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RAPPORT Nr. 74

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Igneous stratigraphy of Archaean anorthosite at Majorqap qâva, near Fiskenæsset, South-West Greenland

by

John S. Myers

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Abstract

Majorqap qâva provides one of the best preserved examples of a major group of anorthosites and associated gabbroic rocks which are characterised by extremely calcic plagioclase and are widespread throughout the Archaean complex of Greenland. The anorthosite outcrop is part of a sheet of layered igneous cumulates which were deposited in a number of cycles from magma intruded into basic volcanic rocks. It consists of six major units which in upward succession are: lower gabbro (10 m), ultramafic (30 m), lower leucogabbro (60 m), middle gabbro (40 m), upper leucogabbro (60 m), and anorthosite (200 m). The lower four units are considered to represent sequences of plagioclase-pyroxene, olivine-pyroxene, plagioclase, and plagioclase-pyroxene cumulates respectively, and the upper two units are plagioclase cumulates with intercumulus hornblende and plagioclase respectively. Plagioclase is the most abundant cumulus mineral and extensively occurs as equant crystals 2 to 10 cm in diameter. The anorthosite outcrop is enclosed by gneiss which was derived by deformation from sheet-like granitic intrusions younger than the anorthosite complex. The gneiss was more ductile and partly cushioned the anorthosite complex from the ravages of later deformation and metamorphism by absorbing a greater amount of strain and recrystallisation.

CONTENTS

INTRODUCTION

Anorthosites and associated gabbroic rocks are widespread throughout the Archaean complex of Greenland. They are of special interest, not only because of their unusual composition with extremely calcic plagioclase but because, more than any other rock group in the Greenland Archaean, they extensively preserve their primary textures and layering, and in some places igneous minerals. They provide some of the oldest known examples on earth of layered igneous rocks that are well exposed. They are most abundant in the Fiskenæsset region of South-West Greenland, where the anorthosite contains chromite layering (Ghisler, 1966). This feature led Windley (1966, 1967) to conclude that the anorthosites and associated gabbroic rocks and amphibolites represent metamorphosed gravity-stratified igneous rocks, and he called them the Fiskenæsset complex (Windley, 1969, 1971).

Previous work

The igneous stratigraphy of part of the Fiskenæsset complex was first mapped in 1966 by Gormsen (1971) and in 1970 in more detail by Windley (1971; Windley *et al.*, 1973). In some places the anorthosites and associated gabbroic rocks are fringed by units of amphibolite which were once thought to be part of the layered plutonic anorthosite complex (Ghisler & Windley, 1967; Windley, 1971). They are still grouped with the Fiskenæsset complex in some recent publications (Windley *et al.*, 1973; Windley & Smith, 1974) although it has been found that these amphibolites are mainly derived from volcanic rocks (Kalsbeek & Myers, 1973; Windley *et al.*, 1973) which were intruded by the anorthosite complex. These amphibolites occur throughout the Fiskenæsset region and are not specifically associated with outcrops of the anorthosite complex (Kalsbeek & Myers, 1973; Andersen & Friend, 1973). Therefore in this account the term Fiskenæsset complex is restricted to the anorthosite and associated layered plutonic rocks with calcic plagioclase and minor interlayered ultramafic rocks.

Regional geology

The Fiskenæsset complex outcrops throughout the Fiskenæsset region (fig. 1) as strips typically less than 500 m wide and up to 25 km long, and as trains of

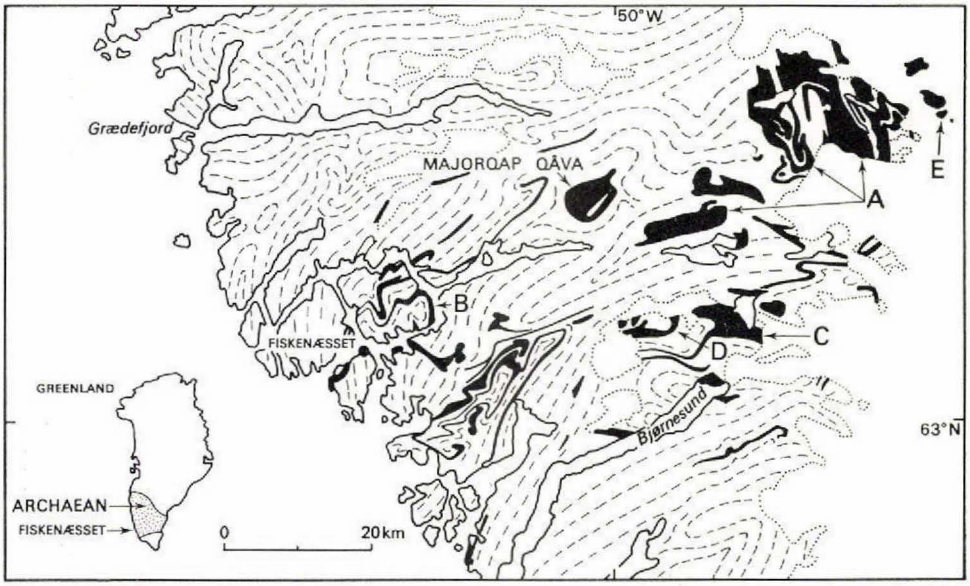
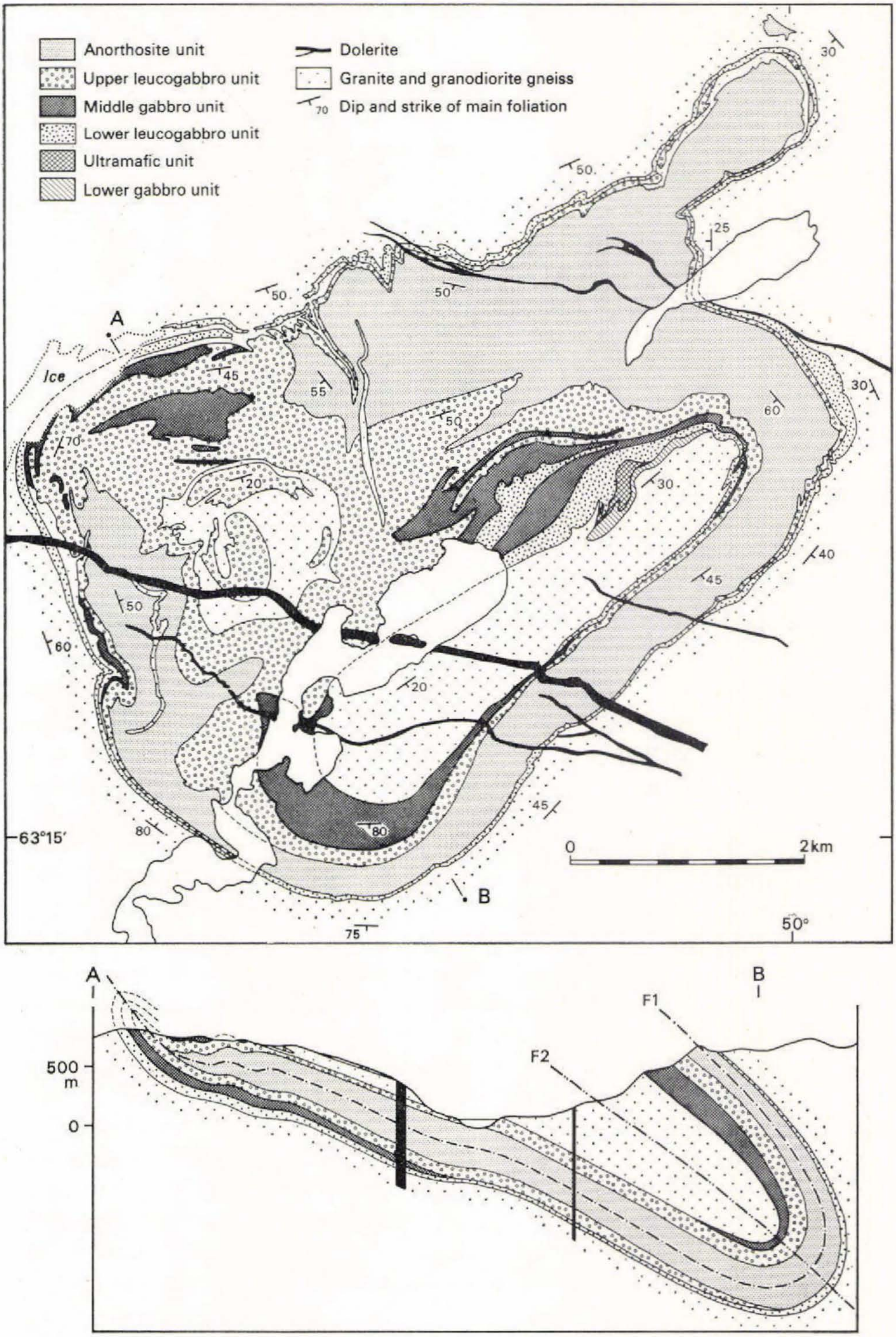


