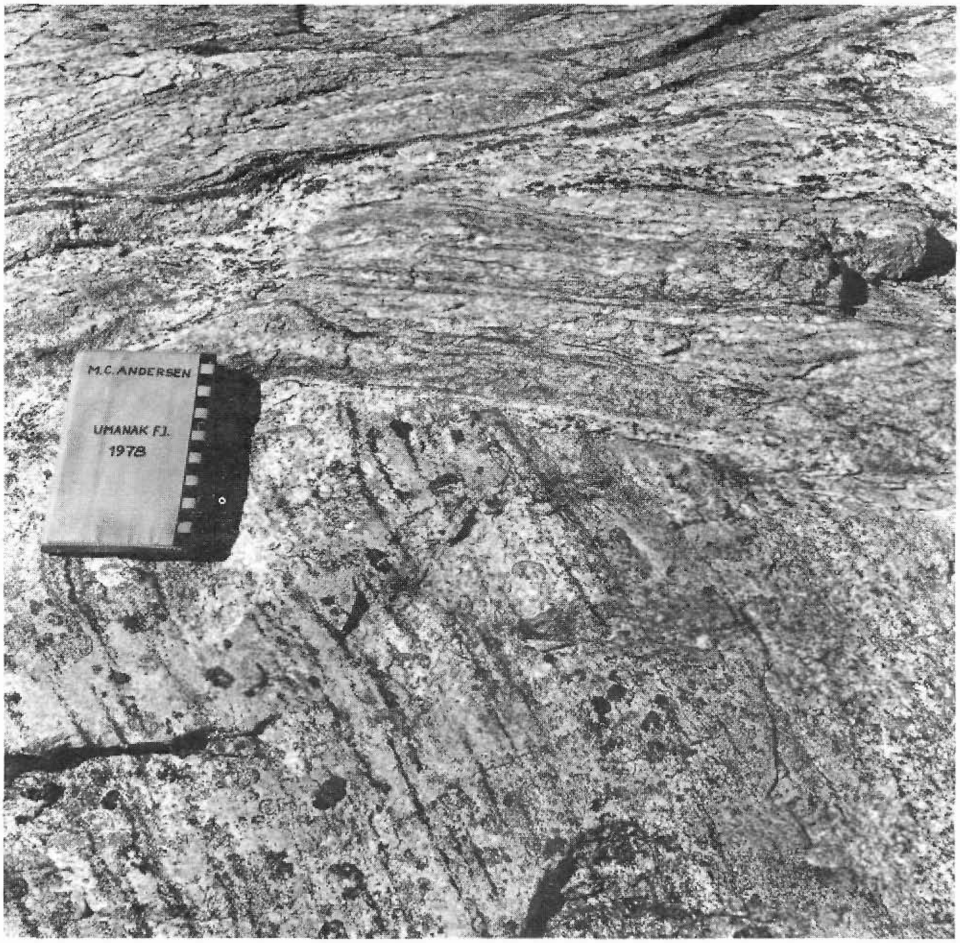

Fig. 4. Outcrop of the Tunulik sheet showing how the orientation of foliation in the anorthosite/leucogabbro blocks varies from block to block.

slopes on account of the reluctance of lichens to grow on this rock type. Weathered surfaces are generally chalky white and lustreless, but some blocks have yellowish surfaces. The fresh rock is grey or white with a transparent lustre. The texture is medium-grained, granular; no large cumulate plagioclase crystals of the type known from the Fiskenæsset complex (Bridgwater *et al.*, 1976, figs 40 and 48) have been observed in the Tunulik sheet. The percentage of dark minerals is usually between 5 and 10, but up to 30% dark minerals are present in the least leucocratic blocks. There is no systematic variation in the distribution of blocks with different colour indices, and no relic primary igneous stratigraphy could be mapped out in the body. The greatest variety of blocks is seen in the outcrops west and south-west of Qeqertârqo.

