GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 37

A CONTRIBUTION TO THE GEOLOGICAL INVESTIGATIONS IN THE REGION OF IVIGTUT, SW GREENLAND

BY

STEPHEN NEVILLE AYRTON

WITH 63 FIGURES IN THE TEXT
AND 19 PLATES

AVEC UN RÉSUMÉ EN FRANÇAIS

С РУССКИМ РЕЗЮМЕ

Reprinted from
Meddelelser om Grønland, Bd. 167, Nr. 3

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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CONTENTS

Abstract.

As part of the research project carried out by G. G. U., the study of the territory situated to the NW of Ivigtut, between the fjords of Tigssalûp ilua and Sermiligârssuk, was undertaken. This peneplain, where the effects of quaternary erosion, in particular glacial abrasion are important, is geologically part of the Canado-Greenlandic shield. Since the investigations of C. E. Wegmann (1938), the geological history of this region has been roughly divided into an orogenic phase, during which the Ketilidian chain was born, and a phase of tension with block-tectonics and emplacement of dykes (Gardar period). Recent studies have brought to light two intermediary periods, the Kuanitic period, when the intrusion of dolerites took place, and the Sanerutian period, during which transformation of the pre-existent rocks occurred, due to a rise of the thermal front.

During the Ketilidian period, a mountain chain was formed, in which one may distinguish a migmatized infrastructure and a suprastructure composed of an ectinite series. The principal differences between these two units are in structure and lithology. The macroscopic and microscopic petrology of these rocks is reviewed.

The suprastructure includes pelitic, basic, quartzo-feldspathic, ferruginous and magnesian schists, which have recrystallized in the first two greenschist subfacies according to F. J. Turner and J. Verhoogen (1960). The infrastructure is characterized by various gneisses (banded, streaky, homogeneous) of which only one member rises out of the ordinary, i.e. the gabbro-anorthosites; the origin of these curious rocks is strongly debated. The apparition of a garnet in these gneisses suggests a slightly deeper metamorphic facies. As a whole these rocks represent probably the transformation of the Arsuk group (C. E. Wegmann, 1938).

Rust-zones may have various origins. In the greenschists they are probably pyrite-bearing sedimentary layers. In the gneiss they are more often related to crush-zones.

Pegmatites are mainly of the simple quartzo-feldspathic type. Zoning, pinch-and-swell structure, ptygmatic microfolding are current phenomena. Complex pegmatites containing minerals of pneumatolytic or hydrothermal origin are less frequent. Most of these were probably formed by slow diffusion of acid material in zones of weakness.

Whether it be in the infrastructure or in the suprastructure, there exist lenses of ultrabasic rocks, especially serpentinites or talcschists. Reaction phenomena in a contact zone with a pegmatite are described. Several arguments are put forward in favour of the hypothesis of a sill emplaced in the fresh and water-filled sediments of the geosyncline.

All these rocks underwent intense folding which may be divided into three phases:

1) a N–S to NNE pre-migmatitic phase.
2) a major WNW migmatitic phase.
3) a NE to ENE mainly post-migmatitic phase.

There is no evidence of a considerable break between the different phases.

During the first one, small steep folds were formed, the style of which suggests a predominance of schistose material.

The second phase is characterized by the formation of a synclinal suprastructure and migmatitic up-doming in the infrastructure, resulting in big folds, more or less recumbent, separated by steep synclines. Metamorphism attained maximum intensity.

Where both phases were very active, crossfolding and wild-folding occurred. An example of the use of the Wulf-net in unravelling one of these problems is given.

The effects of the third phase are not very visible in this area since they involve semi-plastic refolding, twisting and bending on a very large scale. Shearing of the suprastructure may be the main result. Microclinization seems also to belong to this phase.

The result of Ketilidian tectonics is the individualization of a suprastructure and an infrastructure, separated generally by a structural break.

The polymetamorphic character of Ketilidian rocks is summed up, the various transformations through metamorphism succintly described, and the close relationship between migmatization and regional metamorphism affirmed.

Migmatization and its relationship to tectonics reveal some interesting features. A complete migmatitic front may be traced from infrastructure to suprastructure. The close association between its emplacement and the WNW folds is quite evident. The distribution of the migmatitic facies in the recumbent anticline, NNE of Angmassivît, demonstrates this fact particularly well. Migmatization and the second phase of folding are clearly contemporaneous. Where resistant barriers (quartzitic horizons) exist, the arrested migmatitic front is concordant with the primary bedding of the suprastructure.

Element migration and metasomatism are reviewed. It is shown that sodium has migrated farther than potassium, which remains localized in deep zones. Calcium migration accounts greatly for the formation of basic oligoclase, amphibole, calcite and epidote.

Hydrothermal veins and pellicles on joint-planes are frequent. Their main constituents are magnetite, biotite and chlorite.

During the Kuanitic period, three generations of tholeitic dolerites were emplaced in three distinct directions. Their width and density of distribution can vary considerably.

A rise in the thermal front characterizes the Sanerutian period. All the preexistent rocks undergo low-grade metamorphism. In particular, the Kuanitic Dykes are transformed into metadolerites, according to the process described by J. SUTTON and J. WATSON (1951). Migmatitic and metasomatic introduction of material is insignificant. Several fault-systems and crush-zones have been distinguished.

Absolute age determinations suggest correlation between the Sanerutian reactivation and the Nagssugtôqidian orogeny, the remains of which are to be found between Søndre Strømfjord and Disko Bugt, also on the W coast, but further N (A. BERTHELSEN, 1961).

The Gardar period begins by the emplacement of lamprophyric dykes. A comparison is established between these dykes and the hornblende-lamprophyres of the Skærgaard region on the E coast of Greenland. In both cases they derive from a basaltic magma enriched in volatiles (mainly alkali-compounds and H_2O).

The Brown Dykes constitute the most important group of the hypabyssal complex of the Gardar period. Three generations are distinguished, solely on the basis of their direction, which varies between ENE and NE, the first being that of the oldest dykes (BDo), the second, that of the last (BD2). Intrusion phenomena are noted: swarm, bayonet, "en échelon", disposition etc. Moreover, one observes variations of grain-size (chilled-margins, gabbro-pegmatites etc.), of texture (mainly ophitic), and of petrology (acid, basic segregations, "pegmatitoïdes", transversal variations; in composition, they go from quartz dolerites to troctolitic dolerites). They contain phenocrysts, xenocrysts, gneissic or anorthositic xenoliths. A few considerations on the very unlikely existence of a magmatic chamber with great horizontal extent are followed by the description of contact phenomena with effect on the encasing rock, a homogeneous gneiss, which is locally transformed into granophyre; the process is described with some detail.

The youngest member of this hypabyssal complex, a group of trachytes, displays quite a wide diversity. In fact this field denomination includes types going from undersaturated (phonolite, tinguaite) to oversaturated (calco-alkaline rhyolite). While a process of differentiation readily explains the petrogenesis of most of these dykes, in the case of a rock with free silica, a certain amount of contamination must have occurred.

Faulting has played a very important part in this period. Two main fault-systems determine the great WNW fjords and the lateral NNE fjords. The displacements of the major system are considerable. Moreover, there exist numerous other fractures of smaller extent.

Some rare pneumatolytic mineralizations are reviewed.

A great lapse of time separates the end of the Gardar and the emplacement of two generations of dolerites, more or less parallel to the coast. These hypabyssal rocks are to be compared to a similar swarm on the E coast. They are probably related to the Plateau basalts further N and came up through parallel fractures, caused by a (Tertiary?) coastal flexure.

Acknowledgements.

We would like to express our hearty thanks to Professors H. BADOUX and M. VUAGNAT for the support they have always given us throughout our studies and in particular during the accomplishment of this thesis. It is due to them that this study has been carried out in such agreeable and fruitful circumstances.

Whether it be with G. G. U. (Grønlands Geologiske Undersøgelse) or in the laboratory of the Geological Institute of the University of Lausanne, many people have given us their support, in particular Mr. K. ELLITSGAARD-RASMUSSEN, Director of G. G. U., to whom we owe the opportunity of conducting this study, Professor at the University of Aarhus, Dr. A. BERTHELSEN, formerly attached to G. G. U., thanks to whom a synthesis of the area was possible, and Dr. MARCEL BURRI, senior lecturer of the University of Lausanne, who guided our first steps in Greenland. To them go our foremost thanks.

We express our gratitude to all our companions with whom we worked, whether in the field or laboratory, for their helpful contribution, as well as to Miss E. PASCHE, secretary, and Messrs. G. MARGOT and R. DUNANT, assistants at the Geological Institute of the University of Lausanne.

PREFACE - TOPOGRAPHICAL FRAME

During the summer months of 1957 and 1958, we were given the opportunity to participate in the geological expeditions organized by G. G. U., in SW Greenland, with a view to the elaboration of the geological map of the area. The project, in which many geologists took part, began with the survey of the Ivigtut region, known for its cryolite occurrence. This map is now being submitted for publication. The territory that was attributed to us is situated in the northern part of the sheet, approximately 40 km to the NW of Ivigtut.

Our zone (Plate A and fig. 1), to be precise, extends from 61°22′5″ to 61°31′0″ n.l. Its northern frontier is the large fjord of Sermiligârssuk, the axis of which is NE; at its extremity is to be found the glacier of the same name: this outlet of the ice-cap is very active and continually sends forth icebergs.

Another natural frontier limits the area to the S, i.e. Tigssalûp ilua, the axis of which is E–W, with a length of about 30 km and an average width of 3–4 km. Our territory covers sheet D3 of the topographic map (scale 1:20,000[1]), to which one must add the SE corner of sheet E4 and the NE corner of sheet C3. To the E is sheet D4, mapped by our colleague, M. Weidmann, of the University of Lausanne; to the W, F. Jacobsen, from the University of Copenhagen, surveyed sheet D2.

Morphology.

(Pl. 10).

It appears that before glaciation, the peneplain had already reached an advanced stage. The plateau, in the full sense of the word, shows little variation in average altitude, which is between 400 and 700 m. Only to the NE do summits 850 and 890 m high attract attention, the height of the area being easily explained geologically. Cliffs are frequently observed, especially bordering Tigssalûp ilua. They are very abrupt and probably result from weathering along joint planes.

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[1]) The sample numbers which are to be found further on correspond with the classification of G.G.U., by whom the entire collection is held.

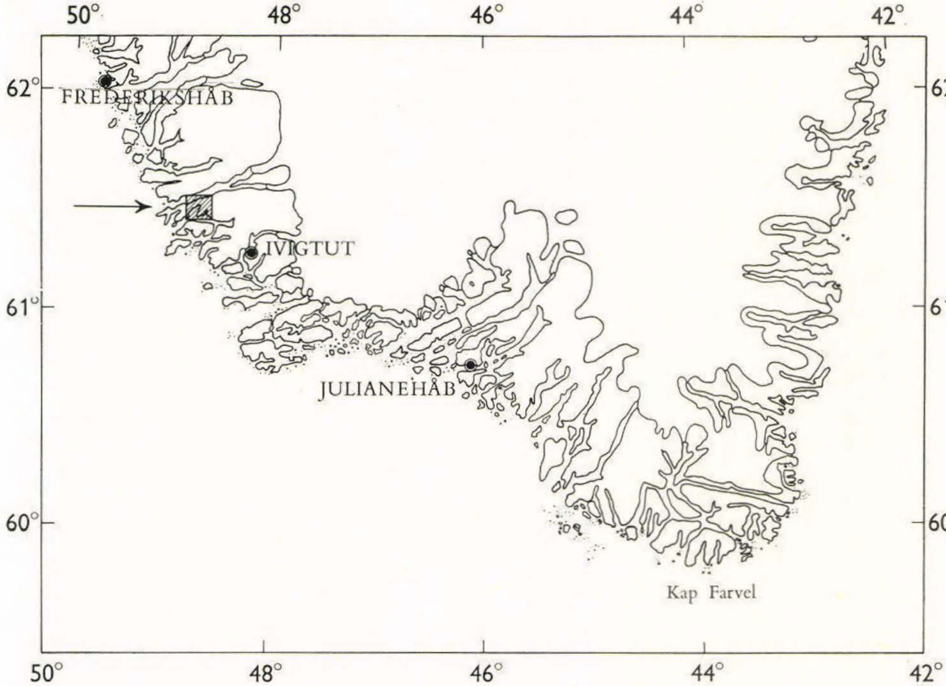


Fig. 1. The southern tip of Greenland and the location of the region under consideration.

While the coast of Sermiligârssuk is not very jagged, that of Tigssalûp ilua is deeply cut into by a series of little lateral fjords, more or less parallel, from 3 to 5 km long, about N10E in direction; they are closely related to geological phenomena, as we shall see further on. All except that of Kangerdlugssuaq, are prolonged by a valley—double in the case of Qerrulik—in which flows a torrent.

The hydrographic network is composed of a multitude of lakes, the smallest of which cannot be represented on the map; the largest, however, lake 470 m, covers a surface of about 10 square km. It is evident that water plays an important morphological role.

Alluvium nappes of various size cover the valleys. Small alluvial plains occur at Eqaluit, Angmassivît and the small bay west of Akuliarusiarssuk. These plains form deltas where they enter into the sea. At the junction of the two branches of Qerrulik valley, imbricated cones bear evidence of the variations in relative importance of the two systems. Alluvium deposits attain a thickness of about 10 m in the NE corner of the region, just before disappearing into a large bay.

West of Angmassivît, in the elliptical depression partially filled by a lake, as well as on the semicircular peninsula E of Eqaluit, very marshy ground shows cryoturbation symptoms (striped and sometimes

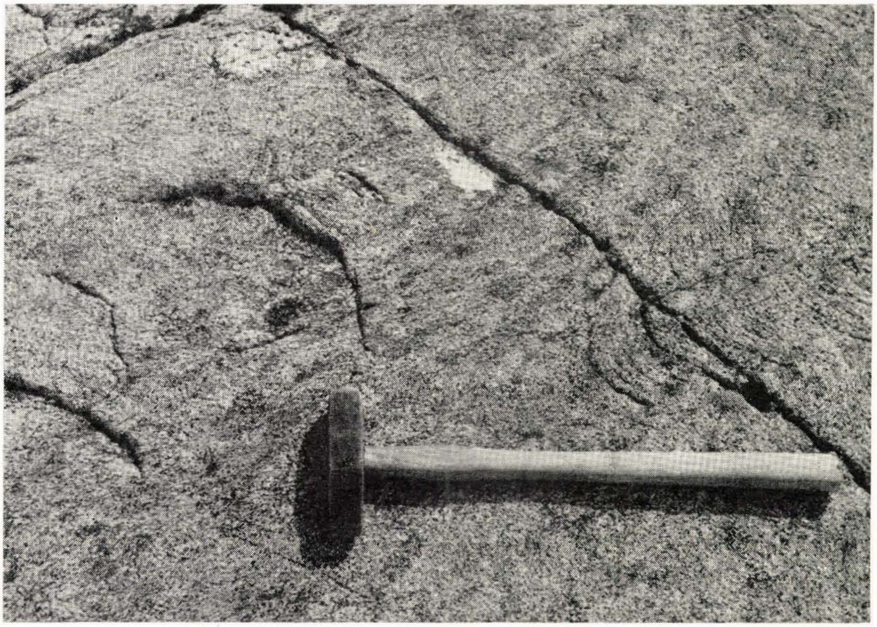


Fig. 2. Glacial grooves: to the left, crescentic gouges, to the right, crescentic fractures.

polygonal ground); they are also to be found here and there in the valley to the NE, where long, narrow lakes have formed.

Glacial activity has naturally been very important. In particular, it has overdeepened the pre-existent valleys (eroded by water), by enlarging and deepening them (H. Lister and P. S. Wyllie, 1957). The best example is found in the SE area, where the U-form of the valley is well defined.

The different periods of glaciation (R. F. Flint, 1948) are not visible in our region. Only the retreat of the glacier has left its ubiquitous mark. Near the front of the Sermiligârssuk glacier one may see, on the walls of the fjord, the old ice limits at an altitude of 50–60 m; they separate a light lower zone, from which the ice has recently receded, from an upper one, long since uncovered (A. Weidick, 1959).

Erratic blocks, about ten cubic m in volume, and important morainic deposits abound everywhere. The thickest accumulation of glacial material is to be found in the central part, SW of lake 470 m, where a veritable desert of blocks may be seen covering almost all the subjacent rock. But these blocks have not been carried a long way. Frost appears to have played a considerable role in their genesis, the fine material having subsequently been cleared away by water or by wind, another important agent of erosion.

However, the presence of foreign blocks bears witness to a much more important transport. One observes, especially on polished surfaces, frequent glacial stripes and grooves. They only indicate local movement from which one should not hurry to draw general conclusions. Fig. 2 shows two systems of grooves: to the left crescentic gouges, to the right crescentic fractures (R. F. Flint, 1957).

The quality of exposure is excellent, as vegetation is not abundant at an altitude approximately above 150 m.

The place names used on the map are all of native origin. Moreover, the same names occur frequently, as they relate to features of the coastal regions, the Greenlanders venturing but rarely into the interior. Besides, this area has in all probability never been visited. Only members of the Geodetic Survey of Greenland have passed through to establish triangulation points, generally situated on the coast or the clifftops; these have been combined with aerial photographs in order to set up the topographic map (scale 1:20,000), the basis for our geological survey.

General Geological Situation.

This territory is geologically part of the Canado-Greenlandic shield, of Pre-Cambrian age.

In his famous work on SW Greenland, "Geological Investigations in Southern Greenland" (1938), C. E. Wegmann had already established the chronology of the geological events of the area. It has served as a basis, as well as his pertinent observations, for subsequent studies. He divided the history of the country into two big cycles:

A. **The Ketilidian,** comprising two superposed stratigraphic units: the Sermilik group, essentially sedimentary, and above, the Arsuk group, mainly volcanic. These groups are folded, metamorphosed, gneissified, even granitized.

B. **The Gardar,** comprising, from the bottom up, the Igaliko sandstone (which now only exists in one locality, to the S), followed by a thick volcanic series, itself succeeded by the intrusion of numerous and various massifs (granites, syenites, essexites). During this period of tension, block-tectonics played an important role.

These two cycles are separated by a very long period of erosion.

C. E. Wegmann also postulates a Pre-Ketilidian cycle, which would be represented by the gneisses of the Ivigtut region (C. E. Wegmann 1939, 1948c).