Fig. 1. Sketch map of the Fiskenæsset region showing the distribution of the Fiskenæsset anorthosite complex (black), simplified compositional banding of gneisses and amphibolites (thin broken lines), and ice boundaries (dots). Based on unpublished GGU maps. An inset shows the location of Fiskenæsset within the Archaean complex of Greenland.

smaller inclusions in quartzo-feldspathic gneisses and amphibolites. Most of the gneisses appear to be derived from granitic intrusions younger than the Fiskenæsset complex (Myers, 1975a), and the amphibolites are mainly derived from basic volcanic rocks older than the complex (Kalsbeek & Myers, 1973; Escher & Myers, 1975). The anorthosite outcrops appear to be disrupted fragments of a single or small number of layered igneous sheets. They are most abundant in a belt 50 km wide which extends for nearly 100 km from the coast west of Fiskenæsset, eastwards to the inland ice cap (fig. 1).

The region shows a long history of intrusion, deformation and metamorphism, summarised by Kalsbeek & Myers (1973). Zircons from one of the youngest granite intrusions have given a U-Pb concordia age of 2835 ± 10 m.y. (Pidgeon *et al.*, 1975), and a late metamorphic event shows a Pb/Pb whole rock isochron age of 2850 ± 100 m.y. (Black *et al.*, 1973). These ages date some of the youngest events in the geological history and provide a minimum age for the Fiskenæsset complex which is one of the oldest rock groups.

There are regional variations in the amount of deformation, metamorphism and disruption by granitoid intrusions which the Fiskenæsset complex has suffered. The large outcrops in the eastern part of the region (fig. 1, locality A) are extensively disrupted by the intrusion of large volumes of granitoid material, whereas the thinner outcrops in the west of the region (fig. 1, locality B) are less disrupted by



Anorthosite unit
Upper leucogabbro unit
Middle gabbro unit
Lower leucogabbro unit
Ultramafic unit
Lower gabbro unit
Dolerite
Granite and granodiorite gneiss
70 Dip and strike of main foliation
Ice
A
B
63°15′
50°
0
2km
500 m
0
F1
F2

granitoid intrusions but are generally strongly deformed, disrupted by thrusts and faults, and are locally recrystallised with granulite facies assemblages. The igneous stratigraphy and primary structures and minerals of the complex are best preserved in the central part of the region at Majorqap qâva (fig. 1; Myers, 1973), and in outcrops to the south (fig. 1, localities C & D) briefly described by Walton (1973).

Majorqap qâva outcrop

The Majorqap qâva anorthosite outcrop is sub-rectangular in plan, 7 km long and 5 km wide, and is incised by a valley 1000 m deep. In three-dimensions the anorthosite sheet forms a basin inclined to the south-east (fig. 2). The outcrop pattern shows the interference of three sets of folds with axial surfaces at high angles to each other (fig. 3). The first major fold (F1) is a recumbent isoclinal syncline which was refolded into a tight synform (F2) with south-easterly dipping axial surface. These structures were refolded by open folds (F3) with sub-vertical axial surfaces trending NW–SE.

The major stratigraphy of the Majorqap qâva outcrop is described with emphasis on the primary macroscopic igneous features which are abundantly preserved, and

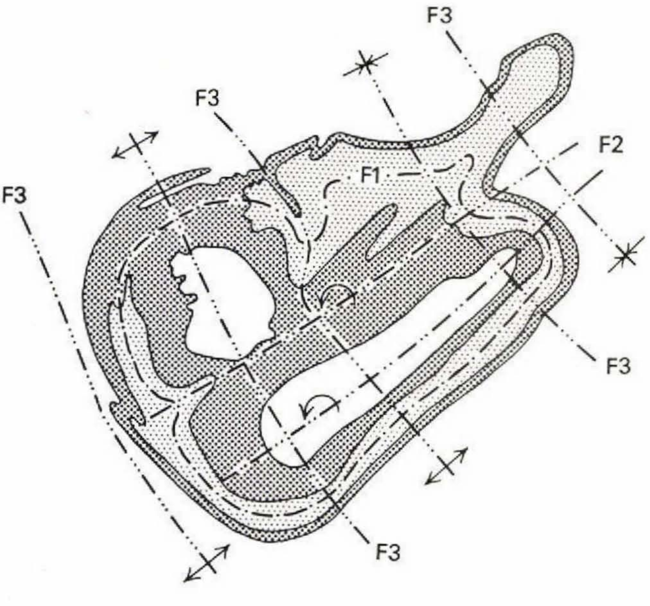


Fig. 3. Outline of the Majorqap qâva outcrop showing fold traces F1, F2 and F3. Leucogabbro and gabbro – dense stipple, anorthosite – open stipple.

← Fig. 2. Simplified geological map and section of the Majorqap qâva outcrop of the Fiskenæsset anorthosite complex.

conclusions are drawn from fieldwork about the igneous crystallisation history. The geochemistry of these rocks is briefly discussed by Myers (1975b). These accounts supersede a preliminary note on the Majorqap qâva outcrop given by Myers (1973) before mapping was completed and the structure and stratigraphy of the outcrop were elucidated.

STRATIGRAPHY

The generalised stratigraphy of the Majorqap qâva outcrop is shown on fig. 4, and details of the succession are summarised on Table 1. The terms used to describe the magmatic sediments follow the definitions proposed by Jackson (1967).