The dark minerals are mainly hornblende and biotite. These are concentrated in parallel

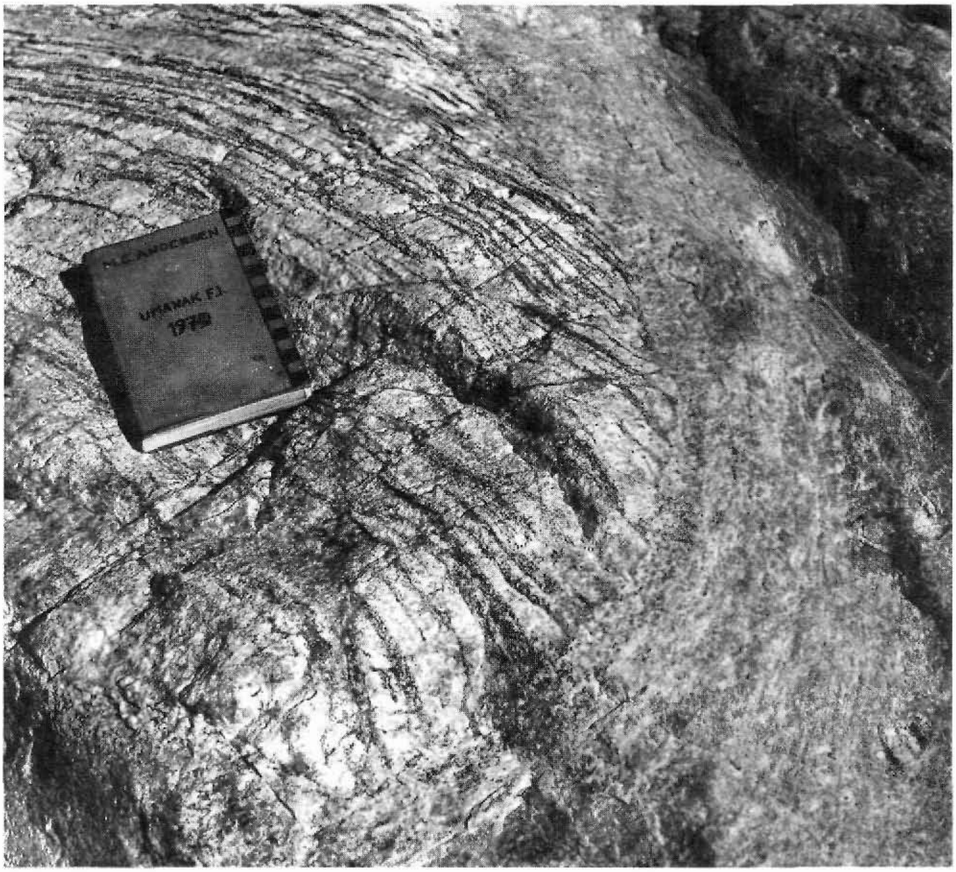

Fig. 5. Block of leucogabbro enclosed in granitic gneiss. Note how the foliation in the matrix gneiss wraps around the block, cross-cutting the foliation within the block.

schlieren 3–50 cm long which give the rocks a crude foliation. The orientation of this foliation is *not* parallel from block to block (fig. 4). No fold patterns or other systematic patterns can be traced out when the foliation is followed through a group of blocks.

The matrix gneiss is for the most part well foliated. The foliation wraps around the anorthosite/leucogabbro blocks and thus is generally concordant to the external form of the blocks. Where the dark schlieren in the anorthosite/leucogabbro are cut off at the margin of a block, the foliation in the matrix gneiss is discordant to the crude foliation within the block (fig. 5).

Petrography

The anorthosite/leucogabbro has a granoblastic to mosaic texture; the crude foliation seen in large hand samples cannot be detected at the scale of a thin section.

Plagioclase forms grains generally up to 5 mm in size, although larger crystals – at one locality up to 3 cm long – do occur. In some slices there is a bimodal grain-size distribution, grains 0.1–0.6 mm in size with 120° triple junction forming zones separating larger grains or sometimes patches up to 5 mm across which seem to be relic larger grains. Both the larger and the smaller grains show albite and pericline twinning; the albite twinning often tapers out. Compositions have been determined optically by measuring the angle between α' and (010) on a universal stage and reading the corresponding An content from the figure by Tröger (1971, p. 129). The larger grains show both normal and reverse zoning, while the small polygonal grains are unzoned. The lowest An value recorded (An_{61}) was determined at the margin of a larger grain. Otherwise compositions are in the range An_{82}-An_{68}.