The work of G.G.U. has brought to light the following chronology (A. Berthelsen, 1961):

A. **The Ketilidian,** still comprising the Sermilik and Arsuk series, characterized by folded, metamorphosed, gneissified and granitized rocks. The migmatitic front has risen to a more or less high level in the series, and its limit separates an infrastructure from a suprastructure, differentiated in particular by their tectonic style. Three stages of folding have been distinguished, but they are not visible everywhere. Emplacement of ultrabasic rock seems to have taken place at different epochs. There also forms late- to post-kinematic granite.

B. **The Kuanitic,** during which tension fractures developed, soon to be filled by basic rock. At least three generations of dykes were emplaced.

C. **The Sanerutian,** during which a general reactivation took place, transforming and sometimes deforming the Kuanitic Dykes. It accompanies the emplacement of large masses of granitic rocks.

D. **The Gardar,** as Wegmann describes it. A detailed chronology has been established, particularly through the analysis of the very important block-tectonics which separate the different dyke intrusions.

E. **The Post-Gardar,** represented by non-tectonized swarms of doleritic dykes. Although their age is not known, they appear to be clearly detached from the Pre-Cambrian cycles. A Tertiary age has been suggested.

The Pre-Ketilidian may exist solely in the form of pebbles (of granite, gneiss and crystalline schists) in the inferior levels of supracrustal Ketilidian rocks.

This chronology will serve as a plan for our description. Indeed, manifestations of these different periods are all to be found in our region.

A. **The Ketilidian.** We were able to distinguish two phases of folding with certainty. A third phase was deduced from a synthesis of the whole area (folding on a very large scale), and is difficult to identify in a restricted territory. Certain facts, nevertheless, seem to support this hypothesis. Metamorphism, migmatization, even granitization, exist in varying degrees. It is also possible to separate the suprastructure from the infrastructure. Some ultrabasic lenses seem to have been emplaced early in the Ketilidian period.

B. **The Kuanitic.** Intrusion of three systems of doleritic dykes. Block-tectonics.

C. **The Sanerutian.** Metamorphism and weak migmatization. Local reactivation. Transformation of the Kuanitic Dykes with slight local deformation.

D. **The Gardar.** Intrusion of several generations of dykes belonging to different petrographic families. Very important block-tectonics.

E. **The Post-Gardar.** Intrusion of two generations of doleritic dykes.

Summary. As part of the research project carried out by G. G. U., the study of the territory situated to the NW of Ivigtut, between the fjords of Tigssalûp ilua and Sermiligârssuk, was undertaken. This peneplain, where the effects of quaternary erosion, in particular glacial abrasion are important, is geologically part of the Canado-Greenlandic shield. Since the investigations of C. E. WEGMANN (1938), the geological history of this region has been roughly divided into an orogenic phase, during which the Ketilidian chain was born, and a phase of tension with block-tectonics and emplacement of dykes (Gardar period). Recent studies have brought to light two intermediary periods, the Kuanitic period, when the intrusion of dolerites took place, and the Sanerutian period, during which transformation of the pre-existent rocks occurred, due to a rise of the thermal front.

THE KETILIDIAN PERIOD

It is during this period that an old mountain chain was built, to which C. E. WEGMANN (1938) gave the name of "Ketilides". It is characterized by folded rocks that one may divide, in the Ivigtut region, into a migmatitic infrastructure and a metamorphosed but not migmatized suprastructure, comprising the ectinite series.

The relations between these two units are extremely interesting and will be studied mainly in the chapters on migmatization and tectonics. One may simply state that the principal differences reside in structure and petrology.

A. Description of the Ketilidian rocks.

Suprastructure and Infrastructure:

I. Macroscopic.

1. **The suprastructure.** Several bands of low-grade metamorphic schists are concentrated in the NW part of our region. The main one crosses the whole territory determining a deep depression; in the NE part, long lakes have formed. The width of this zone is quite constant, measuring about 500 m; its direction is slightly sinuous and forms an arch weakly convex towards the N.

The lithological composition of these rocks shows little variation. They are mainly chloritic and/or amphibolitic schists, with intercalations of a more quartzitic composition, and concordant and compact basic lenses. The predominant colour is dark green; from afar, this series contrasts clearly with the lighter gneiss.

The schists are practically everywhere vertical to sub-vertical (Fig. 3). Moreover, intense shearing has produced a certain amount of retrograde dynamometamorphism of the whole series, causing a cataclastic reduction of the grain-size. One may therefore call these schists phyllonites and diaphthorites.

Some rare pegmatites have reached and penetrated into this zone. They are nearly always concordant. This disposition may be due to the original emplacement or to ulterior shearing which has drawn out

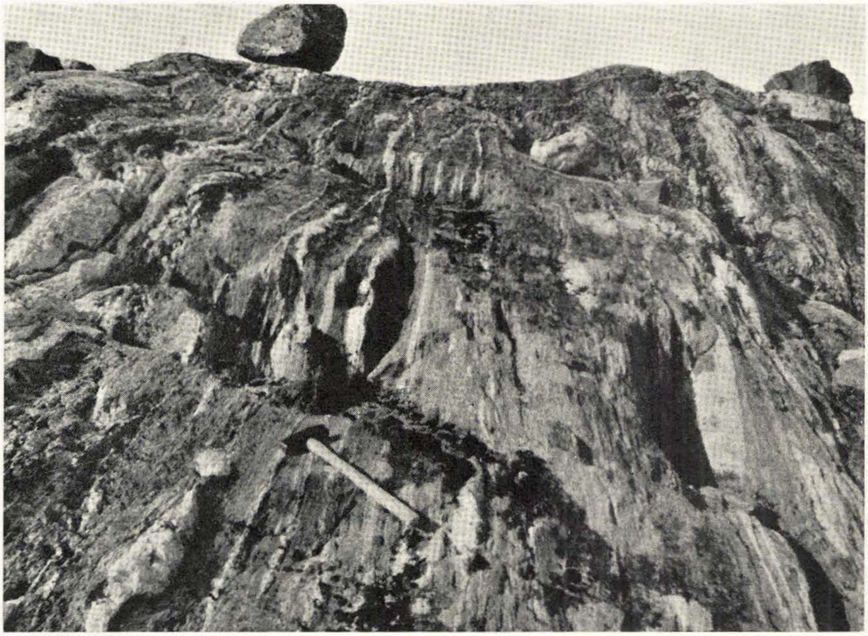


Fig. 3. Detail of the greenschists. Basic and quartzo-feldspathic beds alternate quite regularly.

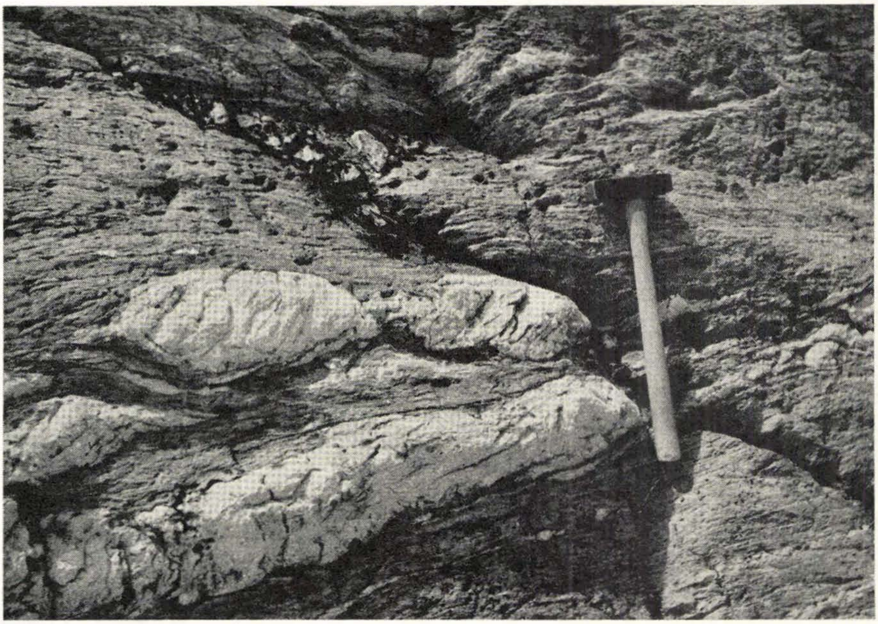


Fig. 4. Discordant pegmatites drawn out and boudinés in the suprastructure. The lenses thus formed appear to be concordant.

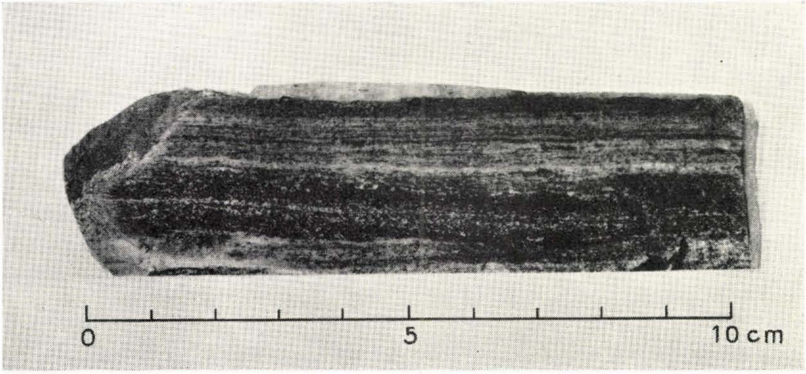


Fig. 5. Slightly migmatized greenschist, containing a great proportion of amphibole, some albite, epidote, and a little quartz, sphene, apatite, calcite, tourmaline and microcline. (No. 38486). Valley of Eqaluit.

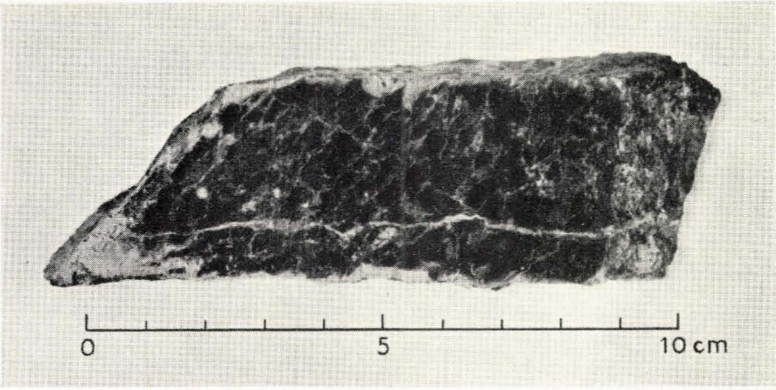


Fig. 6. Concordant amphibolite. Amphibole crystals form at least 80 % of the rock, the rest being made up of albite, microcline, quartz, epidote, chlorite and biotite. (No. 32844). Small peninsula on the S coast of Sermiligârssuk.

these veins in concordant lenses (Fig. 4). Moreover, practically all pre-existent structures have been erased by these violent movements.

In spite of the fineness of grain-size which nearly always prevented us from distinguishing the minerals in the field, we appropriated this zone to the metamorphic facies of the greenschists, which subsequently was confirmed through microscopic examination.

A typical sample of these schists shows a finely schistose rock, the S-planes of which are quite naturally determined by the phyllosilicates, amongst which chlorite is largely predominant. Amphibole, feldspar and quartz are sometimes sufficiently well formed for one to distinguish them (Figs. 5 and 6).

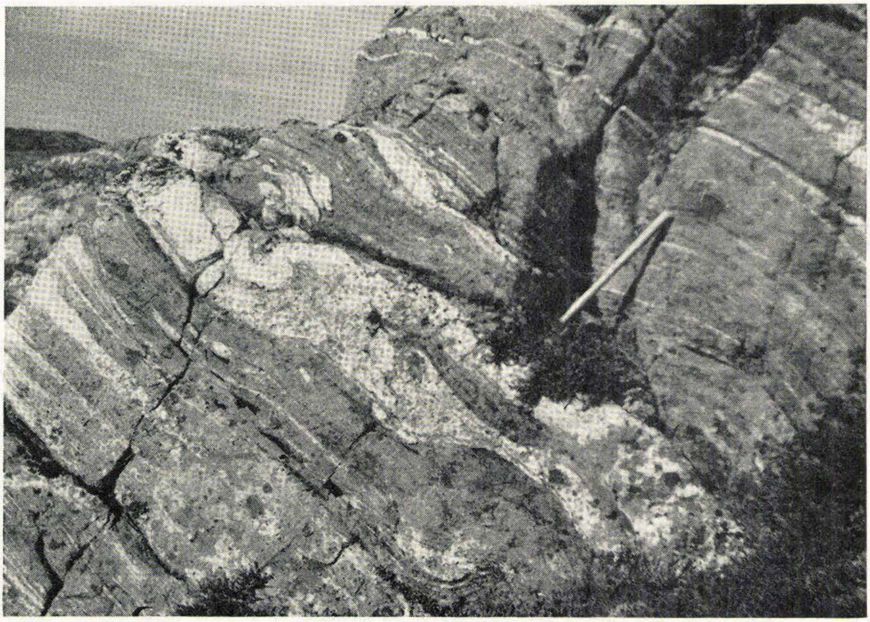


Fig. 7. Banded gneiss in Akuliaruserssuaq. The dark beds are very amphibolitic. A concordant pegmatite shows a slight pinch-and-swell structure.

2. **The infrastructure.** It is composed of gneissic rocks, massive or schistose, whose aspect has lead to the following subdivision:

Banded gneiss. The melanocratic and leucocratic beds are parallel, and more or less of equal thickness. The beds with a majority of white minerals are generally more massive; they may even be separated by schistose intercalations of flaky minerals. The thickness of the beds varies between 0.5 cm and over 1 m; in average they oscillate between 5 and 20 cm (Figs. 7, 8 and 9).

Veined gneiss. Here the leucocratic veins have a more capricious disposition. It is they, however, that determine the orientation of the rock. Generally, as in the case of Fig. 10, they are much less abundant than the melanocratic parts.

Streaky gneiss. This is a leucocratic gneiss, the orientation of which is determined by discontinuous streaks or schlieren of dark minerals, constituting a very small proportion of the rock.

Homogeneous gneiss. All directions have disappeared from this rock, nearly exclusively quartzo-feldspathic. Its homogeneous character and its common coarseness in grain-size remind one rather of a granite. Moreover, joint-systems, two of which are predominant, one horizontal, the other vertical, determine big steps. It is normal that this rock,

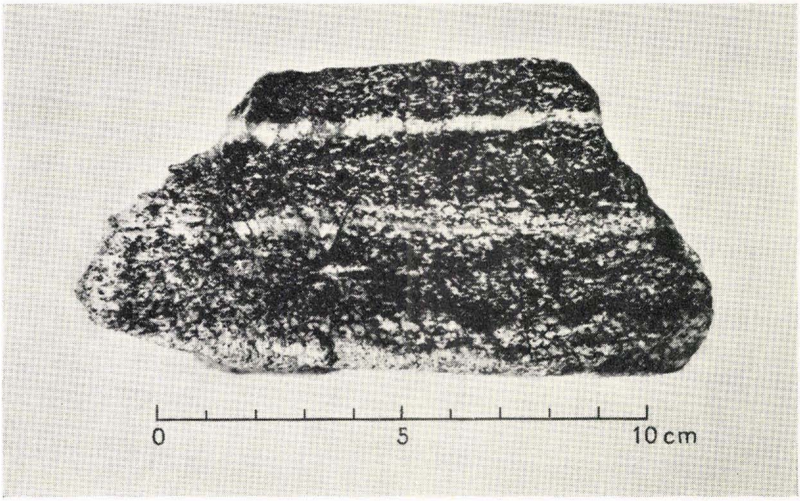


Fig. 8. Banded gneiss, containing essentially oligoclase, quartz, amphibole, epidote and biotite. (No. 32998). Angmassivît.

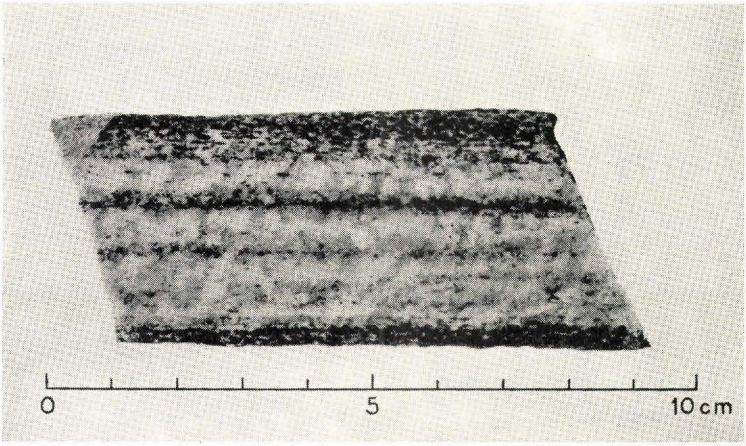


Fig. 9. Banded gneiss, composed of oligoclase, epidote, amphibole, biotite, muscovite and a little microcline, quartz and sphene. (No. 38529). Northern part of Akuliarusserssuaq.

offering a greater resistance to erosion, should constitute a marking feature in the topography. Indeed, the high areas N of lake 470 m (summits 850 and 875, 890) are carved in this rock.

Agmatites. This group of rocks forms a zone which nearly everywhere borders on the greenschist bands of the suprastructure.

Here basic or gneissic lenses are separated by acid veins (aplites and pegmatites), in great abundance (Fig. 11), belonging to several generations, and which run in a very haphazard manner.