The outcrop is made up of six major igneous units, each composed of a large number of layers formed by crystal deposition. Mineral-graded layers occur within all the major units but most layers are isomodal and the composition and colour index of most rocks fall into narrow ranges: anorthosite <5 % mafics, leucogabbro 15 to 30 % mafics, gabbro 45 to 55 % mafics, and ultramafic rock >95 %

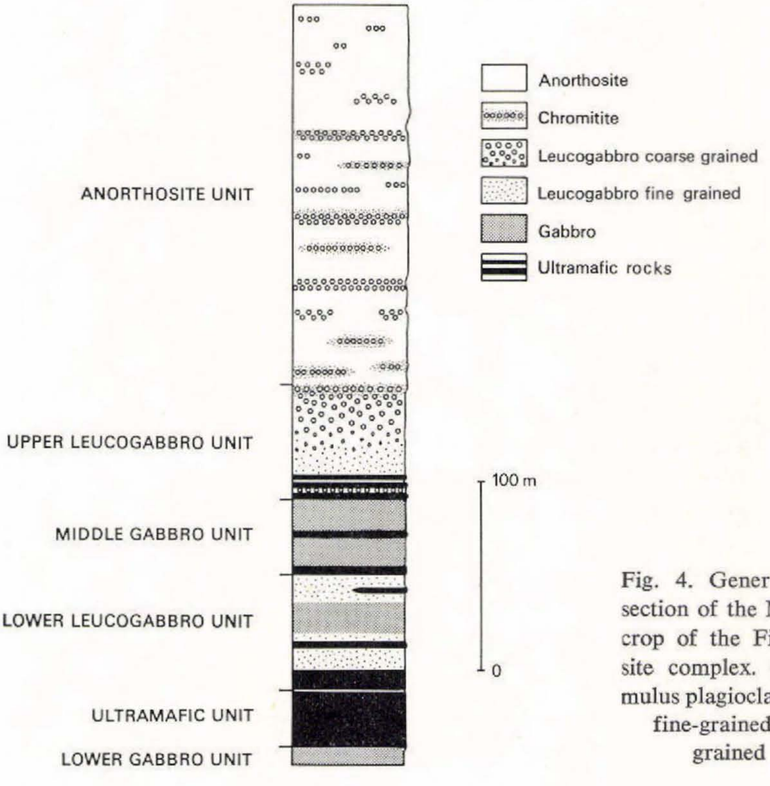


Fig. 4. Generalised stratigraphic section of the Majorqap qâva outcrop of the Fiskenæsset anorthosite complex. (Grain size of cumulus plagioclase in leucogabbro: fine-grained <2 cm, coarse-grained 2 to 10 cm).

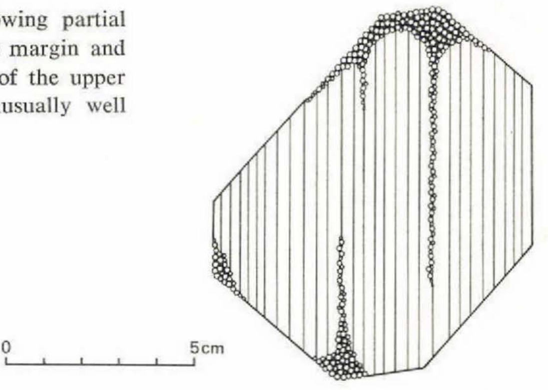


Fig. 5. Cumulus plagioclase crystal showing partial recrystallisation at pressure points on the margin and along twin planes. From the upper part of the upper leucogabbro unit; typical except for unusually well developed crystal faces.

mafics. Most rocks are composed of plagioclase and hornblende with various minor amounts of mica. Ultramafic layers mainly consist of hornblende, olivine, pyroxene, spinel and magnetite.

Although igneous textures and structures are widely preserved, most rocks were either partly or completely recrystallised during metamorphic and tectonic events which followed the primary crystallisation of the igneous complex. Igneous mineral assemblages are completely preserved in only a few places but for ease of description igneous rock names are used without the prefix 'meta', regardless of the degree of metamorphic recrystallisation.

Many large crystals, of which plagioclase is the most widespread, occur within coarse-grained metamorphic mineral assemblages showing a variety of intensities of development of tectonic fabrics. Although similar large crystals were formerly thought to be metamorphic porphyroblasts (Windley, 1967), they are here considered to be primary igneous crystals because they occur most abundantly where the rocks are least deformed and igneous textures are best preserved. Some have well developed crystal faces, and coarse-grained metamorphic mineral assemblages can be seen in various stages of growth around their margins and along twin planes (fig. 5).

The overall igneous textures and kinds of crystal layering structures suggest that the rocks mainly originated as igneous cumulates, but because most cumulus crystals have metamorphic rims, postcumulus overgrowth and postcumulus replacement of cumulus crystals, equivalent to diagenetic processes in sedimentary rocks, can seldom be recognised. The distribution of the surviving cumulus minerals within the layered intrusion is shown in fig. 6.

Lower gabbro unit

This unit is a 10 m thick layered sequence of gabbro, leucogabbro and melanogabbro. The rocks are strongly deformed and most consist of a post-tectonic

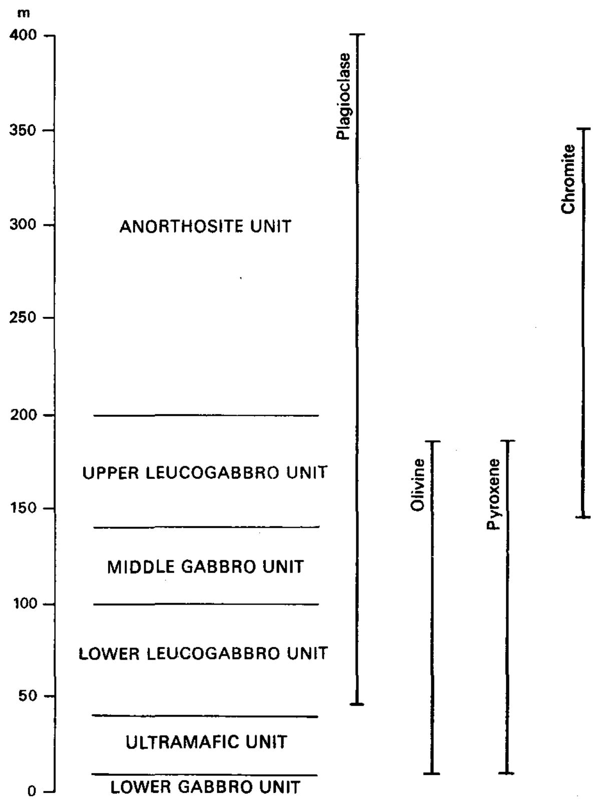


Fig. 6. Distribution of existing cumulus minerals.

metamorphic mosaic of plagioclase and hornblende. The lower part of the unit is intruded by sheets of gneiss and its base and original thickness are unknown.

Ultramafic unit

The ultramafic unit lies conformably upon the lower gabbro and consists of layers of olivine cumulate, olivine-pyroxene cumulate and hornblende rock, which form nine mineral-graded cyclic sub-units. In many of the layers, cumulus and relict cumulus olivines are size-graded with sizes decreasing upwards from 1 cm to 1–2 mm in diameter. The basal sub-unit is hornblende rock which is overlain by the thickest olivine cumulate in the sequence.

Lower leucogabbro unit

The base of the unit is marked by an olivine cumulate layer up to 8 m thick which grades upwards into layers of hornblende rock (3 m), gabbro (5 m), and leucogabbro. It is the lowest of a sequence of cycles in which plagioclase cumulates are dominant. Most of the unit consists of leucogabbro with relict equant cumulus plagioclase (An 86–78), 1 to 5 mm in diameter, and recrystallised postcumulus hornblende (fig. 7, and Myers, 1973, p. 48, fig. 11). Many layers are mineral-graded on the scale of a few centimetres to a few metres. Mineral-grading is marked by variations in the proportion of felsic and mafic minerals (figs. 8a, b), and some layers are size-graded with cumulus plagioclase decreasing in size upwards from 2 cm to a few millimetres in diameter (fig. 8i). Individual mineral-graded layers range from leucogabbro to gabbro and anorthosite with similar texture. A few discontinuous layers of ultramafic rock up to 2 m thick occur throughout the unit and each is mineral-graded from olivine-pyroxene-magnetite cumulate upwards to pyroxene-magnetite cumulate to hornblende rock, which grades upwards into gabbro and leucogabbro (fig. 8c). Some ultramafic layers contain minor monomineralic layers of olivine and magnetite-spinel up to a few centimetres thick (fig. 8h).