In addition to the commonplace albite and pericline twin lamellae, some plagioclase grains show a third set of lamellae. These are 1–2µ thick, imperfectly tabular, and may give a false impression of being spindles. The lamellae lie at an angle of about 17° to (010). In every respect these lamellae resemble Huttenlocher intergrowths (Smith, 1974) that have been described by many authors (e.g. Kalsbeek, 1970, p. 30) from plagioclases with a bulk composition $An_{>65}$. Such lamellae are attributed to "solid-state dissociation of a homogeneous calcic plagioclase into *e*-plagioclase and anorthite" (Smith, 1974, p. 544).

Hornblende occurs in up to 3 mm large anhedral-subhedral grains that are pleochroic in bluish to brownish greens. Occasionally diopside is associated with the hornblende, the latter usually rimming the former.

Biotite forms flakes up to 2 mm long. It is pleochroic from colourless to light green in some slices, while in others it is pale to muddy brown in colour. Intergrowths with light green chlorite are common. Light green chlorite showing anomalous interference colours can also form independent flakes up to 2 mm in size; these occur both isolated and in aggregates with epidote.

Epidote forms anhedral grains up to 1.5 mm across that can occur alone or in aggregates with chlorite, or as fillings in cracks. Strongly altered samples contain fine-grained epidote in aggregates with sericite. Very small amounts of calcite can occur in these rocks.

Scapolite is locally a minor constituent of the anorthositic rocks. It forms anhedral, equidimensional grains up to 1 mm in size. Bright second order interference colours indicate a meionitic composition.

Opaque minerals have only been observed in very few samples. The opaque assemblage consists of pyrite and chalcopyrite in approximately equal amounts, often clustered with magnetite. A thin limonite rim surrounds the sulphide grains and separates them from the magnetite grains; large sulphide grains are crossed by limonite-filled cracks. Pyrrhotite has been observed only once in association with the pyrite and chalcopyrite.

Chemistry

Major element analyses and norms of six samples of anorthositic rocks from the Tunulik sheet and one from Eqaluit qáqât on the north side of Nûgssuaq peninsula are presented in Table 1, and from these data an AFM diagram has been plotted (fig. 6). Analyses of anorthositic rocks from the Fiskenæsset complex and from the Neria area, both within the Archaean craton of Greenland, are included in Table 1 for comparison. A few comments are warranted.

The variation in composition from nepheline-normative to quartz- and hypersthene-nor-

Table 1. Chemical analyses and CIPW norms of anorthositic rocks from the Umanak area, with analyses of anorthosites from the Fiskenæsset and Neria areas for comparison

	1	2	3	4	5	6	7	8	9
	83625	83631	251401	246804	246849	246813	83649	70320	92579
SiO_2	49.55	49.55	48.65	50.12	52.56	48.58	53.01	49.45	47.10
TiO_2	0.08	0.10	0.27	0.09	0.07	0.22	0.01	0.07	0.13
Al_2O_3	29.45	28.89	27.32	29.49	27.77	21.82	28.68	29.58	30.60
Fe_2O_3	0.46	0.16	0.27	0.29	0.18	1.86	0.16	0.48	0.57
FeO	1.12	1.41	2.72	1.11	1.08	3.99	0.17	1.29	1.36
MnO	0.02	0.03	0.06	0.02	0.02	0.10	0.01	0.03	0.03
MgO	0.82	0.77	1.83	0.58	0.66	5.81	0.09	1.23	1.45
CaO	13.03	13.52	13.28	13.43	12.57	13.16	11.90	14.08	13.70
Na_2O	3.25	3.22	3.17	3.37	3.44	2.52	4.21	3.15	2.52
K_2O	0.52	0.36	0.48	0.81	0.37	0.53	0.38	0.20	0.96
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
H_2O	0.70	0.62	0.71	0.83	0.26	0.98	0.39	0.44	0.52
	99.01	98.64	99.65	99.15	98.99	99.58	99.02	100.02	98.96
Q	–	–	–	–	3.09	–	1.41	–	–
or	3.07	2.13	2.86	4.79	2.19	3.14	2.25	1.18	5.67
ab	26.82	26.84	23.51	28.37	29.11	20.24	35.63	24.82	16.49
an	64.25	63.31	59.42	61.61	59.24	46.71	58.24	66.00	67.86
ne	0.37	0.22	1.92	0.08	–	0.60	–	1.00	2.62
di	0.29	3.07	5.76	–	2.54	15.11	0.62	3.08	–
hy	–	–	–	–	2.18	–	0.38	–	–
ol	3.04	1.94	4.36	2.52	–	11.28	–	3.00	4.59
mt	0.29	0.30	0.57	0.26	0.24	1.09	0.06	0.33	0.36
il	0.15	0.19	0.52	0.17	0.13	0.42	0.02	0.13	0.25
ap	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05
C	–	–	–	0.49	–	–	–	–	0.55
An mol%	69.31	69.97	70.43	67.18	65.73	68.51	60.64	71.48	79.51
FeO*/MgO	1.87	2.02	1.62	2.36	1.88	0.98	3.49	1.40	1.29