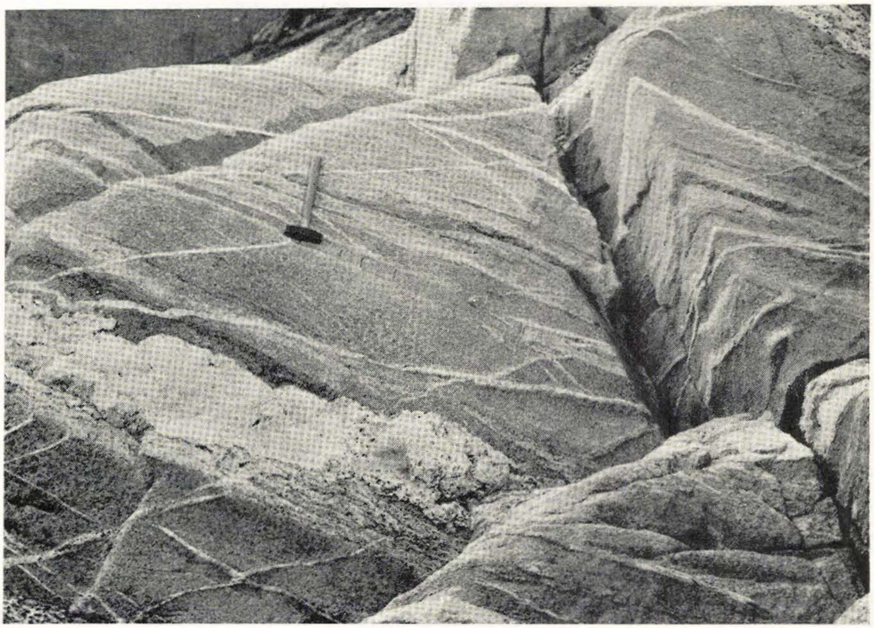


Fig. 10. Veined gneiss. The leucocratic veins determine the orientation of the rock, but many are discordant. Dark material is clearly more abundant.

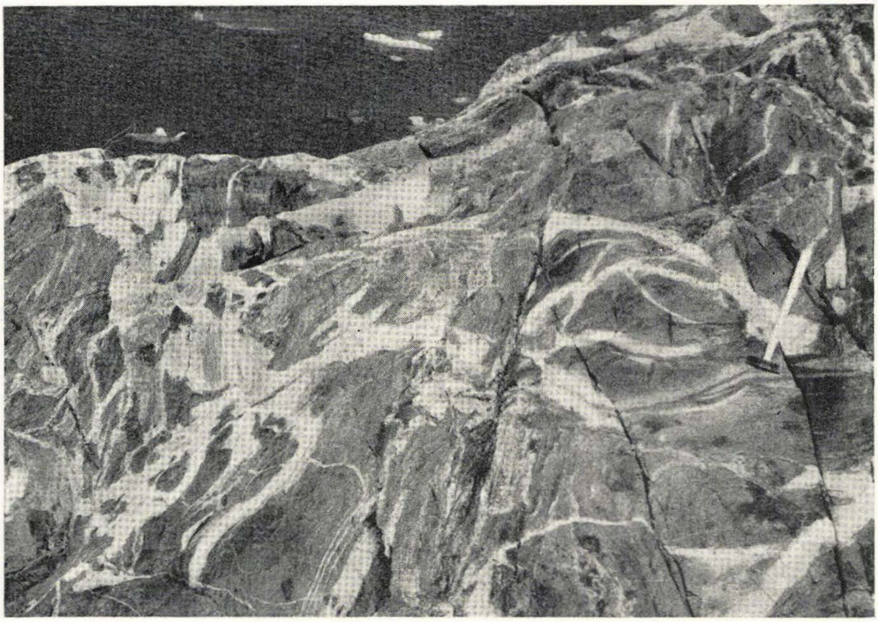


Fig. 11. Agmatites on the coast of Sermiligârssuk. The haphazard disposition of the acid veins is quite typical. Displacements from one lens to another and syn-migmatitic microfolding are frequent.

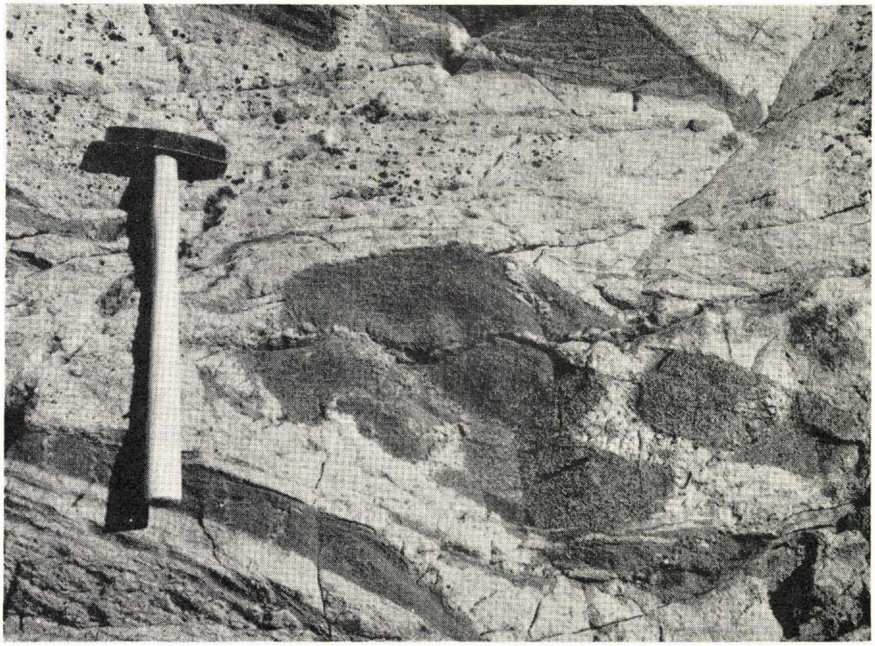


Fig. 12. Agmatitic blocks and lenses. The outline may be angular or rounded. In some places, the dark patches form but a small proportion of the total rock.

The proportion between the interstitial material and the lenses varies enormously; it may occur that only a few rare blocks are preserved in a leucocratic mass. The form of the lenses is very variable; their outline may be angular or rounded (Fig. 12).

Often these lenses are composed of schistose or massive, more or less pure amphibolites; in certain cases, the proportion of amphibole reaches 90 to 95 $^0/_0$, and the size of the crystal 2–3 mm.

While one can, in most cases, follow the structure from one lens to another, it is to be noted, however, that there occur evident displacements and syn-migmatitic microfolds (M. Roques, 1941). The general aspect is one of intense deformation.

Gabbro-anorthosites. Whereas in other regions nearer Ivigtut, this facies constitutes continuous bands, a very useful horizon for structural analysis, in ours it appears but sporadically, in the form of lenses concentrated in the banded gneiss of the southern part.

It is more or less an augen-gneiss composed typically of dark minerals (amphibole, biotite) and of a rather basic plagioclase (Fig. 13). Quartz is practically always absent. The origin of this curious rock is the object

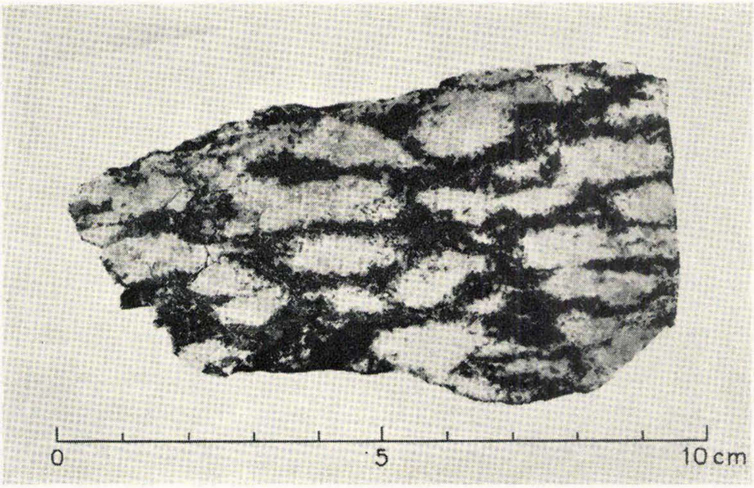


Fig. 13. Gabbro-anorthosite containing andesine-labradorite, biotite, green hornblende, epidote, allanite, apatite, and sphene. (No. 38546). Northwestern part of Akuliaruserssuaq.

of strong controversy. Because of its constancy and high Ca content, it may represent the result of metamorphic transformations of calcareous formations, but certain facts seem to disprove this hypothesis.

All these types of gneiss may grade into each other very rapidly. Thus, numerous lenses with a gabbro-anorthositic aspect are actually transitional rocks, in which the plagioclase is too acid, and quartz too abundant, for one to attribute them to this category.

In the same way, the transition from a banded gneiss to a veined gneiss (Fig. 14), or to an agmatitic gneiss is current.

Another example (Fig. 15) shows a pegmatitic vein with three concordant branches which join up, an amphibolitic lens thus becoming agmatitic.

One may find in the gneisses occasional greenschist relics, the composition of which corresponds exactly to that of the greenschists in the suprastructure. Since these rocks have largely escaped migmatization, they will naturally be found less and less as the gneiss becomes more homogeneous.

Fig. 14. Transition from a banded gneiss on the right side, to a veined gneiss in the centre. The leucocratic veins suddenly acquire a capricious disposition.

Fig. 15. An amphibolitic lens becomes agmatitic through the junction of three concordant branches of a pegmatite vein.

II. Microscopic.

All microscopic determinations of minerals were carried out by classical optical methods mainly based on the tables and data compiled by WINCHELL and WINCHELL (1951).

1. **The suprastructure.** According to the mineralogical assemblages we have tried to determine the origin of these schists, basing our conclusions on the facies descriptions of F. J. TURNER and J. VERHOOGEN (1960). It was naturally more indicated to make this attempt in the suprastructure where the rocks have not undergone the effect of migmatization.

Pelitic schists. These are fine-or medium-grained schists, grey or green, dark, often satiny. Where recrystallization occurred in the first greenschist sub-facies (quartz-albite-muscovite-chlorite), one observes an abundance of chlorite in greenish veinlets, and sericite. These phyllosilicates are embedded in a matrix of quartz and plagioclase (an albite-oligoclase). As accessory minerals let us mention: epidote, apatite, biotite, magnetite, limonite, pyrite, sphene associated with leucoxene and ilmenite.

In one case biotite becomes one of the essential minerals. It forms large plates and its pleochroism goes from light brown to dark green. Sphene is more abundant, in a fresher state, and small grains of calcite seem to have been introduced at a later stage. This corresponds approximately to recrystallization in the second sub-facies (quartz-albite-epidote-biotite).

Basic schists. Assemblages corresponding to both sub-facies exist here too. Macroscopically, these are also fine green schists in which only the phyllosilicates may be distinguished.

In the first sub-facies chlorite, sericite, epidote, albite (-oligoclase), quartz and calcite are abundant. Small pink grains of sphene are often scattered throughout the mass and are sometimes surrounded by a cloud of leucoxene and ilmenite. In the centre of the grains of epidote there is often an orange grain of allanite, the whole association sometimes producing zoning phenomena from the centre outwards. Apatite, zircon and tourmaline are accessories, whereas the quantity of biotite is insignificant. Calcite, colourless or slightly brownish, is often a late-stage or secondary formation. Only rare traces of amphibole are to be found. Let us also mention some ore (magnetite, limonite, pyrite), which crystallizes generally in the cleavages of the phyllosilicates.

If the degree of metamorphism is slightly stronger (second sub-facies), an amphibole makes its appearance; it is mainly green but can easily lose its colour, the transition being possible in a single crystal. Thus an actinolite-hornblende becomes a more tremolitic amphibole. The pleochroism is often light brown to dark bluish-green. One notes various inclusions, mainly of quartz. The amphibole crystals determine the orientation of the rock. Moreover, biotite (pleochroism: pale brown to dark green) often becomes abundant. Plagioclase, usually an albite-oligoclase, varying between 5 and 10 % An, is in certain cases an optically negative oligoclase. Its alteration produces sericite and it is frequently filled with saussuritic accumulations, where zoisite is particularly abundant, indicating a higher degree of original basicity. Chlorite is still present, but in variable amounts, as is quartz which may be totally absent. Epidote, often accompanied by allanite, is ubiquitous, as well as rounded grains of sphene which show slight pink pleochroism and occasional lamellar twinning. Sericite-muscovite, microcline and calcite appear but sporadically. As accessories one may mention apatite in large, often abundant grains, zircon (giving rise to pleochroic halos in the phyllosilicates), green tourmaline and some ore (magnetite, ilmenite, limonite, hematite). From time to time one notes a zeolite which forms amygdules or veins; it is a chabazite, common in the fissures of crystalline schists.

These basic schists constitute the most abundantly represented group, and we are of the opinion that they result from the transformation of basic igneous rocks (sills, flows, pillow-lavas etc.), common and even characteristic members of the Arsuk group, as described by C. E. Wegmann (1938). Remains of sills are to be found in the form of the above-mentioned concordant lenses, 1–2 m wide, 30–40 m long, where the proportion of amphibole is considerable.

Quartzo-feldspathic schists. These schists are more massive and very much more leucocratic than the previous ones. Grain-size remains fine or medium. Whereas in the groups already examined the abundance of phyllosilicates determines a mainly lepidoblastic texture, here the predominating minerals form a granoblastic texture.

In the first facies one observes mainly an association between plagioclase, quartz and muscovite. The first is an albite-oligoclase, fluctuating around 5–10 % An. Muscovite constitutes weakly dispersive plates which are generally colourless with a sporadic, slightly pink or green tinge. Very accessorily, there is a little chlorite, epidote, ore (frequently lining the quartz grains), and microcline.

In the second sub-facies these schists show an increase in the proportion of microcline with formation of microperthite and of myrmekite, the apparition of a very pleochroic biotite, quite large grains of sphene associated with ilmenite, some calcite and apatite. A slight schistosity is caused by alignments of fine sericite grains, or by the long plates of muscovite.

These rocks derive very probably from quartzitic or arkosic sandstones. One often has the impression that they must have formed massive and homogeneous layers.

Magnesian schists. Sometimes the green chloritic schists gradually grade into greenish, whitish or grey schists, soft and fine, in which talc is easily distinguishable. They are rather intercalations than lenses and do not seem to be related to the ultramafic rocks.

The matrix is composed of small grains of talc in which are embedded flakes of sericite, difficult to distinguish from the talc, and long thin plates of light green chlorite; these lamellae are twisted and broken up by later mechanical efforts. Carbonates are found in variable quantity and small grains of ore (magnetite, limonite) are scattered throughout the mass. Grains of sphene and epidote are very rare.

N. L. BOWEN (1940) and C. E. TILLEY (1948) have described the transformation of dolomitic and siliceous rocks, intermediate between purely calcareous and pelitic rocks. A low degree of metamorphism produces talc. It appears that a similar phenomenon occurs in our case, rather because of field relations than for mineralogical reasons.

We are quite conscious of the fact, however, that it is sometimes illusory to try to define the origin of a transformed rock from the final product, as its history may be complex, and convergences are frequent.

2. **The infrastructure.** Whereas the components of the various types of gneiss are the same, their proportion varies considerably. The texture is practically always granoblastic with local variations: heteroblastic, grano-nematoblastic, lepidoblastic, cataclastic.

Banded gneiss. As essential minerals one must mention: a) a plagioclase with good twinning, practically always full of sericite flakes, which begin by following crystallographic directions, before spreading haphazardly; saussurite in which zoisite is predominant, also invades the plagioclase; colourless or pinkish, it is in average an optically positive oligoclase, varying between an albite-oligoclase (about 5–10 $^0/_0$ An) and the limit oligoclase-andesine (about 30 $^0/_0$ An). It frequently contains inclusions, mainly quartzitic, in the form of "drops" or "tears", sometimes optically oriented in a single crystal. True micrographic associations are also current. Less frequently one may observe more acid secondary growths. b) quartz, which constitutes beds or interstitial veins composed of small crystals or large grains with undulatory extinction. Some secondary quartz is due to corrosion, alteration; it also forms inclusions in the plagioclase and the amphibole. c) biotite, the lamellae of which are imbricated in each other and form layers. Pleochroism is always very distinct and varies clearly with iron content. When it is a lepidomelane, the colour goes from a light brown, sometimes orange tinge to dark brown or blood red. If it approaches a phlogopite, a green tinge (often olive) appears. Its alteration produces green chlorite, vermiculite, limonite or magnetite. Moreover it contains frequent tiny needles of sagenitic (reticular) rutile, as well as small inclusions of zircon, which have given rise to dark pleochroic halos. d) an amphibole, which is generally green common hornblende. Like biotite, it varies considerably in quantity and may even be absent. Idiomorphic or subidiomorphic crystals are frequent. Its pleochroism varies generally from straw-yellow to dark green or bluish-green (probably indicating in this last case a slight sodium content), but in some cases it may lose all colour, become more fibrous in aspect, thus turning into a tremolite. Twinning is rare. Numerous inclusions are to be noted: apatite, quartz, zircon, sphene. Its alteration normally produces chlorite and/or biotite. e) epidote in yellow or brownish grains of very variable size, frequently forming layers or veinlets. Its optical anomalies and its dispersion are characteristic. In numerous cases the centre of the grains is occupied by a crystal of allanite (Pl. 1 fig. 2), slightly pleochroic (yellow-brownish); it is the nucleus of typical radial cracks and forms, with the surrounding epidote, the already mentioned zoning. Less frequently, there also exist large accumulations of clinozoisite, whereas zoisite is mainly an alteration product. Vermicular inclusions of quartz are common.

Accessory minerals are: f) chlorite, slightly pleochroic, light green to colourless, fibrous or finely crystallized. It also contains zircon inclusions and rare tourmaline needles. Not abundant, it is mainly secondary. g) muscovite, constituting large, slightly dispersive lamellae. It grades frequently into biotite. h) sphene, sometimes very abundant, in large oval-shaped grains with weak pink pleochroism. Several crystals occasionally form a chain, which concords with the foliation. It frequently replaces ilmenite (Pl. 2 fig. 2), but is itself not intensely altered to leucoxene. i) apatite, which is ubiquitous, in frequently idiomorphic rods or grains. j) calcite, practically always the result of late-stage activities (metasomatism, hydrothermal activity etc.). It also forms veinlets. k) garnet, slightly pinkish, strictly localized in the southern part of our region, particularly at Akuliaruserssuaq. In spite of its rareness, it is not without importance since it is probably almandine, characterizing the third greenschist sub-facies (quartz-albite-epidote-almandine), according to F. J. TURNER and J. VERHOOGEN (1960). l) ore including magnetite, ilmenite, limonite (mainly goethite), hematite and pyrite. It constitutes an insignificant proportion. m) tourmaline, quite rare, green-blue to black, distinctly pleochroic; it is a schorlite. n) microcline, the proportion of which is considerably variable. It is often completely absent. Generally fresh, it forms large grains which grow almost anywhere. In particular, it sometimes replaces the plagioclase, indicating that it has been introduced by late-stage metasomatism. When both feldspars are in contact, formation of myrmekite is very often the result: vermicular quartz buds (the size of which is well under a mm) appear near the edge of the plagioclase, which becomes more acid at this point. As regards myrmekite in the migmatites of the Massif Central, M. ROQUES (1955) expresses the opinion that this endometasomatosis represents mainly a siliceous introduction from some distance, and a departure of a certain amount of alumina, lime and potash, and that myrmekite is developed at the simultaneous expense of the plagioclase and the microcline. But the introduction of microcline is probably a late-stage event and we prefer the interpretation of F. K. DRESCHER-KADEN (1948) according to whom the potassic feldspar is formed later than the plagioclase, which is corroded by the potassic solution. There would crystallize in chronological order: plagioclase, vermicular quartz, and microcline. This phenomenon may occur in the absence of microcline, but this is never the case in the migmatites of our region.