Middle gabbro unit

The middle gabbro unit is mostly made up of recrystallised plagioclase-hornblende ± diopside rocks with relict equant and tabular plagioclase crystals (An

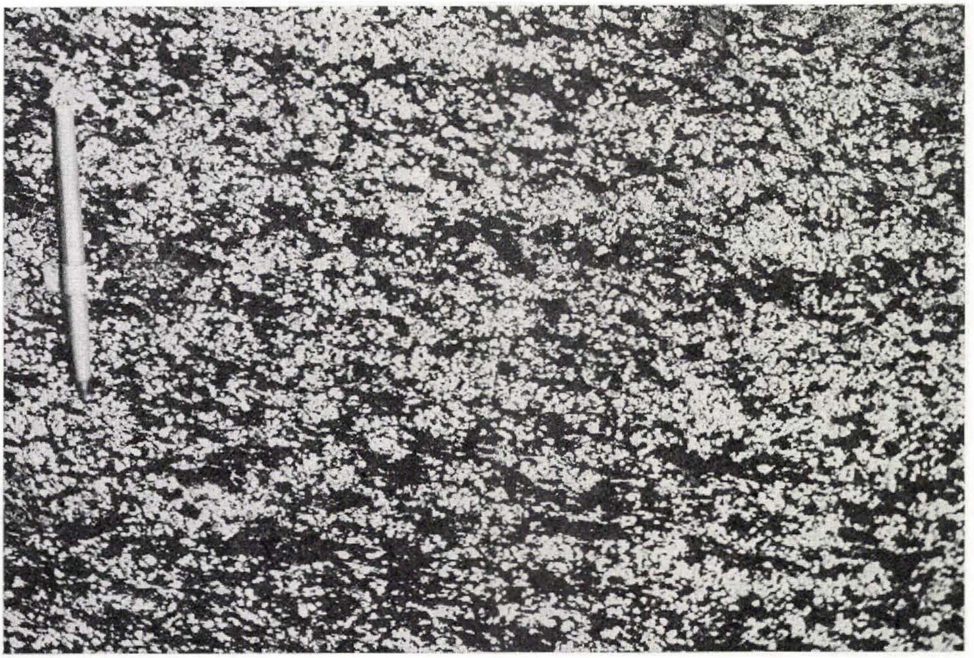


Fig. 7. Relatively fine-grained leucogabbro typical of the lower leucogabbro unit, showing relict equant cumulus plagioclase crystals and interstitial hornblende (? after intercumulus pyroxene).

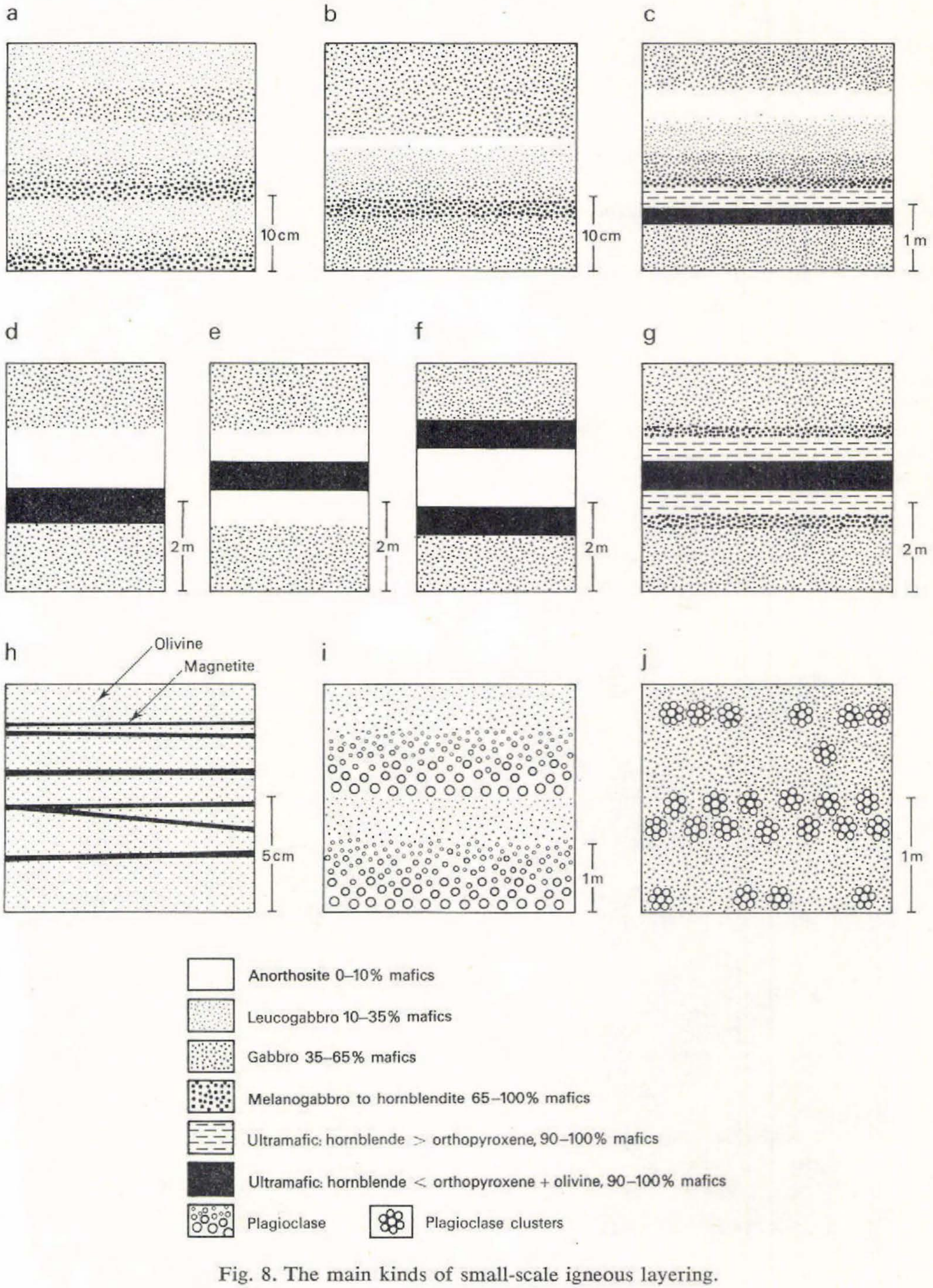


Fig. 8. The main kinds of small-scale igneous layering.

98–90). In some places the base is marked by a mineral-graded olivine-pyroxene cumulate layer up to 5 m thick. The rest of the lower sub-unit 4.1 (Table 1) is gabbro which is either uniform or possesses large numbers of centimetre-scale mineral-graded layers which range from melanogabbro through gabbro to leucogabbro (fig. 8a). These layers are persistent for long distances but in general the grading is weakly defined.

Sub-unit 4.1 is overlain by an olivine-pyroxene cumulate layer 2 m thick (sub-unit 4.2). In some places this layer has a sharp basal contact against uniform gabbro (fig. 8c, d) whereas in other places this contact is gradational from gabbro through melanogabbro (fig. 8g). Olivine is generally absent from the top few centimetres of the ultramafic layer which grades into hornblende rock, and this is overlain by anorthosite up to a metre thick (fig. 8 c). In some places there is hardly any mineral-grading within the ultramafic layer, but the ultramafic layer is associated with a layer of anorthosite in any of the combinations shown in figs. 8d, e and f.