1–6: anorthosites and leucogabbro from the Tunulik sheet.
7: anorthosite from Eqaluit qâqât.
8: anorthosite from the Neria area (Kalsbeek, 1970, table VIIIa).
9: anorthosite from the Fiskenæsset complex (Windley *et al.*, 1973, Table 1).
Analyses 1–7 Grønlands Geologiske Undersøgelse (Ib Sørensen).
All norms are CIPW norms with Fe_2O_3/FeO adjusted to 0.15.

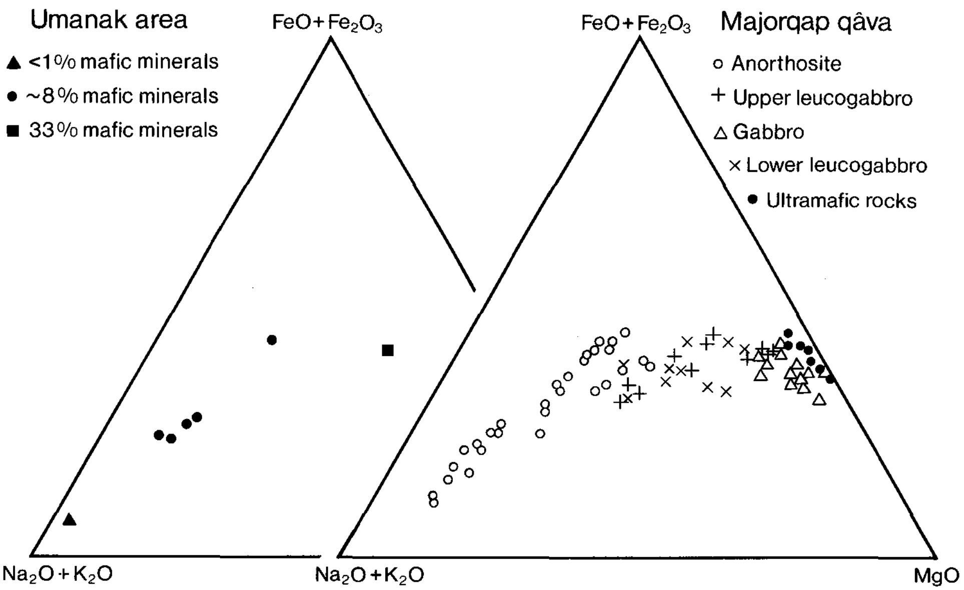

Fig. 6. AFM plot of analyses of anorthositic rocks from the Umanak area, with the plot of analyses from the Majorqap qâva body, Fiskenæsset area (Myers, 1975), for comparison.

mative is unlikely to be a primary feature. The rocks are obviously metamorphic and have been deformed and thereafter enclosed in a granitic melt. The analyses suggest that the chemistry of the rocks was affected by these processes, and especially Si was mobile. Rivalenti (1973) has demonstrated that metasomatic changes affecting Si, Na and K contents have taken place in the outermost 30 cm of anorthositic blocks enclosed in gneiss in the Fiskenæsset area.