As a result of this description, the gneiss appears to be quite common without very definite characteristics.

Streaky gneiss. In relation to the previous category, the principal differences are the following:

1) amongst the ferromagnesian minerals which are naturally in very much smaller quantity than in the previous case (frequently the sum quartz + feldspars exceeds 90–95 %), it is mainly the proportion of hornblende that decreases. Biotite is the most abundant dark mineral, and determines the foliation.
2) microcline is much more widely distributed, as is quartz.
3) muscovite is also more developed.

The introduction of material, especially of alkaline elements, is clearly more important.

Homogeneous gneiss. Here the proportion of dark minerals is even less, while that of microcline and quartz continues to increase. This last mineral forms large grains which interpenetrate each other in a finger-like manner; moreover, it contains tiny inclusions aligned according to a crystallographic direction, in one, two or three parallel rows, oriented or not in a single crystal; the size of these inclusions unfortunately does not permit microscopic identification (in all probability they are Boehm lamellae due to strong deformation). Plagioclase is sometimes less abundant than microcline; it is often difficult to distinguish between true perthitic (Pl. 1 fig, 1) and anti-perthitic associations, which make sporadic appearances, and the replacement of one by the other (generally of the plagioclase by microcline, but albitization phenomena also occur). Hornblende is practically always absent.

Approximately 2.5 km NE of lake 470 m, covering to the E of the great N10E fault a more or less circular surface of about 100 m in diameter, a rock truly granitic in aspect, crops out. It is homogeneous, coarse-grained, massive, with a pink or brick-red colour. The transition to the white homogeneous gneiss of which it represents but a facies, is gradual, and occurs in the space of a few dm. Microcline and plagioclase are even more abundant than quartz, the other components being phyllosilicates (muscovite, chlorite, biotite). The colour is due to a fine pigmentation by hematite. In spite of the proximity of the great mylonite, there has been no crushing, the only effects being a certain local torsion in the twinning of the feldspars and the displacement of some microfaults.

Consequently, from the point of view of petrographic composition, one may see that these gneisses vary from quartz diorite, through granodiorite, to a calco-alkaline granite, the three types corresponding *grosso modo* to the three categories hereabove defined.

Gabbro-anorthosites. In the case of a typical sample, one observes a granoblastic texture assembling the following minerals: a) a plagioclase, the principal component, intensely twinned and zoned, an important character about which we shall say a few words further on. The amount of twinning (often complex) is apparently inversely proportional to the intensity of the zoning. The composition varies between that of a positive andesine (about 45 $^0/_0$An) and that of a labradorite, constituting generally the centre of the grains. Originally it was probably even more basic, but a certain amount of lime has contributed to the formation of extremely dense accumulations of small clinozoisite crystals. Moreover, alteration produces sericite. It contains quartz inclusions. b) a biotite, very abundant, strongly pleochroic (green–dark green–brownish-red brown–reddish), in long lamellae with inclusions of reticular rutile and zircon, producing dark halos. c) a green hornblende tending to have idiomorphic outlines, in big, slightly chloritized crystals. d) epidote in large brownish grains, containing quartz and calcite inclusions, surrounding here and there a crystal of allanite. As accessories one must mention: e) muscovite, colourless or with a slight pink tinge. f) chlorite, often fibrous or in clusters, associated with hornblende and biotite. It also contains reticular rutile. g) sphene, abundant, sometimes in very big grains, with a slight pink pleochroism, replacing ilmenite. h) apatite, i) calcite, j) limonite, all three in insignificant quantities. There is usually no quartz, but a few secondary grains may be found scattered in the mass. Microcline is just as rare.

The zoning of the plagioclase is an important phenomenon, the interpretation of which must only be put forward with care. In the first place, it is difficult to say whether it is an original character, or whether it is due to the effect of metamorphism (recrystallization in particular conditions). In view of the transformations through which the gneisses have passed, one would expect original zoning to be destroyed; but this is not at all certain since the gabbro-anorthosites have probably offered more resistance to these effects than other rocks, which would explain that they are the only ones to possess zoned feldspars.

From there to considering it as a primary character there is but a step. In this case, the original rock might be a gabbroic or anorthositic sill.

Rust-Zones.

Whether it be in the infrastructure or the suprastructure, one observes here and there zones, the colour of which is that of rust, hence their name. They form bands, lenses or patches. Two types may be distinguished.

1) In the greenschists. Here they constitute mainly concordant bands or lenses, usually 1–20 m wide, some tens to hundreds of m, even several km in length. They are ferruginous schists, the composition of which indicates generally a recrystallization in the first greenschist subfacies, according to F. J. TURNER and J. VERHOOGEN (1960). The matrix is principally formed of small crystals of quartz, fibrous veinlets of stilpnomelane, slightly greenish lamellae of chlorite, tiny grains of sericite, streaks of limonite and rare crystals of albite. In this mesostasis are embedded cubic grains of pyrite at different stages of limonitization. Sometimes only skeletons remain; elsewhere they have been completely removed. According to H. RAMBERG (1948), as well as A. NOE-NYGAARD and A. BERTHELSEN (1952), the sulphide content of these schists indicates a sedimentary origin, which is confirmed by their concordance with the enclosing rocks.

2) In the gneiss. Two cases may occur:

a) they may be relics of the above-mentioned ferruginous schists.

b) more often they are due to iron exudation, caused by the crushing of the ferruginous minerals (amphibole, biotite etc.). In mylonites, rusty spots and patches are frequent.

Fig. 16. Pinch- and-swell structures in concordant or slightly discordant pegmatites, in a banded gneiss. S coast of Akuliaruserssuaq.

Pegmatites and Aplites.

As in every migmatitic complex the cortège of pegmatites, aplites and other veins of various nature, is very well represented. Most of them are simple pegmatites, common exudations of the mobilized environment undergoing granitization.

Aspect. They are mainly vertical, sometimes inclined masses. Their course may be rectilinear or sinuous. They may form lenses or sheets of more or less constant thickness, discordant or not with the foliation of the country rock, or bodies without a well defined outline. Their thickness varies from 1 mm to nearly 50 m, their length from a few cm to a few hundred m. We have also observed a few horizontal pegmatites.

The contact with the enclosing rock is often sharp, without a more finely crystallized zone or diffuse edges. Sometimes feldspar porphyroblasts grow in the gneiss near to the pegmatite.

Pinch-and-swell structures (Fig. 16) are frequent but limited to concordant or slightly discordant veins, whereas small ptygmatic folds (indicating compression) are characteristic of veins which clearly cut the foliation, and in particular of aplites. This would correspond very well to the hypothesis according to which aplites are formed during a phase

Fig. 17. Cross-cutting aplites with ptygmatic folding and pinch-and-swell structures in concordant pegmatites. The veins belong to several generations. The black specks in the large pegmatite (about 40 cm wide) at the top of the figure are composed of magnetite. E coast of Akuliaruserssuaq.

of compression, while pegmatites are formed during a phase of expansion both states following each other rapidly, thus allowing the birth of numerous generations (Fig. 17). H. Ramberg (1956), to whom is due an important paper on the pegmatites of the W coast of Greenland, considers that these stresses take place during the growth of the veins; they are therefore contemporaneous with the crystallization.

Most of these veins are of the replacement (not dilation) type according to the criteria of G. E. Goodspeed (1940), but occasionally one may observe curious cases which may be interpreted in several manners. In the case of Fig. 18, for instance, the foliation of the gneiss has been bent back, indicating a certain displacement. Did this take place before, during or after the emplacement of the pegmatite? It is likely, mainly because the vein, 1 m in width, does not seem to have been submitted to mechanical stress, that the torsion was synchronous with the (slow) crystallization.

These sheets start and stop in a very sudden way, either because the zone where the crystallization has taken place has come to an end, or because there is a change of lithology, or for some other reason.

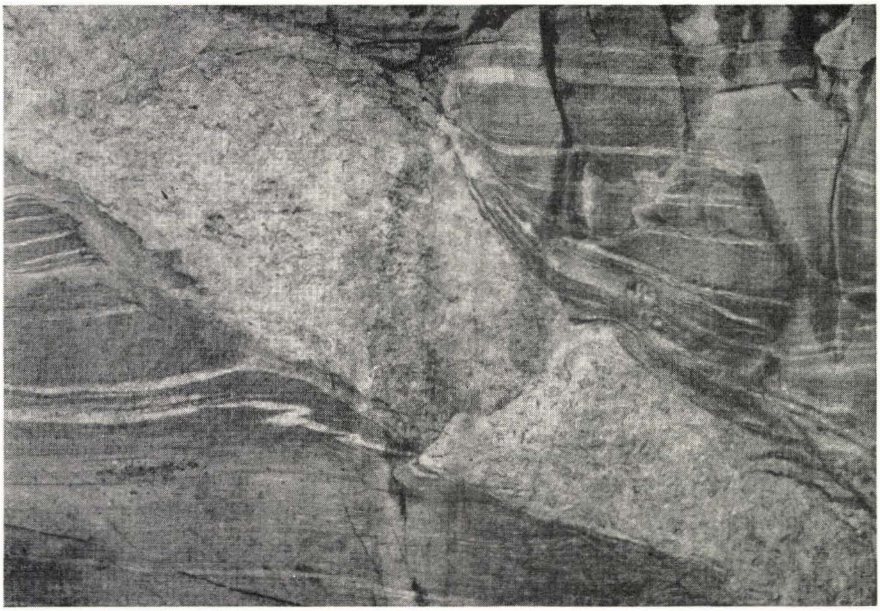


Fig. 18. Bending of the gneissic foliation on either side of a large pegmatite (about 1 m wide). The deformation is probably contemporaneous with the emplacement of the vein. Northern extremity of Kangerdlugssuaq.

Colour. All are leucocratic apart from some basic veins, and the predominant colour is white, but a certain amount of iron tinges the rock in pink, red-brown or violet. The presence of Cu produces green spots of malachite. Microcline may also add a pink nuance.

Grain-size. Between aplite and pegmatite there exist all transitions, and sometimes in the same vein. The variation may occur lengthwise but more frequently from edges to centre. One may note aplitic marginal zones with a coarse-grained centre, or the contrary. In general the grain-size is about 1 mm for the aplites, 1 cm for the pegmatites, reaching 5 cm in certain cases.

Distribution. Few veins penetrate into the suprastructure. They are mainly truly concordant or drawn out in concordant lenses by the shearing of this zone.

It is in the zone of transition to the infrastructure that the pegmatitic network attains maximum density. There, numerous generations of veins form the agmatitic zones (Fig. 19), separating amphibolitic and biotitic blocks, and causing the formation of syn-migmatitic microfolding.

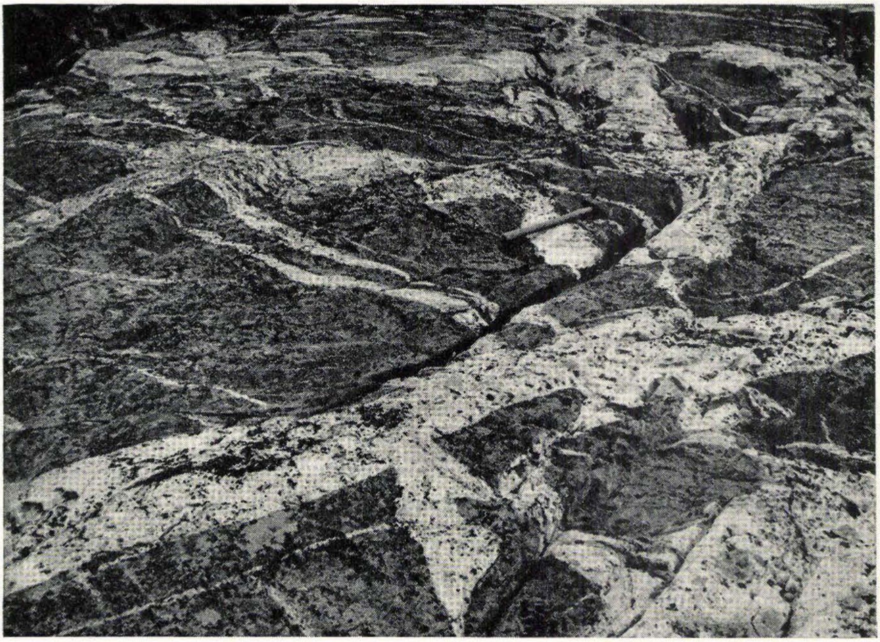


Fig. 19. Network of pegmatites and aplites belonging to several generations, in the agmatitic zones. S coast of Sermiligârssuk.

In the infrastructure they are ubiquitous with strong local concentrations such as the ones near pt. 490 N of Eqaluit, between lakes 280 and 240 in the middle of the area, where they constitute nearly 50 % of the total surface, and NE of lake 470. In these two last cases, however, tectonic factors are very probably to be taken into consideration, as we shall see further on.

Pegmatites, which infiltrate into zones of weakness, are more abundant in basic lenses as these react to mechanical stress rather by fissuration than by plastic deformation (H. Ramberg, 1956). In the quartzo-feldspathic gneisses, the most common case is that of the small concordant vein. The pegmatites seem to become rarer with the disappearance of foliation and with the homogenization of the rock.

The big pegmatite lenses are generally discordant, and in our region are practically strictly composed of quartz.

Petrology. According to E. Raguin (1957), one may divide these rocks into two categories.

a) *The simple pegmatites.* This is the most largely distributed type, with granoblastic, xenomorphic, more or less equigranular texture. The dark minerals never exceed a proportion of 5–10 %.

Quartz. Very abundant. It forms interstitial grains, and drop-like inclusions in the plagioclase with which it is associated in the formation of myrmekite.

Plagioclase. It is an albite, sometimes slightly calcic (5 % An), in one case an oligoclase (about 20 % An). It shows good twinning and alters to sericite, the flakes of which are oriented in the direction of the cleavages of the crystal.

Microcline. It is generally fresher than the plagioclase and often contains flame-like microperthitic inclusions of albite. Here and there one observes true albitization. The proportion between microcline and plagioclase varies, but they are often in equal quantities.

Biotite. It forms green or brown lamellae with a mainly green-colourless, or pale brown to dark brown pleochroism.

Chlorite. It is generally more abundant than biotite and is light green in colour.

Muscovite. Forms quite big lamellae.

Epidote. Its brownish or yellow grains often contain an orange crystal of allanite.

Sphene. It forms pink grains showing slight pleochroism, generally altering to a mass of leucoxene and surrounding grains of ilmenite.

Apatite. Small, rare rods.

Ore. A little magnetite, limonite or hematite.

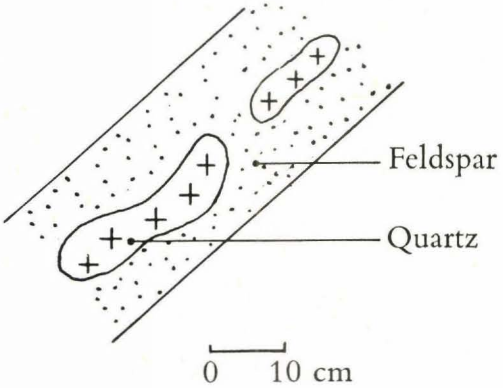


Fig. 20. A zoned pegmatite with mainly feldspathic margins and a purely quartzitic centre.

These rocks may be attributed to the family of the alaskites (kali-alaskite-aplite, according to A. Johannsen, 1931, and J. E. Spurr, 1923). They grade quite frequently into veins of pneumatolytic quartz, with

Fig. 21. A zoned pegmatite with margins composed of well formed quartz crystals and a central part composed of long flakes of green biotite, running more or less in the direction of the pegmatite.

muscovite and/or tourmaline; these may be considered as degenerate products of the pegmatites through the disappearance of the feldspars, especially as the distance from the granitization front increases, quartz migrating farther than the rest. Tourmalinites are also to be found in this cortège and we relate, consequently, certain tourmaline veins in our area to this same pneumatolytic activity.

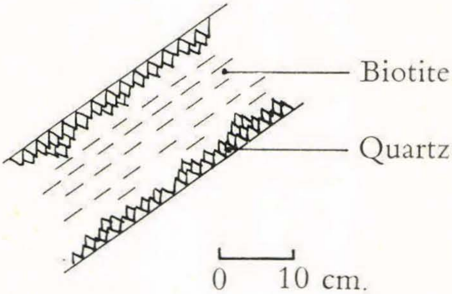


Fig. 22. Schematized disposition of the pegmatite in Fig. 21.

One of these veins displays a very pleochroic schorlite (light brown or pink to green-blue, dark green or black), which forms at least 80 % of the rock; it is accompanied by some sericite, either interstitial or in veins, big lamellae of muscovite, abundant calcite, in veins of several generations, a few veinlets of limonite, very rare small grains of albite, and one or two crystals of magnetite.

When quartz and feldspar coexist, one frequently observes a sort of zoning: the edge of the pegmatite is composed of feldspar only, mainly plagioclase, the centre of the lens being pure quartz (Fig. 20).

Let us examine a few examples of quartz veins without feldspar. In Fig. 21, the detail of which is schematized in Fig. 22, another sort of zoning appears. Here well formed crystals of milky quartz form the marginal zone, whereas the centre is constituted by flakes of green biotite which is by far the most abundant dark mineral. In the centre of the biotitic mass, there are frequent specks of magnetite. Moreover, one may find, in relation to these veins, limonite, tourmaline, chlorite, epidote, apatite, sericite-muscovite and sometimes a little pyrite or chalcopyrite. Quartz is milky rather than transparent. Under the microscope it always shows wavy extinction and is more often xenomorphic than idiomorphic.