The gabbro of sub-unit 4.3 contains mineral-graded layers typically 10 to 15

Fig. 9. Mineral-graded layers in uniform gabbro (sub-unit 4.3), made up of recrystallised plagioclase and hornblende.

cm thick, spaced at intervals of 50 to 100 cm in uniform gabbro (fig. 9). Many layers are trough shaped, they occur sporadically but are generally concentrated in vertical columns; cross-layered, mineral-graded layers were only seen in a few places. The graded layers generally have a sharp base above uniform gabbro and grade upwards from hornblende rock through melanogabbro and gabbro to leucogabbro or anorthosite which has a sharp contact with the overlying uniform gabbro (fig. 8b). The mineral-grading is better developed than in the lower part of the middle gabbro unit and individual graded layers are thicker but of more limited lateral extent.

The relict igneous texture of the upper part of the gabbro unit (sub-unit 4.4) is slightly coarser grained than the lower part, and scattered relict plagioclase laths occur up to 2 cm long. In a few places, sub-unit 4.4 also contains small inclusions of leucogabbro. They are generally rounded aggregates 5 to 20 cm in diameter of equant plagioclase crystals 1 to 5 cm in diameter, similar to those which form a continuous layer at the base of the upper leucogabbro unit. They occur either

Table 1. Stratigraphy of the Fiskenæsset anorthosite complex at Majorqap qâva

Units	Sub-units		General thickness in metres
6 Anorthosite unit 200 m		Anorthosite with schlieren of leucogabbro (fig. 14) and plagioclase-grossularite, and discontinuous layers of leucogabbro and chromitite. Leucogabbro schlieren are evenly distributed; plagioclase-grossularite schlieren and leucogabbro and chromitite layers are unevenly distributed but there is no systematic large scale lithological variation.	
5 Upper leucogabbro unit 60 m	5.4	Leucogabbro, plagioclase-chromite cumulate with a matrix of hornblende and biotite. Cumulus plagioclase is 5 to 10 cm in diameter.	10
	5.3	Leucogabbro, plagioclase cumulate with a matrix of hornblende (figs. 11 & 12). Cumulus plagioclase is 2 to 10 cm in diameter.	35
	5.2	Leucogabbro, plagioclase cumulate with a matrix of leucogabbro. Cumulus plagioclase is 2 to 5 cm in diameter.	5
	5.1	Leucogabbro, plagioclase-aggregate cumulate with 20 cm diameter aggregates of plagioclase crystals 1 to 5 cm in diameter in a matrix of plagioclase and hornblende, interlayered with olivine-pyroxene cumulate channel deposits. The base of the sub-unit is marked by a mineral-graded olivine-pyroxene cumulate layer (fig. 8c).	10

Units	Sub-units		General thickness in metres
4 Middle gabbro unit 40 m	4.4	Uniform gabbro, plagioclase-?pyroxene cumulate with inclusions of leucogabbro (figs. 8j & 10) and scattered tabular plagioclase crystals up to 2 cm long.	8
	4.3	Uniform gabbro, plagioclase-?pyroxene cumulate with sporadic, well defined mineral-graded troughs (figs. 8b & 9).	15
	4.2	Mineral-graded olivine-pyroxene and plagioclase cumulate layers (figs. 8c, d, e, f & g).	2
	4.1	Uniform gabbro, plagioclase-?pyroxene cumulate with widespread poorly defined mineral-graded layers (fig. 8a). In some places the base is marked by a mineral-graded olivine-pyroxene cumulate layer up to 5 m thick.	15
3 Lower leucogabbro unit 50 m	3.4	Leucogabbro, plagioclase cumulate with cumulus plagioclase mostly 1 to 5 mm in diameter but locally up to 2 cm in diameter. In some layers plagioclase is size-graded, and many layers are mineral-graded from leucogabbro to anorthosite (figs. 8a, b, h & i).	20
	3.3	Uniform gabbro, plagioclase-?pyroxene cumulate with cumulus plagioclase 1 to 5 mm in diameter.	10
	3.2	Leucogabbro, plagioclase cumulate with cumulus plagioclase mostly 1 to 5 mm in diameter (fig. 7) but locally up to 2 cm in diameter. In some layers plagioclase is size-graded and many layers are mineral-graded (figs. 8a, b & i).	20
	3.1	Mineral-graded sequence of olivine, olivine-pyroxene, plagioclase-?pyroxene and plagioclase cumulates (fig. 8c).	10
2 Ultramafic unit 30 m		Nine mineral-graded cycles of olivine cumulate each followed by olivine-pyroxene cumulate and hornblende rock.	
1 Lower gabbro unit 10 m		Uniform gabbro with some mineral-graded layers ranging from leucogabbro to melanogabbro.	

as scattered isolated inclusions or in layers one or two aggregates thick (figs. 8j and 10). A smaller number of angular fragments of leucogabbro with similar grain size also occur but are more irregular in size and distribution than the rounded aggregates.

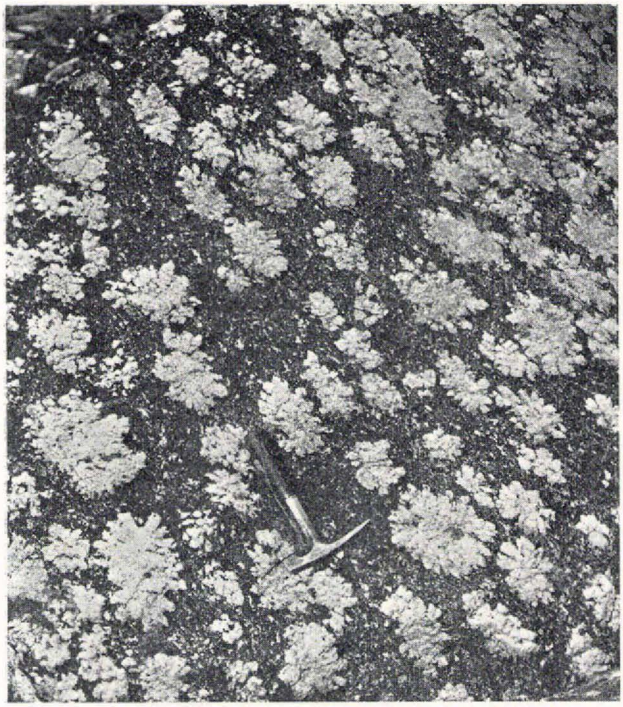


Fig. 10. A crystal-aggregate cumulate; aggregates of plagioclase crystals near the top of the middle gabbro unit (sub-unit 4.4.), viewed normal to the layering surface.

Upper leucogabbro unit

The upper leucogabbro unit is dominated by leucogabbro with equant cumulus plagioclase crystals 2 to 10 cm in diameter in a matrix of hornblende and biotite. Large numbers of cumulus plagioclase crystals are only partly recrystallised whereas most hornblendes and biotites are completely recrystallised. Most igneous plagioclase crystals show normal zonation from cores of An 86 to rims of An 80 (R. G. Platt, pers. comm. 1974) and polysynthetic twinning with thick lamellae. They are pale green in colour because of numerous small inclusions of green hornblende. They also contain a smaller number of inclusions of chromite, green spinel, rutile, apatite, and pale brown mica. During metamorphic recrystallisation, plagioclase crystals were replaced by a mosaic of smaller equigranular plagioclase crystals of similar composition, but free of inclusions. Igneous plagioclase crystals in the lower leucogabbro and anorthosite units are similar to those of the upper leucogabbro unit.

An ultramafic layer 1 m thick occurs at the base of the upper leucogabbro unit and is overlain by a thinner layer of anorthosite (fig. 8c). This is overlain by aggregates 20 cm in diameter of equant cumulus plagioclase crystals 1 to 5 cm in diameter. In some places these crystal aggregates are overlain and interlayered with ultramafic, olivine cumulate trough-shaped layers, each 1 to 3 m thick.