Notwithstanding the changes that may have taken place during metamorphism and deformation, the analyses show clearly that the Tunulik anorthosite/leucogabbro belongs to the same family of rocks as the Fiskenæsset complex and other anorthositic complexes of West Greenland. The same impression is given by the AFM diagram (fig. 6), even though AFM plots of these rocks are very sensitive to the plagioclase : hornblende+biotite ratio of the samples analysed and cannot be interpreted uncritically as representing fractionation trends (Myers, 1975).

Discussion; emplacement of the Tunulik sheet

The following points must be taken into account in any explanation of the emplacement of the Tunulik sheet:

1) The anorthosite/leucogabbro body from which the anorthositic blocks were derived had been deformed and possessed a crude foliation prior to incorporation of the blocks in their present host.
2) During incorporation in granite and emplacement of the sheet the anorthositic blocks became jumbled together, mixed, and rotated at random.

3) No metagabbro and no chromite-rich blocks have been found in the Tunulik sheet (contrast with the Fiskenæsset complex).
4) The matrix (host) gneiss of the Tunulik sheet is different from the bulk of the basement gneiss in the Umanak area, the matrix gneiss being granitic whereas the bulk of the basement gneisses are granodioritic-tonalitic.

Even though the anorthositic lithologies seen in the Tunulik sheet can be matched with parts of the Fiskenæsset complex (see for example Windley *et al.*, 1973, fig. 24), there is little similarity in the field relations of the two bodies. Even where the Fiskenæsset complex has been broken up and occurs as trains of inclusions in gneiss, the stratigraphy of the complex can be followed in the trains of inclusions (Walton, 1973, and second author's own observations), implying that injection of the gneiss precursors did not move the anorthositic rocks very much. However, there are several places in the Archaean craton of Greenland where blocks of anorthositic rocks similar to those in the Tunulik sheet occur as a jumble of disoriented inclusions in gneiss. Where these occurrences differ from the Tunulik sheet is in the character of the host gneiss. In the Tunulik sheet the host (matrix) gneiss is different from the country gneisses, while in the Ivigtut (Berthelsen & Henriksen, 1975), Neria (Kalsbeek, 1970) and Godthåb (Berthelsen, 1960; Chadwick *et al.*, 1982) areas the gneiss hosting the anorthositic blocks has the same composition as that forming the surrounding terrain.

The relationships seen in the Tunulik sheet can best be accounted for by proposing that the anorthositic rocks in the sheet are not in their original position but were carried into their present position as xenoliths in the precursor to the matrix gneiss. This interpretation is similar to that proposed for the anorthositic rocks in the Inûgssûgssuaq nappe south of Ameralik fjord in the Godthåb district (Chadwick *et al.*, 1982). In the Inûgssûgssuaq nappe, however, the anorthositic inclusions in the core of the nappe are enclosed in granodioritic-tonaltic gneiss (Stainforth, 1977), and the core anorthosite-gneiss mixture is enclosed in a coherent membrane of anorthosite/leucogabbro which outlines the nappe structure; in spite of tectonic stretching, facing directions can be determined from the relic igneous stratigraphy in the membrane and inversion of the lower limb of the nappe can be confirmed.

Notwithstanding the obvious differences between the Tunulik sheet and the Inûgssûgssuaq nappe (absence/presence of a membrane; character of gneiss enclosing the anorthositic blocks), the model for the emplacement of the Inûgssûgssuaq nappe proposed by Chadwick *et al.* (1982) is thought to be relevant to the Tunulik sheet. According to this model, rising Nûk magma was trapped below a more competent anorthosite sheet. Accumulating below this, the magma first began to stope fragments off the anorthosite and then lift and stretch the remainder of the sheet which became the membrane of the Inûgssûgssuaq nappe. At first the structure was a dome, then it became a diapir which rose until it reached a higher, more viscous level in the crust. Here the structure spread laterally to become a nappe. The theoretical demonstration of the feasibility of this process is provided by Stainforth (1977).