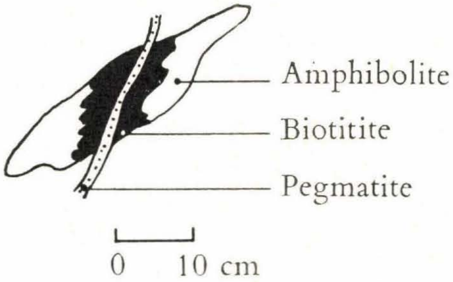


Fig. 23. Replacement, over a few cm, of amphibole by fine flakes of biotite in an amphibolitic lens, due to the emplacement of a small pegmatitic vein.

We observed at the contact between one of these pegmatitic veins and an amphibolitic lens, the replacement over a few cm of the amphibole by a finely crystallized biotite (Fig 23).

Allanite may be particularly well developed. Large crystals up to 3 cm in length are usually surrounded by typical radial cracks (Fig. 24). They form small, local concentrations or clusters and are practically always altered to iron-oxide. This transformation is accompanied by loss of radioactivity.

b) *The complex pegmatites.* They form ill-defined masses rather than sheets and vary considerably in size. Hydrothermal activity and pneuma-

Fig. 24. Large crystals of allanite surrounded by typical fissures. They are usually transformed to iron-oxide with loss of radioactivity. Eqaluit.

tolytic emanations have played an important part in their genesis. They include the ultimate residues of differentiation.

An instructive example is the following: a pegmatite containing large lamellae of muscovite also shows spots of malachite, caused by a little chalcopyrite. Quartz, albite, epidote, chlorite, biotite, pyrite, antigorite, muscovite and a little leucoxene are also present. Moreover, there exists a pink garnet with numerous cracks in which sporadic biotite, chlorite, epidote and ore appear as alteration products; it also reveals a certain heterogeneity (slight local birefringence), and may be classed in the group of the pyralspites. It is most probably a spessartite.

Finally, in a pegmatite, where grains of magnetite are disseminated here and there, we found (apart from quartz, microperthitic microcline, sub-idiomorphic albite, epidote, ore and apatite) a few grains of colourless allotriomorphic fluorite, related to the quartz and sometimes slightly birefringent. This is however the only case in which fluorite was encountered.

Petrogenesis. It is possible that most of these pegmatites were formed by slow diffusion of acid material in zones of weakness. Moreover, in the external zones pneumatolytic activity certainly played an important part.

The formation of these veins is closely related to tectonics. Strong compression commonly produced exudation of siliceous material towards zones of low pressure, and formation of quartz veins, i.e., in particular in the cores of folds, and in the interstices of zones of intense shearing.

The Ultrabasic Rocks.

Several lenticular bodies of ultrabasic rocks are to be found in our region, and as any contribution to this much debated problem may prove useful, we are now going to give a detailed description of them.

The distance that separates one lens or one set of lenses from another is quite considerable. Bodies are generally 1–15 m wide, and 2–150 m long, sometimes even exceeding this last figure. Their form is clearly lenticular, with a pronounced swelling in the middle. The colour of weathering may be dark green, blue, brown, orange or beige; the fresh rock is mainly dark green, sometimes practically black. Their hardness varies greatly, according to the proportion of talc, and they have a high density.

They commonly form small mounds jutting well above the surface of the gneiss. The elongation of the lenses is nearly always concordant with the foliation of the country rock. In the case of slight discordances the angle is about 10° and reaches in one case 30°. One must draw attention to the fact that, if the elongation is not well defined or if the form of the lens is irregular, estimation of its direction may prove difficult.

Petrographically, these ultramafites all enter into the category of serpentinites, probable transformation products of peridotite or dunite intrusions.

A typical lens, near Angmassivît, is composed of a rather hard and compact rock, the surface of which is brown to brick-red, the fresh colour being green to blue-green. The grain-size is fine, and with the naked eye one distinguishes small lamellae of phyllosilicates as well as grains of ore. At the edge of the lens the rock grades into muscovite- and talc-bearing schists.

The microscope reveals a mesostasis of heteroblastic texture composed of fine flakes of colourless serpentine (antigorite), non-oriented and fibrous; in this are embedded lamellae of colourless or slightly brownish chlorite, scarcely or not pleochroic, displaying weak dispersion. These lamellae are frequently bent, indicating that they have undergone a certain amount of stress. The cleavages are well defined and even underlined by alteration to ore (magnetite and some limonite) which fills the interstices. As the angle 2V attains 20–30° it is probably a clinochlore. Moreover, one notes some sericite in small grains or flakes, and a few crystals of calcite and apatite. Consequently there remains no relic of the original minerals.

In the amphibolitic and chloritic schists of the suprastructure in the northern part of our territory, a small lens (50 cm) is constituted by coarse talc-bearing schists, quite microfolded, with small, light or dark veinlets. The rock contains carbonate crystals about 1 mm in length. The talc is outwardly greenish and dark, but when one scratches the superficial layer, the typical white colour appears. The microscope reveals a lepidoblastic texture composed of tiny lamellae of talc; dolomite is very abundant, sometimes twinned; moreover, there are some veinlets of green chlorite and a considerable amount of ore (magnetite-limonite) scattered almost everywhere in small, sometimes idiomorphic grains (Pl. 2 fig. 3). As regards the total composition of the rock, ore attains 3–7 $^0/_0$. Amongst the carbonates, there may also be some ankerite and calcite; grains of sphene-leucoxene are extremely rare.

Consequently, according to the description of serpentinite evolution in increasing metamorphic stages put forward by various authorities (F. J. TURNER, 1948, H. WILLIAMS, F. J. TURNER and C. M. GILBERT, 1955, and A. HARKER, 1956), the transformation is here slightly more advanced than in the preceding case.

Another instructive case is the one we observed on the SW coast of Eqaluit bay. There a serpentine lens, as it approaches a quartzo-feldspathic pegmatite, grades into talcschists followed by first white then greenish tremolite (tending towards actinolite in this last case, Pl. 3 fig. 1), and finally, in contact with the pegmatite, to biotite. A little further on the pegmatite is double, and the veins of biotite are symmetrical in relation to the tremolite vein (Fig. 25).

Let us examine this transition under the microscope.

A) The serpentinite. It is a hard, compact rock; its weathered colour is light brown or greyish; when fresh it is grey or white. Minute grains of ore (0.1 mm) are visible with the naked eye. The groundmass of heteroblastic to cataclastic texture, is composed of lamellae of antigorite which are colourless, not oriented, and are the result of the transformation of olivine at different stages. This last is a forsterite, and slightly ferruginous; it is still abundant and attains 20–30 $^0/_0$ of the rock. Its fissures are filled with ore (magnetite-hematite), and certain grains with a cloud of minute serpentine crystals. Weak zoning is sometimes apparent (variation in iron content during crystallization). Magnetite also forms big grains and attains proportions between 10–15 $^0/_0$. There is no chlorite.

This is the only case where we have observed a considerable quantity of residual olivine. It seems that the original rock may have had a strong tendency towards dunite.

B) The talcschists. The rock is compact but very soft, quite dense, superficially green, white when fresh. The surface is shiny and streaked. The very fine groundmass is composed of grains and plates of talc; in this mass are sometimes embedded idiomorphic grains of magnetite (3–5 %), and some hematite. Small nests of serpentine appear here and there, and are composed of imbricated fibres. This rock is therefore a steatite.

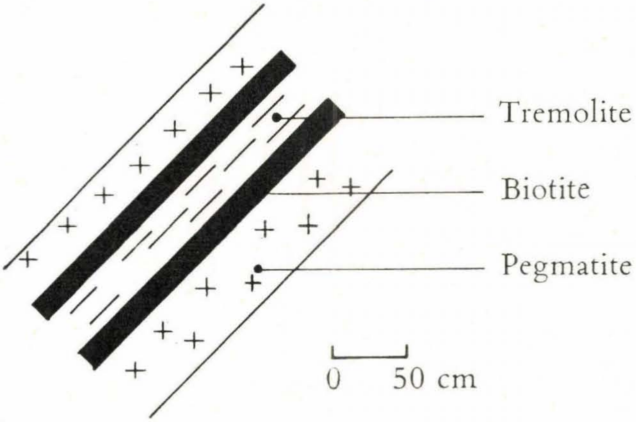


Fig. 25. Tremolite grading into biotite towards the contact with two parallel branches of a pegmatite vein. SW coast of Eqaluit.

C) The tremolite vein. This vein is monomineralic, and solely formed of needles of colourless or slightly greenish or brownish tremolite, the longest of which attains 1–2 cm, varying in average around a few mm. In the interstices they are practically sub-microscopic. One may call the texture lepido-nematoblastic; there exists only locally a preferential direction. Considerable twisting, even microfolds are visible in the fibres, demonstrating the marked stress to which they have been submitted. The change of colour underlines a transition to greener actinolite. The extinction angle $Z\wedge c$ is generally about 20°.

D) The biotite veins. Here the biotite lamellae, generally about 1 cm large, run, apparently, more or less in the direction of the pegmatite. But the microscope reveals that this orientation is only local. The colour of this biotite varies according to the following pleochroism: colourless to brown. The 2V angle is extremely small, the birefringence medium to strong and the refringence slightly above that of Canada balsam.

The extinction is sometimes undulatory. This biotite belongs to the phlogopite-eastonite series and is therefore magnesian with a slight iron content. Some small needles of ore appear in the cleavages.

This reaction between ultrabasic lens and pegmatite is very interesting, since it shows the possible effects of general granitization on this family of rocks. F. J. TURNER (1948) describes, moreover, transformations in which one sees serpentine grading into talc, then into tremolite-actinolite, and finally into biotite in conditions characterized by a rise of temperature and an introduction of silica. These conditions have been completely fulfilled during the emplacement of the pegmatite.

Petrogenesis and emplacement. Like the country rock these serpentinite lenses show little variation in their degree of metamorphism; it is the same in both cases, indicating, therefore, that they have probably both undergone the same transformation. They show, moreover, pratically no variation in aspect or in mineralogical composition, in zones of different degrees of granitization. This would tend to show that these ultramafites oppose strong resistance to this process, which is not surprising on the part of these very homogeneous masses.

The distribution of the lenses, their position in relation to the big structures, their concordance with the directions of the encasing rock, all this induces us to believe that we are in the presence of a horizon which follows the big folds, and that consequently its emplacement pre-dates their formation, during which it was drawn out, boudiné and metamorphosed. Apparently, it came into existence before any tectonic movement.

It seems therefore to us that these sporadic lenses constitute a sill emplaced in the geosyncline and interstratified in the fresh and water-filled sediments. In the Ivigtut area, as in many other regions of the world, it is quite evident that this group of rocks belongs to the ophiolitic cortège. As for the sill itself, it may very well be locally multiple, with a variable number of members. Moreover, it may present irregularities. N. L. TALIAFERRO (1943) states about the serpentinites of California that, whereas they are essentially concordant, the sills, small and large, frequently transgress the stratification and vary in thickness over short distances, and also that it is not rare to find a single thick sill on one side of a syncline, and on the other side a number of thin sills, separated by beds of sedimentary material.

This problem is particularly well represented to the E in the region mapped by M. WEIDMANN, who has studied it with some detail.

B. Ketilidian Tectonics (Pl. 11 and 12).

The building of the Ketilidian mountain chain is quite complicated, as would be expected in any Pre-Cambrian belt. The history of the various events, the succession and relations of the different deformations, were only brought to light through the application of the following methods:

1) Careful measuring of all structural elements, including strike and dip of foliation, schistosity, lineation, elongation (of lenticular bodies for instance), strike and dip of microfolds, trend-verticals (direction of small fold-axes), striation and cleavage.
2) Structural analysis as put forward by C. E. Wegmann in several of his papers (particularly 1929a and b, 1930, 1935, 1951).
3) Systematic plotting on Wulf diagrams (nets).

As will be seen, this analysis has once again revealed the necessity of considering all sides of a problem. Many points concerning petrology and lithology are quite easily cleared up when placed in their structural setting. Of course, some areas are still clouded in mystery, and probably will remain that way (areas of homogeneous gneiss for instance), but that is all the more reason to try and find the answer elsewhere.

This leads us very normally to the consideration of the validity and meaning of what we measure in the field (and, therefore, of what we plot in diagrams).

a) In the suprastructure, composed of schists, there are various types of S-planes, amongst which a vertical or sub-vertical (slaty) cleavage is predominant. This cleavage, which, in the opinion of L. U. de Sitter (1960a) is characteristic of the suprastructure, has obliterated nearly all primary structures. A few small, steep folds have been observed, which show that this schistosity is at least parallel to the axial planes of the main folds, if not to the original bedding outside the zones of "charnières". This cleavage is most probably of the dynamic type, but some of it may be due to load metamorphism. In any case, it is another example of coincidence between schistosity and bedding (H. H. Read, 1957). Similar observations can be made in the tight folds of the Devonian and Silurian schists, on the borders of the Hospitalet-Aston massif (Central Pyrenees; H. J. Zwart, 1960).

The suprastructure has also undergone intense shearing (particularly evident in the boudinage and drawing-out of discordant pegmatites; refer to the chapter on pegmatites) due to the tectonic discordance between suprastructure and infrastructure, producing a superimposed

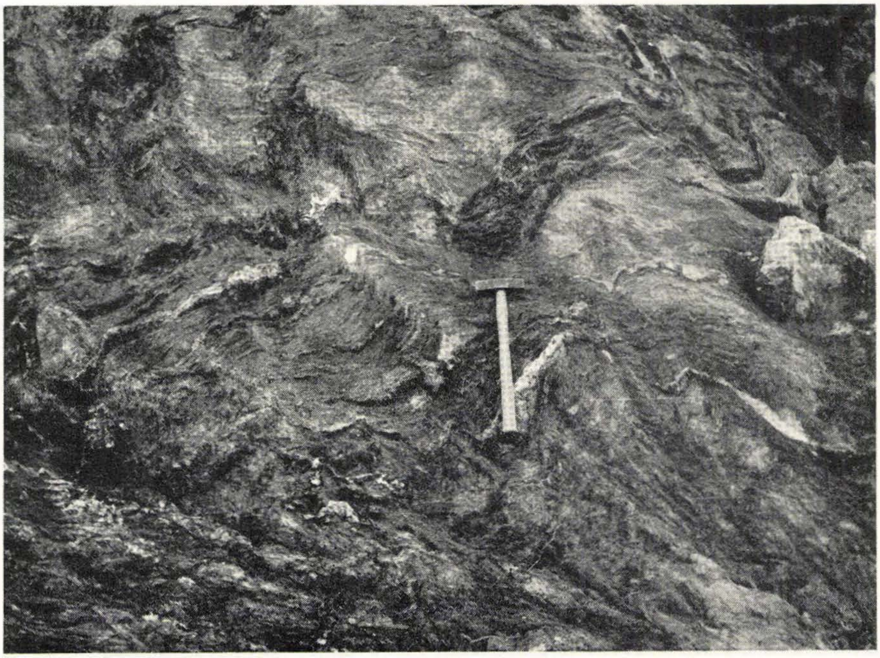


Fig. 26. Shearing producing irregular microfolds and strain-slip cleavage in the greenschists of the suprastructure.

vertical schistosity parallel to the border between the two units. This border is itself parallel to the main axial plane. Measuring S-planes in this zone, therefore, usually amounts to the measuring of the strike of this axial plane.

During the shearing-stage, irregular microfolds and strain-slip cleavages were formed (Fig. 26).

b) The foliation of the gneiss in the infrastructure is considered to coincide with primary bedding but not necessarily with bedding-planes, i. e. the original planes of discontinuity. The process involved is mainly mimetic crystallization (H. H. READ, 1957).

This affirmation is based mainly on two facts: 1) in some places, where there exists a gentle transition between regularly banded gneiss and practically untransformed sediments, the concordance between foliation and bedding has always been observed; 2) the rare horizons that can be traced for some length are all concordant with the foliation. These are: concordant amphibolitic layers (probably old basic sills), rust-zones (almost certainly the transformation of sedimentary beds), and the gabbro-anorthosite series.

A. NOE-NYGAARD and A. BERTHELSEN (1952) consider that the foliation of high-metamorphic gneiss in the Nagssugtôqidian belt (West

Fig. 27. Disharmonic microfolds in an incompetent layer composed of amphibolitic schists, overlying a competent massive quartzo-feldspathic bed. Syn-migmatitic deformation.

Greenland) coincides with bedding, except in the case of incompetent layers of hypersthene-bearing gneiss where "the development of the foliation planes seems to be related to small-scale folding of the drag fold type".

We have also observed disharmonic small-folds in incompetent layers. Fig. 27 shows a good example of this phenomenon in an amphibolitic schistose layer, on top of a quartzo-feldspathic competent bed. This type of deformation is most probably syn-migmatitic rather than pre-migmatitic. Consequently, in this exceptional case, the foliation does not represent primary stratification.

The "stockwerk" folding (C. E. Wegmann, 1935) of the Ketilidian orogeny has been divided into three phases during which intense deformation occurred:

A) a N–S to NNE pre-migmatitic phase.
B) a major WNW migmatitic phase.
C) a NE to ENE mainly post-migmatitic phase.

Deformation was practically continuous. At least, there is no apparent break between the different phases. This concords with the conclusions of J. Sutton (1960) and L. U. de Sitter (1960 a). The effects of metamorphism attained maximum intensity during the second phase, and thereafter diminished more or less progressively.

The consequence of these three tectonic events, to which one must add crossfolding (contemporaneous with the different phases), is the creation of complicated structures and wild-folding.

We will now examine the detail of each phase.

The N—S to NNE pre-migmatitic folding.

E. H. Kranck (1957), in his general schema on folding movements in the zone of the basement, considers that during the first stage, strong mechanical deformation occurs in supracrustal conditions. There is little recrystallization. Subsequently, this deformation will "be recognized only locally, as fragments in the migmatitic gneisses and granites." Linear structures and foliation are contorted or bent by later movements.

In some parts of the Ivigtut region, this phase resulted in important repetitions due to small- and large-scale recumbent folds. Small, slightly overturned isoclinal folds seem to be the main consequence in our area. The general style suggests that the formations in which this deformation took place, were composed essentially of schists. Migmatization was therefore most probably absent. The effects of metamorphism, if any at all, were weak.