Generally between one and five major ultramafic layers occur and are mineral-graded with upper and lower parts rich in orthopyroxene, hornblende, chromite and spinel, and a central portion rich in equant olivine crystals 3 to 5 mm in diameter (fig. 8g). Some ultramafic layers are overlain by a thin layer of anorthosite. All these layers make up sub-unit 5.1 (Table 1).

The uppermost ultramafic layer of sub-unit 5.1 is overlain by a layer up to a few metres thick of equant plagioclase crystals 2 to 5 cm in diameter in a leucogabbro matrix consisting of equant plagioclase crystals 1 to 5 mm in diameter and interstitial hornblende (sub-unit 5.2). This is overlain by leucogabbro (sub-unit 5.3) composed of equant plagioclase crystals 2 to 10 cm in diameter in a matrix of hornblende with smaller amounts of biotite (figs. 11 and 12, and Myers, 1973, p. 49, fig. 12). Throughout the upper part of the upper leucogabbro unit (sub-unit 5.3) there is a steady upward increase in the size of cumulus plagioclase from 2 to 10 cm. Generally the grain size is relatively uniform in any one place.

Chromite occurs locally throughout the upper leucogabbro unit as a major cumulus mineral both in leucogabbro with plagioclase and hornblende and in

Fig. 11. Coarse-grained leucogabbro typical of the upper part of the upper leucogabbro unit (sub-unit 5.3) with relict cumulus plagioclase crystals and interstitial hornblende (? after intercumulus pyroxene).

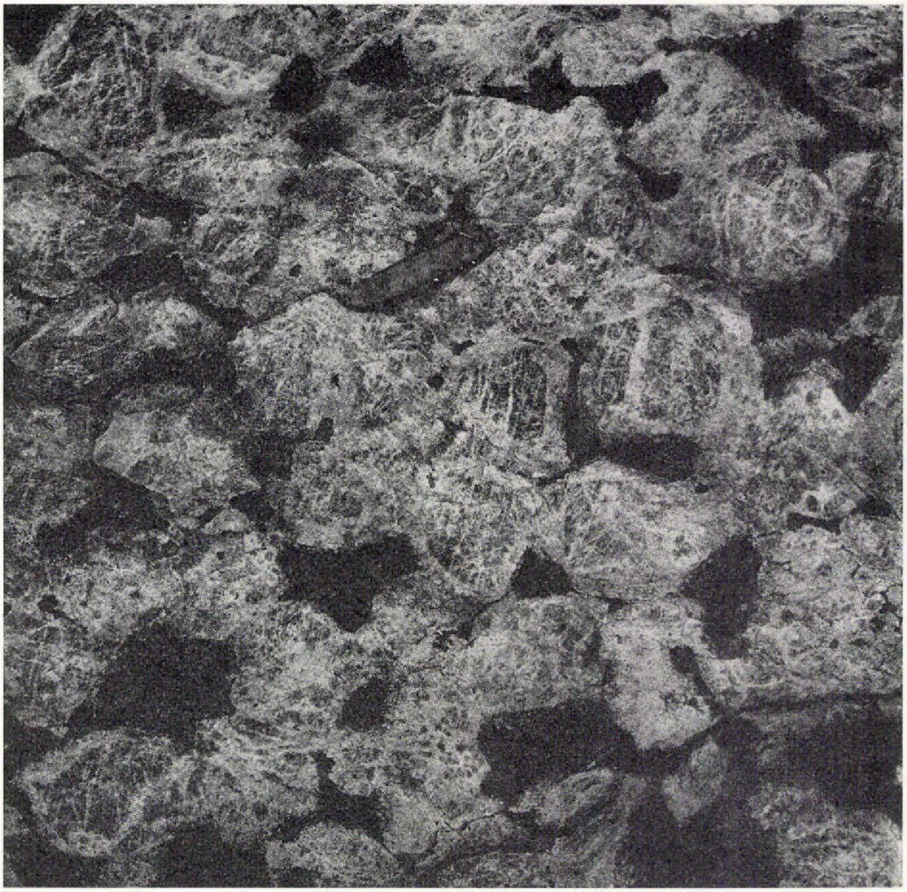


Fig. 12. Leucogabbro in the upper part of the upper leucogabbro unit (sub-unit 5.3) showing partly recrystallised cumulus crystals of plagioclase with interstitial hornblende. Dark cores of igneous plagioclase are enclosed by lighter, metamorphic plagioclase. Length of pen-knife is 9 cm.

ultramafic layers and troughs with cumulus olivine and orthopyroxene. It is most abundant in a layer 10 m thick (sub-unit 5.4) at the top of the upper leucogabbro unit where it occurs as a major cumulus phase with cumulus plagioclase crystals 10 cm in diameter in a matrix of hornblende and biotite.

Anorthosite unit

The anorthosite unit locally veins the top of the upper leucogabbro unit, cutting across both deformed and undeformed igneous layering.

The anorthosite unit is more strongly deformed than the lower three units and is more thoroughly recrystallised. It mostly consists of an equigranular mosaic of plagioclase 1 mm in diameter with minor amounts of hornblende and mica and contains schlieren of leucogabbro.

Where the anorthosite unit is little deformed or recrystallised it consists of equant plagioclase crystals of various sizes up to 10 cm in diameter, irregularly scattered in an even grained matrix of equant plagioclase crystals 1 to 5 mm in diameter with various small amounts of biotite and hornblende. The interstitial mafic minerals are locally concentrated to form evenly distributed, irregularly shaped patches of leucogabbro (fig. 13). The leucogabbro patches contain irregularly distributed equant plagioclase crystals, similar to those in the intervening anorthosite patches, in an even-grained aggregate of equant plagioclase 1 to 5 mm in diameter with interstitial hornblende. In most of the unit the leucogabbro patches are strongly deformed and are schlieren (fig. 14).

There does not appear to be any major systematic lithological variation within the anorthosite unit. A small number of plagioclase-grossularite lenses and thin discontinuous layers of plagioclase and plagioclase-chromite cumulates occur but are unevenly distributed throughout the unit. The plagioclase and plagioclase-chromite cumulate layers consist of equant plagioclase crystals generally of uniform size 2 to 5 cm in diameter, equant chromite crystals up to 1 mm in diameter and interstitial biotite and hornblende.

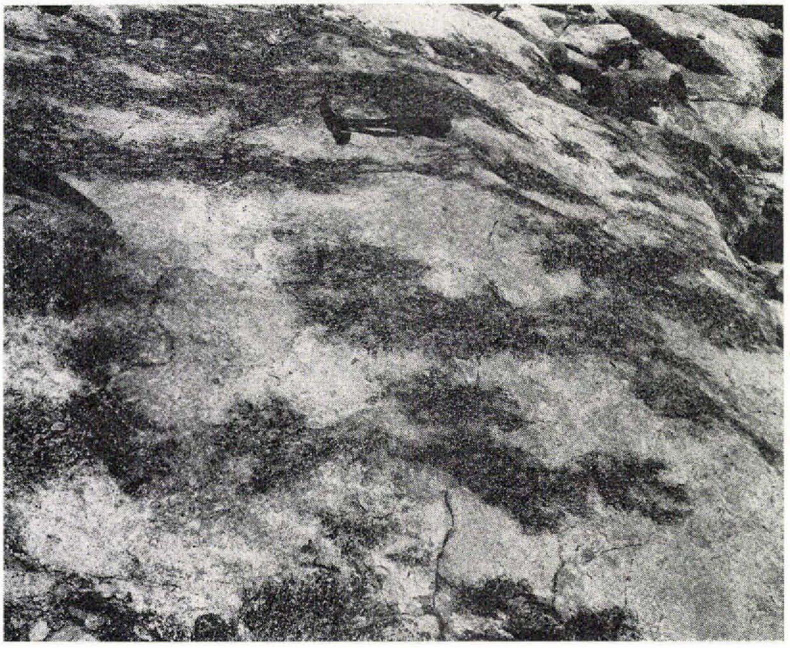


Fig. 13. Relatively little deformed patches of leucogabbro in anorthosite, typical of low deformation zones within the anorthosite unit.