The development of the Tunulik sheet is thought to have started in the same way as that of the Inûgssûgssuaq nappe (fig. 7). However, whereas the rising Nûk magma in the core of the Inûgssûgssuaq structure had roughly the same composition as the earlier phases of Nûk gneiss into which it intruded, the acid magma of the Tunulik sheet was granitic and hence there was a greater density contrast between the rising melt and both the anorthositic rocks and the pre-existing granitoids. As a result this granitic melt broke through the anorthosite at some stage, bringing the stoped anorthositic blocks with it. Any heavier metagabbroic or chromite-layered rocks there may have been in the original anorthositic sheet were left be-

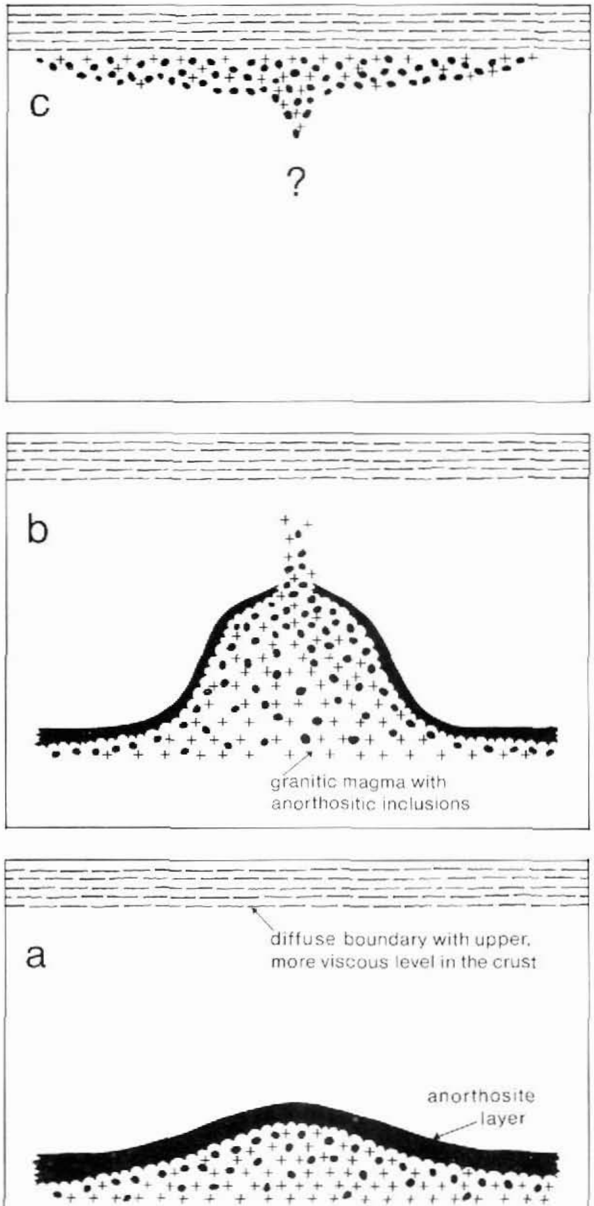

Fig. 7. A model for the development of the Tunulik sheet, based on the model of Chadwick *et al.* (1982, fig. 5). (a) Granitic magma rising in the crust meets an anorthositic sheet; due to its lower density the magma begins to stretch and lift the sheet in a dome while at the same time stoping blocks off the bottom. (b) Doming and stoping proceed until the magma breaks through the top of the dome, carrying blocks of stoped-off anorthosite with it. (c) On meeting a more viscous level in the crust the rising magma-anorthosite inclusion mixture spreads out laterally into a sheet.

hind. On reaching a level where the increasing viscosity of the country rocks prevented further upward movement, the granitic melt-anorthosite mixture spread laterally to give rise to the Tunulik sheet which was subsequently folded into its present shape.

The alternative to this interpretation is to suggest that a granitic magma intruding a basement consisting of deformed leucogabbro/anorthosite and granodioritic-tonalitic gneisses selectively sought out the leucogabbro/anorthosite mass and disrupted this into inclusions before crystallising and subsequently – or perhaps during crystallisation – being deformed to become a gneiss. The leucogabbro/anorthosite may have been sought out by the granite because this rock type was already fractured at the time of emplacement of the granitic magma, or was more easily fractured than the surrounding gneisses when the granitic magma arrived. This interpretation is simpler than that adapted from Chadwick *et al.* (1982), but it does not so satisfactorily explain the complete jumbling of lithologies in the anorthositic inclusions that characterises the Tunulik sheet.