The places where this phase is particularly evident are:

1) E of Qerrulik. A few small anticlines and synclines may be observed. The direction of their axis is N5–20E.
2) N of Akuliaruserssuaq. Several micro- and small-folds are slightly overturned to the W; their E flank is gentle, and their direction practically N-S.
3) W coast of Kangerdlugssuaq.
4) S of summit 590. Here the direction of a microfold is N168E.
5) E of summit 500. Folds 50–100 m in extent, and some microfolds, are slightly overturned to the NE. Their direction varies between N160E and 165E.
6) Here and there in the suprastructure flexures may be seen in the vertical schists. The folds and microfolds themselves are usually vertical.

This last feature appears to be fairly constant throughout the area: the dip of the older fold-axis is nearly always that of the younger foliation (second phase). This means that the older axis was probably horizontal and constant before the subsequent deformation. It is also proof of the existence of this first phase in case one should wonder whether these folds are not just crossfolds belonging to the migmatitic phase.

The relation between the two is equally underlined by the fact that the more or less perpendicular angle between the two fold-traces has been preserved, even where the later one has undergone a change of direction (Fig. 28).

After elimination of the effect of the subsequent phases, the general trend of this fold-axis appears to be N–S to NNE.

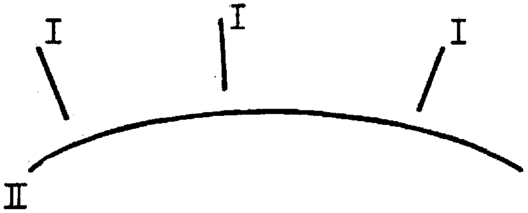


Fig. 28. The more or less perpendicular angle between the fold-axis of the first tectonic phase, and that of the second, is preserved, even where the latter has undergone a change of direction. This demonstrates their relationship.

The WNW migmatitic folding.

During this main phase infrastructure and suprastructure became individual units. The rocks of the infrastructure attained a particularly mobile and plastic state through the effects of migmatization.

The main elements are, from S to N:

1) A narrow and very steep syncline, slightly overturned to the S. No "charnières" are visible; the heart of the fold is marked by layers dipping at an angle of 70 to 80°, elsewhere practically sub-vertical ("synclinal pincé").

2) A vast brachyanticline. This large arch stretches right across the southern part of our territory. It is also slightly overturned, at least dissymmetrical. Strike and dip of the axis varie from W to E. On the W coast of Akuliaruserssuaq, the strike is approximately ENE, and the dip about 20° to the W. As one goes towards the E, the strike becomes progressively E–W, and finally WNW; the dip tends to become horizontal (with local variations), and actually dips to the E as it enters into the region mapped by M. Weidmann. The axial culmination is situated practically at the limit between the two areas.

The zone of the "charnière" is very large and usually complicated by: a) contemporaneous small-folding with the same fold-axis. b) contemporaneous crossfolding. c) the pre-existent folds of the first phase, which become crossfolds belonging to J. Sutton's fourth category (1960): "crossfolds brought to their present position by distortion during later

Fig. 29. A gentle, open "charnière" in the vast, southern dome. The rock is banded amphibolitic gneiss. Akuliarusiarssuk.

folding." Where all three complications exist simultaneously, the consequence is "wild-folding." In some places though, the "charnière" is composed of a very gentle, open structure (Fig. 29).

It is in this brachyanticline that garnets and the lenticular gabbro-anorthositic bodies are to be found.

3) Another steep syncline. To the E, the core of the fold is practically vertical, whereas, W of Akuliarusiarssuk, the axial plane becomes less inclined, underlying the following structure.

4) A large anticline. The variations in the strike and dip of the fold-axis are important. From E to W, the strike turns from WNW to E–W, to ENE, NE in the region of Akuliarusiarssuk, and back to ENE at Akuliarusínguaq. At the same time, the fold which is only dissymmetrical to the E (steep S flank, gentle N flank), becomes more and more overturned and finally recumbent, in the region of Angmassivît, the axial plane dipping at an angle of approximately 40°. Moreover, the dip of the fold-axis becomes increasingly inclined. In the NE, it is more or less horizontal; with the quite violent change of direction, it begins to plunge to the SW, and very rapidly attains an angle of 40 and finally 60°. This variation is emphasized by the minor folds.

The style of the fold is illustrated by the microfold in Fig. 30. Note the concentration of pegmatitic material in the core.

Fig. 30. A microfold illustrating the style of the recumbent anticline. In fact, it is a very good replica of the main structure. Note the concentration of pegmatitic material in the core.

In the zone of transition between the brachyanticline and this recumbent fold, one may observe a change of style in the small folds, which become progressively narrower, and more frequent. One has the impression that they were squeezed together. In some places faulted anticlines were formed. The general trend of these folds, before deformation by later movements, was WNW.

5) The suprastructure. Following on, concordantly to the foliation of the infrastructure in most places, a large, deep and steep synclinal wedge-like structure shows the already mentioned isoclinal folds and vertical to sub-vertical schistosity. C. E. Wegmann (1938) has summed up this relationship by stating that "the synclinal structure of the suprastructure is not the internal structure of the complex, but indicates its boundary towards the metamorphic areas (infrastructure). Thus it has come into existence during the granitization."

The alternation, to the SW, between non-migmatitic bands and granitized zones corresponds usually to steep synclines and anticlines, but the emplacement of some gneissic wedges is due to the effects of crush-zones.

In all places, the suprastructure lies on top of the infrastructure, and in a synclinal position. The very fact that the greenschist areas are in depressed zones explains why they have escaped removal by the action of erosion.

One of the consequences of its position is the appearance towards the S of the southernmost band of greenschists; this is due to the increasingly plunging axis of the infrastructure which permits higher levels to be preserved. But the axis of the suprastructure is only locally concordant with that of the infrastructure. This is evident N of Eqaluit where the migmatites plunge at a much steeper angle than the greenschists; at the same time, there is a difference in the strike of the two fold-axes.

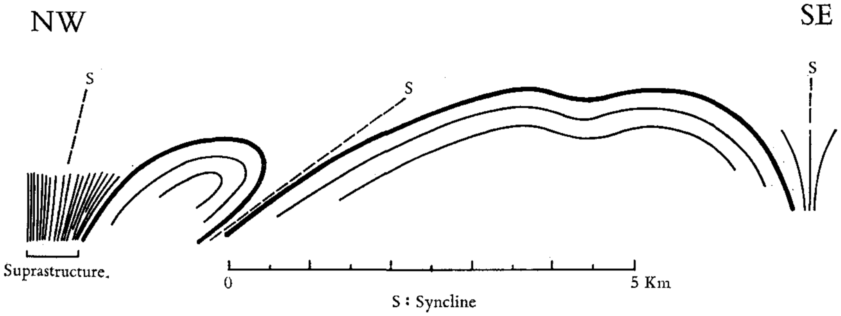


Fig. 31. Schematized cross-section through the whole territory, oriented approximately NW/SE through Akuliarusiarssuk.

As do most features (faults, dykes, foliation), going towards the E, the direction of the suprastructure tends to become E–W. This is a very general characteristic.

The above schematic cross-section (Fig. 31, drawn approximately from NW to SE through Akuliarusiarssuk) shows the dejective style of these structures, and bears a striking resemblance to the one drawn by H. J. ZWART (1960) through the Hospitalet-Aston massif, in the Central Pyrenees.

The tectonics and style of the infrastructure agree closely with the description of several other authors. The main characteristics are:

1) Big recumbent flow folds. J. HALLER (1956) has given detailed accounts of various types of migmatitic folding, and nappe-structures, emphasizing this common feature.

2) Plastic up-doming. The whole infrastructure of our area may be considered to be one big dome, the heart of which is situated in the resistant region, NE of lake 470, composed of homogeneous and granitic gneisses.

3) Emplacement of considerable pegmatitic material, mainly in tension joints related to the general structure. Laccolithic pegmatites in anti-

clinal "charnières" are not uncommon (A. NOE-NYGAARD and A. BERTHELSEN, 1952).

4) Extensive feldspathization, especially in zones of tectonic movement.

5) Tilting of the vertical cleavage of the suprastructure due to the up-doming.

6) Late-stage shear-zones along the boundary between suprastructure and infrastructure, particularly along the border of the migmatite domes (E. H. KRANCK, 1957).

7) On a small scale, drag-folds, crenulated-folds and arrowhead structures were formed.

The use of the Wulf-net proved to be indispensable in the unravelling of some of the complicated areas. Fig. 32 shows an example of a simple "charnière" in the brachyanticline, E of Qerrulik, whereas Fig. 33 illustrates the combination of the first two fold-systems N of Angmassivît.

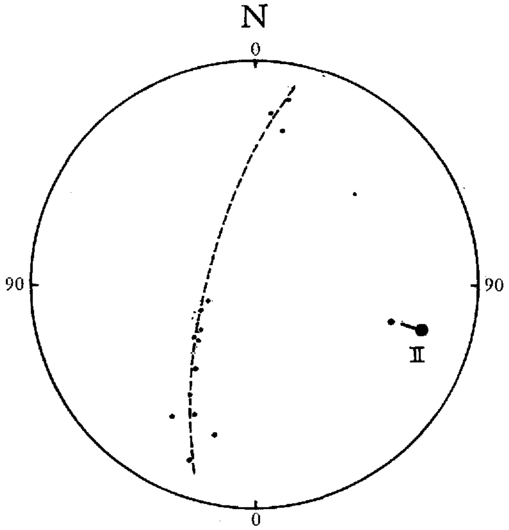


Fig. 32. An example illustrating the use of the Wulf-net. A simple "charnière" in the brachyanticline has been plotted. Dispersion is weak. E of Qerrulik.

To complete the picture of this second phase, we must add that it was during this stage that metamorphic and migmatitic effects attained maximum intensity. It has been seen that recrystallization took place in the three greenschist sub-facies, according to F. J. TURNER and J. VERHOOGEN (1960), corresponding to the greenschist and epidote-amphibolite facies of P. ESKOLA (1920–1921). The relations between migmatization and tectonics are particularly interesting and will be examined in a special chapter.

Dislocations are rare, as would be expected in the case of movements involving very plastic and mobile rocks. Overthrusts, frequently late features, are about the only manifestation of this kind, and their extent is quite small (20–50 m). Nevertheless, the rock is usually finely crushed, and quite often takes on a red tinge due to microclinization. A similar process is the one involving potassic metasomatism in the crush-zones of calco-sodic granites (this is more or less our case), to which H. and G. TERMIER (1956) draw attention. They consider that this occurs at a point in the history of the orogeny, which marks the beginning of a phase characterized by fracturation and fault-movements. These features are then the dominant dynamic events as compared to folding. The tectonic sequence in our area coincides very well with this schema.

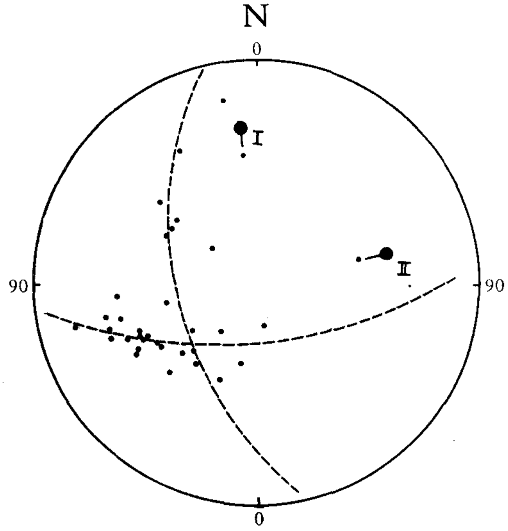


Fig. 33. An example illustrating the use of the Wulf-net. Here two fold-systems intersect each other. In spite of some dispersion, the fold-axes are easily revealed. N of Angmassivît.

Elsewhere bluish patches may appear in crushed gneissic formations. The answer to this colouration is to be found under the microscope, which reveals small, urchin-like clusters of fibres or needles showing distinct blue pleochroism (dark blue to light blue or even colourless), maximum absorption being parallel to the plane of the polarizer. This and other characteristics indicate the presence of crocidolite or blue asbestos (a magnesian, fibrous riebeckite or glaucophane, Pl. 6, fig. 1.)

The NE to ENE mainly post-migmatitic phase.

The effects of this third phase are not very visible in our territory, since they involve semi-plastic refolding, twisting and bending of the previous folds on a very large scale. In fact, these late-stage movements were only brought to light through the compilation and synthesis of all field data, due to A. Berthelsen (1960 and 1961).

A definite bend in the vertical layers and fold-axes is visible in the north-western part of the area mapped by M. Weidmann. The adjacent area in our territory is composed of homogeneous gneiss which unfortunately reveals nothing. Similar bending has been mapped by E. Bondesen on Sermersût island, SW of our area, and in the region of Eqaluit bay, the plunging head of the recumbent anticline is violently twisted and distorted. On a large scale the torsion-axis runs NE to ENE, and should pass through our territory near the boundary between supra- and infrastructure.

Since no complete bending is visible, we consider that the movement might have resulted locally in shearing. This would account for some of the phyllonitization and diaphthoresis of the greenschists. At the same time, some displacement might have occurred, but this is practically impossible to estimate.

It is plausible that late microclinization belongs to this phase. At least it follows very clearly the main stage of migmatization.

To sum up, one may state that different phases of folding resulted in the individualization of a suprastructure composed of greenschists, and an infrastructure composed of migmatitic gneisses. The disharmonic character of movements in each level generally created a structural break between them. Transitional contacts are preserved only locally.

C. Metamorphism.

In view of the numerous transformations that occur during the Ketilidian period as well as during the subsequent periods, it will perhaps be useful to summarize the polymetamorphic history of these rocks.

1) During the first phase of folding (pre-migmatitic), it is possible that the original, essentially volcanic rocks underwent some degree of metamorphism, since they were probably rendered schistose. But there is no real proof to support this suggestion.

2) The second phase, as we have already seen, marked the culmination of metamorphic effects. A slight and gradual increase in the metamorphic grade may be traced from N to S, or from suprastructure to infrastructure. *Grosso modo*, we may define a narrow chlorite zone along the

coast of Sermiligârssuk, a central biotite zone, and a southern garnet zone.

3) Metamorphism may not have played a very important part during the third phase of folding. If anything, retrograde dynamometamorphism may have been responsible for part of the phyllonitization and diaphthoresis of the suprastructure.

4) As we shall see, a subsequent low-grade recrystallization occurs during the Sanerutian period, with slight retrograde effects.

5) Hydrothermal and pneumatolytic activity made sporadic appearances right through the evolution of the orogeny.

This may appear to separate metamorphism from migmatization. Convenience only induced us to adopt this schema, and we hasten to correct any false impressions. It seems most likely that "migmatization is the prime cause of regional metamorphism" (H. H. READ, 1957).

D. Migmatization (Pl. 13).

A detailed examination of the migmatization process reveals some very interesting features. A complete front may be traced right through from suprastructure to infrastructure. All the different terms defined by M. ROQUES (1941) and J. JUNG and M. ROQUES (1952) are present. This sequence and the corresponding "field" terms are displayed in the following table.

Facies.		*Field terms.*
Suprastructure		Greenschists
Agmatites Phlebites	Diadysites (epibolites, veined gneiss, discordant and ptygmatic veins)	Agmatitic Migmatites
Embrechites: Stromatites		Augen-gneiss
Arterites		Banded gneiss
Stictolites		Streaky gneiss
Nebulites		Nebulitic gneiss
Anatexites		Homogeneous gneiss
Anatectic granite		Gneiss-granite

This "migmatitic stratigraphy" represents a succession of events closely related in space mainly, but also in time (if one considers a certain level). One could divide it into three main phases:

a) Feldspathization, producing big porphyroblasts of plagioclase. This is particularly evident in the suprastructure where the subsequent phases are absent (Fig. 34).

b) Migmatization, creating visibly and typically "mixed" rocks.

c) Granitization, resulting in the formation of a truly homogeneous rock.

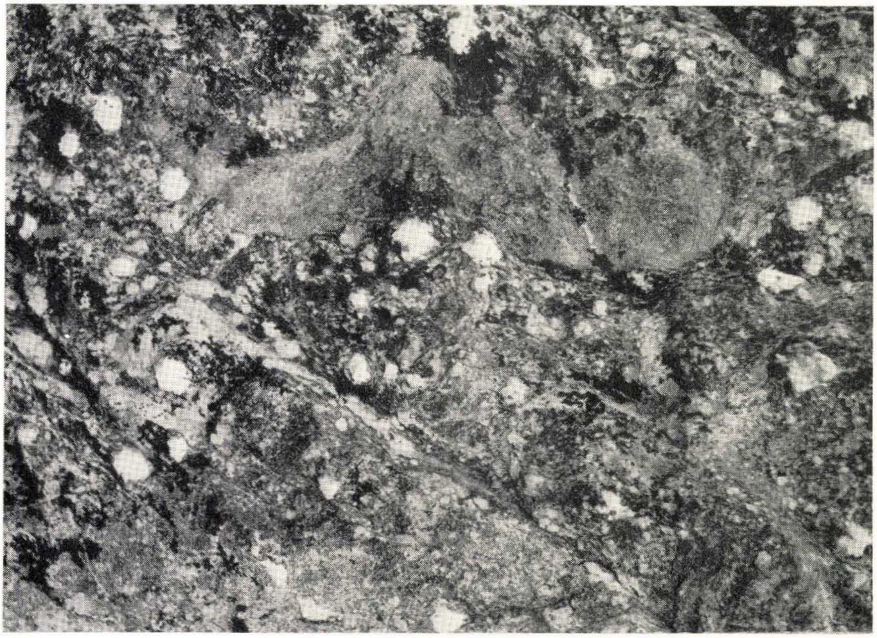


Fig. 34. Big porphyroblasts of plagioclase (about 2–3 cm in diameter) grow in the greenschists of the suprastructure. This is an early stage in the process of migmatization, i.e. feldspathization, which usually precedes, in space as well, the front of the migmatites.

Transitions between these phases, as between the different facies of the sequence may be more or less rapid, more or less gradual. The distance between the deepest terms and the suprastructure is variable, the shortest being about 1500 m, and average between 2 and 4 km.

We have already mentioned in the chapter concerning the description of Ketilidian rocks the existence of a red granite, NE of lake 470. In spite of its small extent, this rock is quite important, since it represents the final stage of this whole process, in other words the formation of an anatectic granite, H. H. Read's (1957) autochthonous granite.