Fig. 14. Strongly deformed patches of leucogabbro forming schlieren, typical of high deformation zones within the anorthosite unit.

REGIONAL COMPARISONS

A field study of all the major anorthosite outcrops of the Fiskenæsset region (fig. 1) (Myers, unpublished) shows that the anorthosite succession at Majorqap qâva is incomplete and lacks the lowest and highest parts of the intrusion (Table 2). The lower gabbro unit is better preserved in some other places than at Majorqap qâva; it occurs up to 50 m thick and locally preserves layers of leucogabbro and gabbro with relict cumulate textures. It is underlain by amphibolite which preserves relict pillow lava and pyroclastic structures in a few places. The ultramafic unit is also better preserved in a few other places but the sequence of rock types is similar to that at Majorqap qâva. The igneous features of the lower leucogabbro, gabbro and upper leucogabbro units appear to be best preserved at Majorqap qâva although these units are also well preserved at locality D, fig. 1.

In many places, anorthosite similar to the anorthosite unit at Majorqap qâva is overlain by garnet anorthosite or garnet leucogabbro up to 50 m thick. In a few places (locality E, fig. 1) this is overlain by an upper gabbro unit, about 50 m thick, which contains abundant magnetite and consists of mineral-graded layers of gabbro, leucogabbro and melanogabbro, with some layers of olivine-pyroxene-magnetite and plagioclase-magnetite cumulates. This unit is overlain by amphibolite, probably derived from volcanic rocks. At locality D, fig. 1, similar amphibolite locally preserves relict pillow lava and pyroclastic structures (Escher & Myers, 1975) and lies directly upon garnet leucogabbro at the top of the anorthosite unit.

Table 2. Correlation of stratigraphy of the Fiskenæsset anorthosite complex

Complete succession		Majorqap qâva		Qeqertarssuatsiaq		
Units	General deformed thickness in metres	Units	General deformed thickness in metres	Zones Windley (1971)	Windley (1973)	Maximum thickness in metres
				10 Pyroxene amphibolite	(metavolcanics)	
7 Upper gabbro	50			9 Ultramafic group	(grouped with metavolcanics)	50
				8 Garnet anorthosite		75
6 Anorthosite	250	6 Anorthosite	200	7 Hornblende chromitite		20
				6 Anorthosite		130
5 Upper leucogabbro	60	5 Upper leucogabbro	60	5 Ophitic gabbro	(leucogabbro)	250
4 Middle gabbro	40	4 Middle gabbro	40	4 Mafic gabbro	(dark gabbro)	60
3 Lower leucogabbro	50	3 Lower leucogabbro	60	3 Lower layered group	(leucogabbro)	100
2 Ultramafic unit	40	2 Ultramafic unit	30	2 Ultramafic group		100
1 Lower gabbro	50	1 Lower gabbro	10	1 Pyroxene amphibolite	(metavolcanics)	200

The anorthosite outcrops on Qeqertarssuatsiaq (locality B, fig. 1) described by Windley *et al.* (1973) seem to be typical of the western outcrops of the Fiskenæsset complex. They are generally more strongly deformed than elsewhere and are disrupted by thrusts sub-parallel with the igneous layering. Chromite appears to be restricted to one or a small number of layers in the upper part of the anorthosite unit on Qeqertarssuatsiaq (Windley *et al.,* 1973) but to the east, chromite is of widespread but sporadic occurrence throughout the upper leucogabbro and anorthosite units.

COUNTRY ROCKS

The Majorqap qâva outcrop is enclosed by pegmatite-banded gneiss derived from granodiorite which is younger than, and intrusive into, the anorthosite complex. The gneiss immediately adjacent to the anorthosite complex is more strongly deformed than gneiss further away, and is blastomylonite. The Majorqap qâva outcrop may partly owe its relatively fine state of preservation to the cushioning effect of this enclosing gneiss which was more ductile and absorbed a greater amount of subsequent deformations. In other places, where the anorthosite complex is bordered by amphibolite, the anorthosite complex is generally more strongly deformed than at Majorqap qâva.

Most contacts between the metavolcanic amphibolites and the anorthosite complex are concordant or tectonic, but it was generally assumed that the anorthosite complex intruded the amphibolite units (Kalsbeek & Myers, 1973). The clearest intrusive contact of the anorthosite was seen at locality D (fig. 1) where the adjacent amphibolite contains relict pillow lava structure (Escher & Myers, 1975). The deformed pillow lava is locally veined by anorthosite and small blocks of it occur up to a few metres below the top contact of the anorthosite unit.

Most of the amphibolite units are made up of hornblende-plagioclase rocks with granoblastic textures. They are generally massive, or show poorly defined thin discontinuous compositional banding, or contain oblate ellipsoids of leucocratic amphibolite in a matrix of melanocratic amphibolite.

Where these amphibolites are least deformed they extensively preserve pillow lava, pillow lava breccia and agglomerate structures, and contain large numbers of thin amphibolite dykes and sills, and metamorphosed gabbroic and ultramafic sills. In some places magnesia and alumina-rich rocks with anthophyllite and quartz and smaller amounts of cordierite, staurolite and sillimanite are interbedded with the deformed pillow lava, and may represent impure cherts and sediments derived from volcanic debris. The deformed pillow lavas and associated amphibolites are mainly oceanic tholeiite in composition (C. R. L. Friend, pers. comm., 1974).

Although the amphibolite units were formerly thought by Windley *et al.,* (1973) to represent a cover succession lying on a basement of the quartzo-feldspathic gneisses, no criteria have yet been seen in the Fiskenæsset region by which to distinguish such a basement from the widespread gneisses. In a large part of the region the gneisses can be seen to be derived from granitoid intrusions younger than the amphibolite and anorthosite units (Myers, 1975a). No evidence has yet been seen of any quartzo-feldspathic gneisses older than the anorthosite and amphibolite units. A few amphibolite dykes cut most of the gneiss types of the Fiskenæsset region as well as the amphibolite units and the anorthosite complex and so here they cannot be used to subdivide the gneisses as has been done in the Godthåb area 100 km to the north (McGregor, 1973).

DISCUSSION AND CONCLUSIONS

The igneous textures and kinds of crystal layering structures indicate that the rocks of the Fiskenæsset complex at Majorqap qâva are igneous cumulates. Mineral assemblages in the best preserved rocks are mixtures of igneous and metamorphic crystals. Many cumulus minerals have partly survived but their rims are generally metamorphic and so different kinds of postcumulus magmatic growth cannot be distinguished. Most interstitial minerals between relict cumulus crystals appear to be metamorphic. With these reservations, Table 3 shows the cumulus crystals which are preserved in the main rock types and the inferred original cumulus and intercumulus assemblages.

Hornblende has only been seen as a cumulus mineral in crescumulate structures in late magmatic stage pipes which cut the layering of the leucogabbro and gabbro units. Hornblende forms rims a few centimetres thick on both sides of most ultramafic layers, and in this situation is clearly a metamorphic mineral associated with local hydration of the margin of olivine-pyroxene cumulate ultramafic layers. In some leucogabbros, hornblendes between cumulus plagioclase crystals contain cores of older pyroxene. It is thus inferred that much of the hornblende in the rocks is metamorphic and may have formed by reaction between olivine and plagioclase or the breakdown of pyroxene. The main rock types may therefore have formed as one, two or three phase cumulates similar to those of other layered intrusions, such as the Bushveld and Stillwater complexes (Jackson, 1967), by the precipitation of plagioclase, olivine, pyroxene and chromite (Table 3).