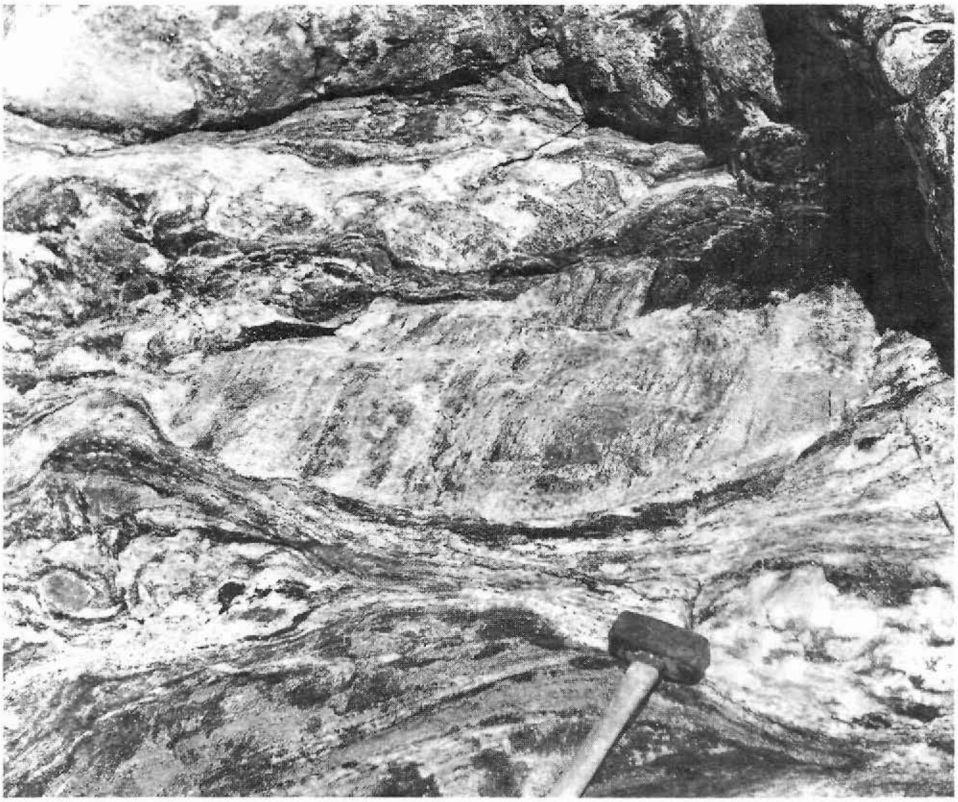

Fig. 8. Leucogabbro blocks enclosed in biotite-hornblende gneiss south of Qaersorssuaq. Note how the internal foliation in some leucogabbro blocks is oriented almost at right angles to the foliation in the enclosing gneiss.

OTHER OCCURRENCES OF ANORTHOSITIC ROCKS IN THE UMANAK AREA

On the south side of Drygalski Halvø, south of Qaersorssuaq (fig. 2), there is a horizon of relatively coarse, irregularly banded, hornblende-biotite gneiss with lenses and balls of leucogabbro and hornblendite up to 1 m long. The leucogabbro is yellowish in colour on account of epidotisation. Although the leucogabbro lenses may be parallel to the layering in the surrounding gneiss, their internal structure is often anything but (fig. 8). Since these leucogabbro lenses and balls have obviously been moved since they were first deformed and acquired their crude foliation, there is no reason to believe that they were originally associated with the hornblendite lenses they are now found alongside. Similar occurrences of anorthositic rocks are found on the south side of Talerua and 24 km north-west of Eqaluit qâqât on the north coast of Nûgsuaq peninsula.

At Eqaluit qâqât there is a prominent horizon rich in lenses up to 4 m across of relatively coarse white anorthosite (see 83649 in Table 1) as well as grey leucogabbro with schlieren of hornblende and biotite. The enclosing gneiss is banded granodioritic-tonalitic gneiss in no way different from the country gneisses. This occurrence is very similar to occurrences north of Godthåb (Berthelsen, 1960) and in the Ivigtut region (Berthelsen & Henriksen, 1975). The horizon may prove to be a useful marker in the mapping of the south-east part of Nûgssuaq peninsula.

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