Relations between migmatization and tectonics. One only has to look at the map showing Ketilidian structures (belonging mainly to the second phase) and the one representing the different migmatitic facies to be struck by the close resemblance between the two. An intimate connection is evident.

It is difficult to say that the formation of the big folds was anything but syn-migmatitic. There are naturally three possibilities:

a) the migmatitic front rose more or less horizontally in strata that had already been folded during the first phase. It was then folded during the second phase. Thus the migmatitic facies followed the folds, with some slight discordances.

b) migmatization was strictly contemporaneous with the folding of the second phase.

c) migmatization took place at the end of the second phase, when the folds were more or less formed. Granitic material was introduced concordantly along the planes of the structure. This is the most unlikely possibility, since the typical style of the folds indicates that the rocks must have acquired great mobility and plasticity before or during their deformation.

Since there is some hesitation as to the exact moment of the rise of the migmatitic front, we prefer to call the second phase of the Ketilidian orogeny syn-migmatitic. There is no doubt that migmatization was closely controlled by tectonics. The clearest example of this fact is to be found in the recumbent anticline N of Akuliarusiarssuk. Its core is composed of homogeneous gneiss. As one goes towards the adjacent synclines, the degree of migmatization becomes progressively weaker. To the W and SW, as the axis begins to dip towards the SW, higher levels of the migmatitic sequence appear in the core as well. However, there are some discordances. For instance, the homogeneous zone in the core of this fold does not remain in the same position NE of Akuliarusiarssuk. This may also be due to late-stage effects. In any case, concordance is the rule.

Such is usually the case between the arrested migmatitic front and the primary bedding of the suprastructure. This is mainly due to the presence of resistant layers which have prevented a further advance of migmatization. These barriers are most probably quartzitic horizons. Where these do not exist, unconformability occurs, and the higher levels of the migmatitic front are largely developed.

Element migration and Metasomatism. The conclusions of P. Lapadu-Hargues (1945) seem to fit in quite well with many facts that we have been able to observe in our region. Especially evident is the farther migration of sodium as compared to potassium, which remains localized in deep zones. This accounts for:

a) the growth of sodic feldspars which precede the main bulk of the migmatites;

b) the fact that, as migmatization increases, and banded gneiss grades into streaky gneiss, amphibole is practically entirely replaced by biotite;

c) the increase in the amount of microcline, going towards the deeper levels. In the red autochthonous granite, the proportion of microcline is higher than that of plagioclase. As it has already been mentioned, the formation of microcline is probably a late-stage event;

d) the fact that muscovite becomes increasingly abundant as one descends in the migmatitic stratigraphy.

Other types of metasomatism include:

e) calcium migration. This is indicated by the formation of basic oligoclase and amphiboles. Single crystals, patches and veins of calcite are frequent; they seem to be more clearly late-stage pneumatolytic effects, which may attain very high levels. Some calcite is, however, the result of magmatic activity belonging to the Gardar period. Epidote, another indication of this migration, constitutes frequent thin green films on joint-planes.

E. Hydrothermal segregation.

The most common case is a dark pellicle on joint-planes, composed of finely crystallized chlorite and magnetite.

One flat-lying vein is worth a detailed description. It is situated 600 m N of points 850, in the region composed of homogeneous gneiss. In the vicinity of the vein, there are several lenticular bodies and veins of the same material, and frequent rusty traces of iron-oxides. The vein itself is about 7 cm thick, schistose, and dark brown in colour with odd white quartzo-feldspathic patches. Small crystals of magnetite are conspicuous; they are embedded in a mass of phyllosilicates, and vary in concentration. Some crystals of pyrite are also visible.

Through the microscope one may observe the following sequence in three thin sections (Nos 38509, 38510, 38511) cut in samples containing apparently different proportions of magnetite:

1) big phenocrysts of acid oligoclase, slightly altered to sericite and rarely saussurite, are closely associated with large crystals of quartz showing undulatory extinction. Other phenocrysts include idiomorphic to sub-idiomorphic crystals of apatite containing small inclusions of epidote-zoisite, and big octahedra of magnetite. The groundmass is composed of very abundant biotite (showing a dark or light brown to light green pleochroism), sericite and zoisite, and less frequent apatite, hematite altering to limonite, magnetite, and very little chlorite and interstitial quartz. There is a close relationship between biotite and sericite, a transition between the two may be observed in a single grain. To summarize, the phenocrysts are mainly acid, the groundmass basic. Apart from the high magnesia and iron-oxide content, the surprising amount of phosphate is to be noted.

2) plagioclase is completely absent. Xenomorphic apatite is very abundant. Brown pleochroic goethite and plates of muscovite attain large dimensions. Chlorite is frequent. The other minerals are quite the same as in the first sample. The proportion of iron-oxide has increased.

3) the only difference between the previous thin section and this one is the absence of quartz.

If one considers the transition between the three rocks, the relationship between the basic matrix and the acid (quartzo-feldspathic) pegmatitic material becomes evident. As the proportion of the first increases, that of the second diminishes gradually, plagioclase being the first mineral to disappear and finally quartz. The final product is composed mainly of magnetite, biotite and chlorite, forming the bulk of the hydrothermal vein (a basic complement of granitization?).

This concludes a review of the effects of migmatization in our region. Subsequently, during the Sanerutian period, remobilization will take place, but introduction of new material will be practically nil.

F. Summary and conclusions of the Ketilidian period.

During the Ketilidian period, a mountain chain was formed, in which one may distinguish a migmatized infrastructure and a suprastructure composed of an ectinite series. The principal differences between these two units are in structure and lithology. The macroscopic and microscopic petrology of these rocks is reviewed.

The suprastructure includes pelitic, basic, quartzo-feldspathic, ferruginous and magnesian schists, which have recrystallized in the first two greenschist sub-facies according to F. J. TURNER and J. VERHOOGEN (1960). The infrastructure is characterized by various gneisses (banded, streaky, homogeneous) of which only one member rises out of the ordinary, i.e. the gabbro-anorthosites; the origin of these curious rocks is strongly debated. The apparition of garnet in these gneisses suggests a slightly deeper metamorphic facies. As a whole these rocks represent probably the transformation of the Arsuk group (C. E. WEGMANN, 1938).

Rust-zones may have various origins. In the greenschists they are probably pyrite-bearing sedimentary layers. In the gneiss they are more often related to crush-zones.

Pegmatites are mainly of the simple quartzo-feldspathic type. Zoning, pinch-and-swell structure, ptygmatic microfolding are current phenomena. Complex pegmatites containing minerals of pneumatolytic or hydrothermal origin are less frequent. Most of these veins were probably formed by slow diffusion of acid material in zones of weakness.

Whether it be in the infrastructure or in the suprastructure, there exist lenses of ultrabasic rocks, especially serpentinites or talcschists. Reaction phenomena in a contact zone with a pegmatite are described. Several arguments are put forward in favour of the hypothesis of a sill emplaced in the fresh and water-filled sediments of the geosyncline.

All these rocks underwent intense folding which may be divided into three phases:

1) a N–S to NNE pre-migmatitic phase.
2) a major WNW migmatitic phase.
3) a NE to ENE mainly post-migmatitic phase.

There is no evidence of a considerable break between the different phases.

During the first one, small steep folds were formed, the style of which suggests a predominance of schistose material.

The second phase is characterized by the formation of a synclinal suprastructure and migmatitic up-doming in the infrastructure, resulting in big folds, more or less recumbent, separated by steep synclines. Metamorphism attained maximum intensity.

Where both phases were very active, crossfolding and wild-folding occurred. An example of the use of the Wulf-net in unravelling one of these problems is given.

The effects of the third phase are not very visible in this area since they involve semi-plastic refolding, twisting and bending on a very large scale. Shearing of the suprastructure may be the main result. Microclinization seems also to belong to this phase.

The result of Ketilidian tectonics is the individualization of a suprastructure and an infrastructure, generally separated by a structural break.

The polymetamorphic character of Ketilidian rocks is summed up, the various transformations through metamorphism succintly described, and the close relationship between migmatization and regional metamorphism affirmed.

Migmatization and its relationship to tectonics reveal some interesting features. A complete migmatitic front may be traced from infrastructure to suprastructure. The close association between its emplacement and the WNW folds is quite evident. The distribution of the migmatitic facies in the recumbent anticline, N of Angmassivît, demonstrates this fact particularly well. Migmatization and the second phase of folding are clearly contemporaneous. Where resistant barriers (quartzitic horizons) exist, the arrested migmatitic front is concordant with the primary bedding of the suprastructure.

Element migration and metasomatism are reviewed. It is shown that sodium has migrated farther than potassium, which remains localized in deep zones. Calcium migration accounts greatly for the formation of basic oligoclase, amphibole, calcite and epidote.

Hydrothermal veins and pellicles on joint-planes are frequent. Their main constituents are magnetite, biotite and chlorite.

Fig. 35. Igneous banding in a Kuanitic Dyke. The layers are vertical and parallel to the direction of the dyke. The light bands are only a few mm thick.

THE KUANITIC PERIOD

During this phase of tension and fracturation the intrusion of at least three generations of basic dykes took place. Their general directions are, in chronological order: N100E (AD1), N160 — 170E (AD2), and N20 — 60E (AD3). These dykes are nearly always vertical, only those bearing a NE direction have sometimes a tendency to dip from 70 to 80° to the NW. The relationship between the two first generations is not visible in our territory, and we refer for this to the criteria of relative age put forward by M. Weidmann, further to the E. On the other hand, numerous intersections leave no doubt as to the age of the third.

It is to be noted that these dykes are concentrated in the centre and to the E of our territory, while they are practically non-existent in the western part (Pl. 14).

The transformations these dykes underwent during the subsequent Sanerutian period did not conceal the fact that they originally belonged to the dolerite family, of tholeitic tendency. One may still observe acid segregations, gabbro-pegmatites, even igneous banding phenomena (Fig. 35). This banding is generally parallel to the plane of the dyke,

Fig. 36. A small swarm of Kuanitic Dykes. There are about 15 to 20 members, each between 5 and 50 cm wide. They divide and join up in a very capricious manner. 200 m S of summit 590, NNE of Angmassivît.

more or less vertical; the light layers are a few mm thick. Here and there gneissic xenoliths (reaching in one case 30 cm in diameter) have been torn from the walls.

As the general map of these dykes indicates, they may be slightly sinuous, but this is more probably due to ulterior modifications rather than to the original emplacement. It happens, nevertheless, that a dyke, on encountering an obstacle (a very compact gneiss lens, for example), may make an abrupt detour. Where the greatest flexure takes place, small fractures develop, even a certain schistosity.

They divide very often and sometimes form small swarms, especially near their end (Fig. 36). The different branches are, on an average, 0.5 m wide.

The first generation (N100E) is not frequently represented. A very large dyke (20–50 m wide) belonging to this group, begins as rapidly as it disappears. Bifurcate to the W of lake 280, it passes S of lake 470; a more recent mylonitic zone coincides with it.

A huge dyke N160–170E runs through Akuliaruserssuaq (Fig. 37). It is forked where it enters into the sea to the SE, as well as at its NW extremity, on the other side of the little fjord of Kangerdlugssuaq.

Fig. 37. The very large Kuanitic Dyke which runs N160–170E, cutting across Akuliaruserssuaq. Here its width is about 150 m. A Post-Gardar dolerite (TD1; about 30 m wide) is clearly visible in its centre. The snowy depression is caused by a Gardar dolerite, emplaced after the amphibolitic dyke and before the Trap dolerite.

In the middle it measures at least 150 m. It contains a much younger dolerite (TD) near its centre; the snowy depression which crosses it is caused by another dolerite (BD) emplaced between the intrusion of the AD and that of the TD.

By their type of emplacement, frequency and aspect, it seems that the first two generations must have followed each other quite rapidly. The third is clearly different: the dykes are much more numerous, more uniform in thickness (on an average between 2–10 m), and more equally distributed. During the interval between the second and third generation, compression occurred forming a set of faults (in particular an early movement of the large E–W mylonite S of lake 470 m).

A curious intersection occurs between a thin dyke (2 m) of the third generation and the enormous dyke running N160E in the centre of Akuliaruserssuaq. At its entrance into the large homogeneous mass, the former, which had followed up till then an almost rectilinear path, begins to wind until its exit. It disappears a little further on. It seems fairly certain that the large dyke, in contrast with the country rock (gneiss) offered no easy path of penetration (Fig. 38).

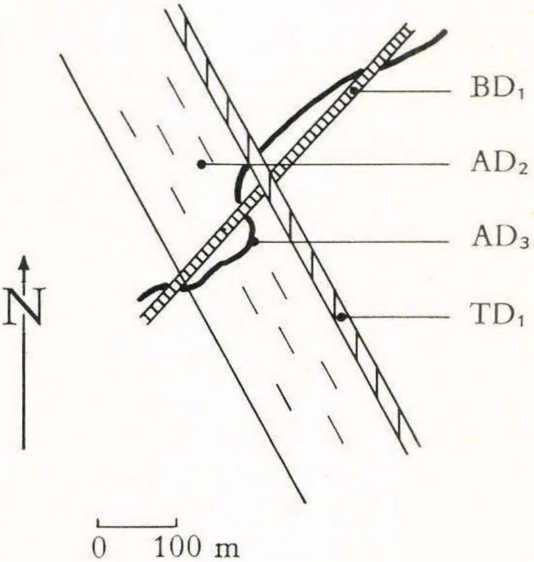


Fig. 38. A small Kuanitic Dyke belonging to the third generation winds its way through the large pre-existent metadolerite, which offered no rectilinear path of penetration.

As far as faulting tectonics are concerned, it is almost impossible to say whether a fault moved just after the emplacement of these dykes, or after their metamorphism which occurred during the subsequent Sanerutian phase. These fractures will be dealt with in the following chapter.

Summary and conclusions of the Kuanitic period.

During the Kuanitic period, three generations of tholeitic dolerites were emplaced in three distinct directions. Their width and density of distribution can vary considerably.

THE SANERUTIAN PERIOD

The phenomena which take place during this period have diverse effects; they vary, moreover, from one place to another. There occurs a rise of the thermal front, which produces a rather general reactivation. The result of its action on Ketilidian rocks is difficult to discern. We are therefore going to examine, in particular, the transformations undergone by rocks not included in the Ketilidian cycle, i.e. the Kuanitic Dykes. As it has already been mentioned, it is not possible to distinguish the different generations either by their petrography or through their transformations.

During the Sanerutian period the dyke rock is transformed into metadolerite or discordant ortho-amphibolite (AD), with the following characteristics.

A. Description of the Discordant Amphibolites (Kuanitic Dykes).

Colour. They may be green, grey-green, brownish, brown-red, grey-blue. They are generally mesocratic or melanocratic, only rarely leucocratic. The fresh colour varies between green-grey, light green and dark grey.

Structure. It is most often massive, but may be banded, even slightly or clearly schistose, the latter being due to dynamic phenomena.

General description and erosion. The rock, unlike the Gardar dolerites does not weather easily: gravel forms only occasionally. The dykes have round, ice-smoothed outlines. Often they are broken up into straight or oblique parallelepipeds, with a lozenge or rectangular base, through the action of three closely set joint systems (the volume of the parallelepipeds is about 0.2–0.5 dm^3). The rock may be very hard, especially where it is compact; these qualities vary mainly with the amount of phyllosilicates. Vacuoles often appear in the schistose dykes; they shall be explained further on.

Texture. The grain-size varies between fine and medium. The original ophitic or sub-ophitic texture frequently subsists and is visible with the naked eye; it forms relics in a blastophitic texture (or heteroblastic with ophitic residues). Quite often the plagioclase forms phenocrysts a few mm long. The amphibole and occasionally the phyllosilicates stand out from the mass but hardly exceed 1 mm. A certain amount of shearing naturally produces a cataclastic, nearly fluidal texture.

The weathered crust to which is due the superficial colour is rich in limonite; it is usually about 1 mm thick.

Mineralogical Composition.

A. Essential minerals.

Plagioclase. It appears in the form of intertwined laths, microlites or quite small phenocrysts. Quite often it is clouded, reddish or brownish, and nearly always shows twinning and zoning; this suggests weak metamorphism, as a higher degree of transformation would probably have destroyed the zoning. Sericitization and saussuritization always exist, at various stages, producing dense accumulations of sericite, zoisite, epidote, quartz, calcite and a less calcic feldspar.

Clouding of the feldspar may be characteristic of a certain amount of thermal metamorphism (A. G. MACGREGOR, 1931). If the rock is not entirely recrystallized, thus allowing its original texture to appear, the brown or red colouration is due to cryptocrystalline inclusions of iron-oxide (hematite), exuded from the feldspar lattice. If the recrystallization is complete, the feldspar again becomes clear. These inclusions are often limited to the most basic parts of the plagioclase, sometimes emphasizing the zoning. This is due to the fact that the proportion of Fe contained in the lattice is greater for a basic plagioclase than for albite-oligoclase. The temperature which brings about this exudation is probably quite high.

When the plagioclase is but slightly altered, one may note basic compositions reaching 45 $^0/_0$ An, the zoning corresponding to a variation generally situated within the limits of andesine.

The feldspar often contains quartz in the form of micropegmatitic, frequently graphic associations. This texture seems to be primary; it is common in quartz dolerites.

Pyroxene. Generally it exists only as a more or less transformed relic, and is a slightly violet, titaniferous augite, the proportion of which varies greatly: absent from certain thin sections, it constitutes 30–40 % of the rock in others. It is rarely twinned.

A rhombic pyroxene may possibly exist as well. A few grains of diallage make sporadic appearances.

It is mainly at the expense of the pyroxene that amphibole is formed. When the transformation is not too advanced, the former is surrounded by an uralitic border of green amphibole. But other alterations may occur, producing green chlorite and brown or green biotite.

Amphibole. There are several varieties. The most frequent is a common hornblende, with strong pleochroism going from dark green to light brown. It may show lamellar twinning and various inclusions amongst which sphene and apatite are conspicuous. The crystals are commonly idiomorphic. Alteration mainly produces finely crystallized green chlorite, biotite, and magnetite; the latter starts by filling the cleavages, replaces the edges (Fig. 39, and Pl. 7, fig. 1), and finally entirely fills the amphibole crystal. In many cases, amphibole is completely absent; its former existence may then be only attested by this skeleton-like magnetite.