The sequence of the middle gabbro, upper leucogabbro and anorthosite units represents a major cycle of precipitation with a two-phase plagioclase-?pyroxene cumulate followed by one-phase plagioclase cumulate with ?intercumulus pyroxene, and then by one-phase plagioclase cumulate with mainly ?intercumulus plagioclase. The lower leucogabbro unit may represent the second part of a major cycle of precipitation which began with the ultramafic unit composed of one and two-phase, olivine and olivine-pyroxene, cumulates and was followed by a one-phase, plagio-

Table 3. Cumulus and relict cumulus minerals in the main rock types and inferred initial cumulus and intercumulus assemblages

Rock name	Typical mineral content in percent	Existing cumulus and relict cumulus minerals	Inferred initial cumulus assemblage	Inferred initial intercumulus assemblage
Chromitite	plagioclase 75, chromite 10, hornblende 10, mica 5	plagioclase + chromite	plagioclase + chromite	pyroxene + plagioclase
Anorthosite	plagioclase 96, mica 2, hornblende 2	plagioclase	plagioclase	pyroxene + plagioclase
Leucogabbro	plagioclase 75, hornblende 20, mica 5	plagioclase	plagioclase	pyroxene + plagioclase
Gabbro	plagioclase 50, hornblende 50	plagioclase	plagioclase + pyroxene	pyroxene + plagioclase
Dunite	olivine 96, magnetite 2, spinel 2	olivine	olivine	olivine
Olivine-hornblende-pyroxene rock	olivine 45, pyroxene 32, hornblende 20, spinel 2, magnetite 1	olivine	olivine + pyroxene	pyroxene
Hornblende rock	hornblende 98, spinel 2		pyroxene	pyroxene

clase cumulate with ?intercumulus pyroxene. The lower gabbro unit may represent an earlier cycle of precipitation of two-phase, plagioclase-?pyroxene, cumulates.

Within each major cycle there were numerous minor cycles. In the ultramafic unit the cycles formed alternating sequences of olivine, olivine-pyroxene and ?pyroxene cumulates. In the gabbro unit there were two major sub-cycles of precipitation of plagioclase-?pyroxene cumulates separated by the precipitation of a thin olivine-pyroxene cumulate, ?pyroxene cumulate, plagioclase cumulate sequence. The columns of mineral-graded troughs in the upper part of the gabbro unit (sub-unit 4.3) indicate deposition in channels from currents. The occurrence of scattered irregular-shaped fragments of leucogabbro in sub-units 4.1, 4.3 and a 4.4 suggest that currents may also have stripped off fragments of the underlying leucogabbro and stirred them up with the plagioclase-?pyroxene cumulates.

The sub-cycles of precipitation were more complicated in the leucogabbro units. The lower leucogabbro unit is divided into plagioclase cumulate (sub-unit 3.2), plagioclase-?pyroxene cumulate (sub-unit 3.3) and plagioclase cumulate (sub-unit 3.4) sequences, during which there was intermittent precipitation of thinner sequences of olivine-pyroxene, ?pyroxene, and ?pyroxene-plagioclase cumulates.

A number of sub-cycles of thin olivine-pyroxene, ?pyroxene, ?pyroxene-plagioclase cumulates occur in the lower part of the upper leucogabbro unit (sub-unit 5.1) and are interlayered with plagioclase crystal-aggregate, plagioclase crystal and plagioclase-chromite cumulates. Most of these ultramafic layers are lenticular in cross-section and represent channel deposits interlayered with plagioclase cumulates. Locally cross-layering occurs on a minor scale between the ultramafic and plagioclase cumulates.

The magma was capable of precipitating both olivine and plagioclase cumulates. Because these rocks are interlayered on a fine scale, the layering is probably the result of variations in the style of precipitation rather than rapidly changing physiochemical conditions in the magma or influxes of different magmas. The deposition of ultramafic cumulates in channels suggests that currents were associated with this deposition. In some places a few plagioclase crystals occur within the upper parts of olivine-pyroxene cumulate layers. This, together with the fine interlayering of olivine-pyroxene and plagioclase cumulates, suggests the coevil precipitation of plagioclase, olivine and pyroxene. Some gabbro which escaped deformation and metamorphism shows olivine reacting with plagioclase to form pyroxene.

Perhaps at this stage the magma was precipitating both olivine and plagioclase with plagioclase in excess of olivine. If the olivine settled relatively slowly through a suspension of more slowly sinking plagioclase crystals then olivine might have reacted with plagioclase to form pyroxene which would have been deposited with the excess plagioclase and olivine as plagioclase-pyroxene and plagioclase-pyroxene-olivine cumulates. If however the newly precipitated batch of olivine and ?pyroxene travelled as a coherent body in a fast-moving downcurrent through the suspension of more slowly sinking plagioclase crytsals then reaction between olivine and plagioclase would have been minimal and a poorly sorted olivine-pyroxene cumulate could have been deposited in channels on top of the crystal pile below. The more slowly sinking plagioclase which was already near the bottom of the magma might in some cases have been incorporated into the top of the ultramafic cumulate as it came to rest in the channel.

Cumulus plagioclase in the upper leucogabbro unit (sub-unit 5.3) is generally well sorted and steadily increases in size upwards, suggesting relatively slow steady deposition and a decline in the activity of currents. Chromite was extensively deposited at the top of this unit (sub-unit 5.4) with the largest cumulus plagioclase crystals. This coincides with the transition from interstitial hornblende (?intercumulus pyroxene) to mainly interstitial (?intercumulus) plagioclase between cumulus plagioclase.

Cumulus plagioclase is generally poorly sorted in the anorthosite unit except where it was intermittently deposited in channels with cumulus chromite. Although the plagioclase in these channels is well sorted there is generally little separation of the chromite and plagioclase fractions into separate layers which suggests that they were deposited quickly from fast-flowing currents, similar to those which formed the ultramafic cumulate channels in the lower part of the upper leucogabbro unit.

The anorthosite complex was intruded into a sequence of sub-aqueous basic volcanic rocks interbedded with a small amount of sedimentary rocks probably derived by erosion from volcanic debris. Because of the extensive disruption of these rocks by younger granitoid intrusions and their distortion by later deformation, it is impossible to estimate the original thickness of the volcanic rocks or the original thickness of the anorthosite intrusion. No evidence of any older granitic crust has been recognised in the Fiskenæsset region, although it may be present in the Godthåb region, 100 km to the north (McGregor, 1973).

The metavolcanic amphibolites are mainly oceanic tholeiite in composition, similar to many modern ocean floor basalts, which suggests that at least part of the earth's mantle was then broadly similar to that at the present time. The layered anorthosite complex could therefore have been derived from a tholeiitic magma which, after precipitation of an ultramafic fraction, was intruded higher into the crust, perhaps in a number of stages.

The absence of major ultramafic bodies in the region suggests that if the anorthosite complex was derived by crystal fractionation from tholeiitic magma then the ultramafic residue was at sufficient depth below the complex not to have been brought to the surface during major deformation of the region, or that it sank back to the mantle, perhaps during the intrusion of the enormous volume of granitoid material which engulfs the anorthosite complex. Any alkali-rich fraction which would have formed during fractionation of the anorthosite complex from tholeiitic magma may be part of and indistinguishable amongst the flood of younger granitoid intrusions which make up most of the region.

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