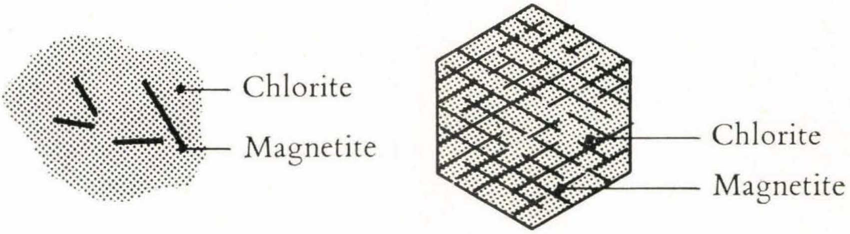


Fig. 39. Skeleton needles of magnetite reproduce the cleavages and the outline of a completely chloritized amphibole.

This hornblende may form elongated plates, which are very light in colour, even locally colourless.

Another variety of hornblende is probably of the basaltic type, with light to dark brown pleochroism. It may very well be primary, in which case the original rock would have been a proterobase.

B. Accessory minerals.

Sphene. It frequently forms abundant small, rounded, elongated or idiomorphic grains, with grey to purple colouring. By their size and refringence they stand out clearly from the finer groundmass. Their alteration sometimes produces leucoxene. Moreover, they generally surround pre-existent grains of ilmenite.

Apatite. It is found in the form of idiomorphic, very elongated needles or thicker-set prisms. Microscopically, hexagonal sections of this ubiquitous mineral are common.

Ore. First of all, primary magnetite forms small grains and dense aggregates. Ilmenite is also abundant, as well as pyrite in small cubes. Less frequently, limonite (lepidocrocite and goethite), hematite and rare chalcopyrite are present as well.

Biotite. It is likely that some biotite is primary and that it dates from a late magmatic phase.

C. Alteration minerals.

Zoisite. It forms dense accumulations of small, colourless, highly dispersive rods, and is a product of the destruction of the plagioclase.

Epidote. This brownish, slightly pleochroic mineral is rare. It sometimes accompanies products due to the destruction of the ferromagnesian minerals.

Quartz. Apart from primary quartz, mainly in micropegmatitic associations (Pl. 6, fig. 2), one observes common interstitial or alteration quartz, in small grains with undulatory extinction. It is often related to saussuritization.

Calcite. Mainly produced by the destruction of feldspars and amphiboles, it is also sometimes related to very late phenomena in connection with Gardar hydrothermal activity. The quartz-calcite association is common. Generally fresh, it may be chloritized along its cleavages. Rarely may one distinguish other finely crystallized carbonates (siderite-ankerite).

Chlorite represents the final stage of numerous alterations, and consequently, is amply distributed. It is usually lamellar or finely crystallized, light green in colour, not very pleochroic. Some cryptocrystalline amygdules are primary. A sporadic greenish-blue tinge indicates a local compositional heterogeneity, corresponding in general to a variation in the proportion of iron.

Biotite is commonly produced by the alteration of amphiboles. It is highly pleochroic grading either from green to brown or from dark brown to light brown. It is less abundant than chlorite, to which it alters.

Sericite. Its needles form very dense clouds in the plagioclase.

Let us now examine the transformations caused by the different phenomena.

Thermal Metamorphism.

The rise of the thermal front naturally caused the reactivation of the country rock at the same time as it affected the Kuanitic Dykes. This brought about weak, local displacements, and irregularities in the course of the dyke. While its edges are often of finer grain-size, they no longer show true chilled margins; sometimes the contact is even quite gradual.

J. Sutton and J. Watson (1951) have described 6 stages of evolution of metadolerites in the NW Highlands. The transformations undergone by the Kuanitic Dykes correspond quite well to the first two:

1) development of secondary hornblende around the pyroxene, without destruction of the original texture. The feldspar is cloudy.

2) replacement of the pyroxene by quartz-hornblende aggregates without destruction of the original texture. The feldspar is still cloudy.

If one refers to the general conclusions of J. D. H. Wiseman (1934), our amphibolitic dykes may reach the first stage of the "normal" trend. In this case, corresponding to the chlorite and biotite zones, there are relics of the original texture, and more or less advanced transformation of the minerals into chlorite, pale-green hornblende, albite and epidote. They may also follow the "abnormal" trend (with amphibolitic tendency, according to A. Poldervaart, 1953), which differs from the "normal" one mainly in the beginning of its evolution. In a first stage, the original texture being preserved, the plagioclase becomes cloudy, pyroxene and iron-ore are surrounded by hornblende; garnet may develop locally, but this is not our case. In a second stage, pyroxene is completely replaced by hornblende and quartz aggregates. The Kuanitic Dykes do not go beyond this stage of evolution.

The degree of metamorphism is therefore quite weak. It corresponds approximately to the second sub-facies of the main greenschist facies, according to F. J. Turner and J. Verhoogen (1960).

H. H. Hess (1933) and T. Vogt (1927) have also described transformations of diabase into greenschists, without stress, through the action of hydrothermal solutions and high temperature respectively.

Although the origin of these amphibolites is not doubted, let us mention, nevertheless, the high iron content (abundant ore, particularly pyrite), which characterizes the ortho-type, according to P. Lapadu-Hargues (1953), and a little Cu in the form of chalcopyrite, an element clearly more abundant in this type than in the para-type, according to the analyses conducted by A. E. J. Engel and C. G. Engel (1951).

B. Migmatization.

Introduction of acid material, related to very widespread granitization S of Ivigtut, is here insignificant. It is possible, nevertheless, that the emplacement of small quartz veins, and even occasional quartzo-feldspathic aplites are due to Sanerutian migmatization. The veins, a few cm in width (in average 0.5 to 5 cm), are generally vertical. In only one case did we observe a horizontal veinlet intersecting an AD. At its contact with the dyke, an abundance of phyllosilicates develops, particularly biotite.

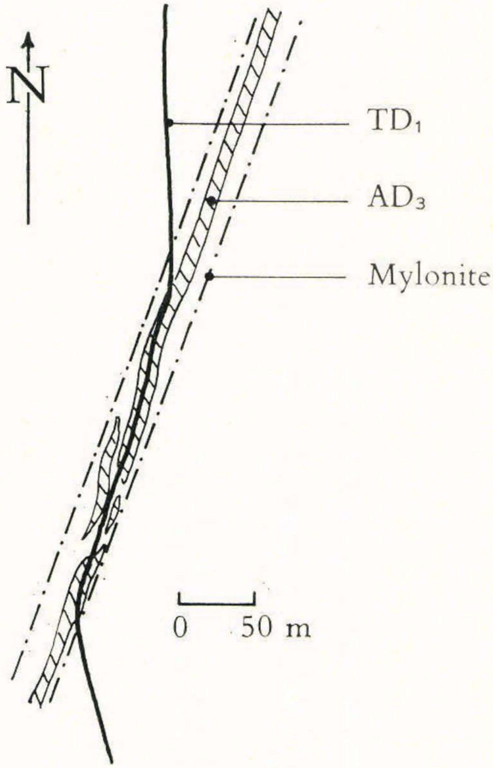


Fig. 40. An AD3 is drawn out and broken up into lenses in the big mylonitic zone of Qerrulik. A Post-Gardar TD1 subsequently followed the same course for about 400 m.

One km ESE of points 875–890 a pegmatite of purple quartz, 7 cm in width, intersects an AD3. The colouring comes from pigmentation of the quartz grains by hematite or limonite. Chlorite and yellowish epidote are abundant. There is also some biotite, magnetite and apatite.

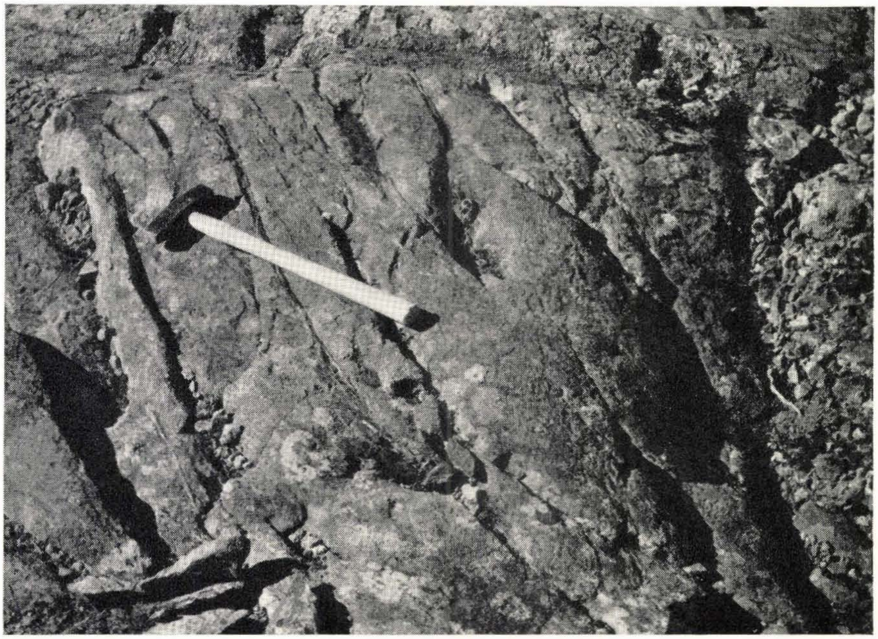


Fig. 41. The proximity of a big fault causes tension joints in an AD3, from which the direction of the movement may be deduced. NE extremity of the great N10E mylonite of Qerrulik.

It is often difficult to distinguish between migmatitic effects and the remobilization of quartz in fault zones. In any case, introduction of material appears to have been negligible, even nil.

C. Dynamometamorphism and mylonitization.

Faults, mylonites and other fault zones have had various effects on the ADs. These are often drawn out, boudinés, even broken up into lenses. Fig. 40 demonstrates this phenomenon, and also shows a Post-Gardar dolerite (TD) which followed the dislocation zone for about 400 m.

Locally, one may observe large swellings, where the width of the dyke may be 10 times its normal size. When the fault does not directly intersect the dyke, tension fissures occasionally develop, revealing the mechanism (Fig. 41, schematized in Fig. 42). Drags in the proximity of the fault-plane are also common.

A quite typical transformation consists in the development of an intense schistosity in the AD, either on one side only, or on both, or even throughout the dyke. The schists, of a soft-green colour, may be very fine or attain 1 cm in thickness. They are always vertical and often have cavities or vacuoles, previously filled with quartz lenses (sometimes folded and a few cm long) or nodules of calcite. Numerous relics of these lenses and nodules still subsist. According to F. J. TURNER and J. VERHOOGEN (1960), in zones of violent differential movements, a transition from amphibolite (hornblende-andesine-biotite) to greenschists (chlorite-actinolite-epidote-sericite) is produced by retrograde metamorphism (diaphthoresis). This transformation brings about a loss of CaO (T. F. W. BARTH, 1952), exuded here in the form of calcite. The quartz lenses probably come from the decomposition of the plagioclase; but in certain cases, they may be pre-existent, boudinés and broken-up quartz veinlets.

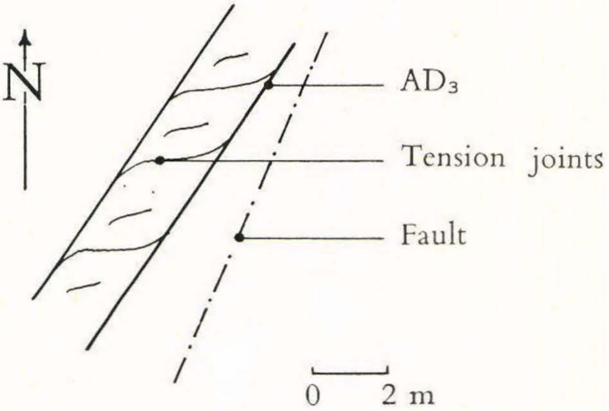


Fig. 42. Schema of Fig. 41, showing the relation between the dyke and the fault.

In his study of the amphibole-bearing gabbro of Mount Stanley (Northern Ruwenzori), P. MICHOT (1938) classified the dynamometamorphic transformations of this rock in the following manner:

1) Torsional deformation; the rock becomes a gabbro-amphibolite.

2) The grains subdivide; transition to an amphibolite.

3) There are no longer any large grains, the grain-size becoming very fine; hornblende slightly enriched in soda. The rock becomes a mylonitic type of amphiboloschist.

P. MICHOT proposed the term "amphibolonites" for these amphibolitic rocks whose recrystallization is contemporaneous with the mylonitization.

In some of our amphibolites, the transformation is similar to that of stage 3.

Hornblende, in particular, takes on a greenish-blue tinge, suggesting an increase in the proportion of soda.

When only the edge of the dyke is schistose, one may observe all the transitional stages from fine, vacuole-bearing schists, then more massive schists, to close joints, and finally to the massive dyke, the complete transition taking place over a few m.

The schistosity is naturally determined by the phyllosilicates, above all by chlorite and sericite, products of the diaphthoresis. Finely crystallized quartz, with undulatory extinction, is abundant. Small cubes of pyrite frequently lie on the surface of the S-planes.

D. Hydrothermal and pneumatolytic activity.

A small quantity of material was introduced through hydrothermal and pneumatolytic activity during the Sanerutian period, mainly after the emplacement of the Kuanitic Dykes, which will again enable us to define the phenomena.

A. Calcium migration. We have already noted the migration of CaO in the case of weak metamorphism of basic igneous rocks. In general it gives birth to calcite. A certain amount undoubtedly contributes to the formation of epidote, quite pure veins of which are occasionally associated with the amphibolites. But large quantities of this mineral are to be accounted for by late hydrothermal activity. Likewise, calcite (and the carbonates in general), which is practically ubiquitous, is mainly related to the pneumatolytic phenomena of the Gardar period.

B. Boron and sulphur migration. Long radiating needles of blue-black tourmaline (a schorlite) form clusters on joint-planes in the Kuanitic Dykes. This phenomenon is probably of Sanerutian age, as the Gardar dykes contain practically no tourmaline at all. The formation of pyrite and chalcopyrite is possibly partly due to hydrothermal solutions rich in H_2S.

C. Carbonic migration. This includes deuteric processes, through which feldspar, augite and olivine are transformed into carbonates at low temperature, with release of silica.

E. Consequences of Sanerutian phenomena on the basement rocks.

We have tried to define these phenomena in relation to the Kuanitic Dykes. In the Ketilidian rocks, a certain amount of reactivation causes local remobilization with partial recrystallization.

F. Sanerutian faulting.

While some faulting occurred between the emplacement of the different generations of Kuanitic Dykes, the most intense movements took place at the end of the Sanerutian period. Two systems are particularly evident. Moreover, one may find in these systems all the transitional stages between fault and mylonite (a fault being essentially a displacement without crushing of the rock, while a mylonite is a zone of crushed rock, with or without displacement).

A. The large E–W crush- and fault-zones.

1. The most important of these zones extends for 8 km in the centre of our territory and stretches into the area mapped by M. WEIDMANN. It is 100–200 m wide and sinistrally displaces an AD2 by about 1200 m. It has almost certainly moved twice, and in the same direction, before and after the emplacement of the AD3s, on which the displacement is about 550 m. Gneiss and dykes are considerably crushed and retrogressively metamorphosed. Rare slickensides show striations dipping 70° to the W, due to a last movement of small importance.

2. To the NE of lake 470, and also continuing to the E, a second E–W zone shows a curious bayonet and "en échelon" disposition, with a local inclination of 70° to the N. The rock is crushed over large areas. Quartz veins and rust zones are produced in which small vacuoles are particularly abundant; they also contain a little pyrite and some phyllosilicates (muscovite and biotite), even a little occasional calcite. The gneiss is reddish.

As it enters into M. WEIDMANN's territory, this zone is at least 100 m wide. Two AD3s have been displaced by about 800 m and again sinistrally. The large AD2 is drawn out and sheared near the N10E fault, where it disappears.

3. To the S of summit 590, a very sinuous AD1, containing large xenoliths torn from the walls, has undergone a displacement of 240 m due to one of these E–W zones. Its W extremity is formed of very numerous ramifications which change direction, take a NW course, before being dislocated by two other faults.

4. In the E part of Akuliaruserssuaq, S of summit 670, the sinistral movement of one of these faults has displaced an AD3 by 20 m.

5. At the foot of summit 850, on the S side, an AD1 is dislocated by a dextral N100E fault, the displacement being about 25 m; a notable swelling is produced. The differences in direction and displacement being slight, this fault may also enter into the category of the large E–W crush- and fault-zones.

B. The N60–70E crush- and fault-zones.

1. To the S of Angmassivît, an AD3 is drawn out along one of these mylonites and displaced by 100 m. Intense crushing produces considerable local swelling and numerous quartz veins. The movement of this mylonite is dextral, unlike most other mylonites of the same generation.

2. To the N of summit 590, one of these faults moved at two different periods. A pre-Kuanitic movement displaced dextrally a zone of schists by 100 m; a post-Kuanitic movement took place in the opposite direction with a displacement of about 8 m.

3. In the valley of the long lakes, in the northern part of the area, several of these faults dislocate ADs, but the displacements are small.

4. A large crush-zone, forming part of the valley to the NE of summit 850, displaces an AD2 by 10 m. It probably moved again later on, even affecting a Gardar trachyte. Dextral.

Less important systems.

C. The NNW faults.

Their movement, which is sinistral, does not exceed one hundred m or so. We observed three or four faults belonging to this category.

D. Other faults.

Numerous other little dislocations took place at the end of the Sanerutian period and before the Gardar, but do not form any well-defined systems.

N.B. The displacements mentioned are always in a horizontal plane, as vertical movements, if they existed, are practically indeterminable, because of the lack of correlating horizons. A few observations seem to indicate that vertical movement was not considerable. These faults are therefore horizontal transcurrent faults.

G. Summary and conclusions of the Sanerutian period.

A rise in the thermal front characterizes the Sanerutian period. All the pre-existent rocks undergo low-grade metamorphism. In particular, the Kuanitic Dykes are transformed into metadolerites, according to the process described by J. Sutton and J. Watson (1951). Migmatitic and metasomatic introduction of material is insignificant. Several fault-systems and crush-zones have been distinguished.

Absolute age determinations suggest correlation between the Sanerutian reactivation and the Nagssugtôqidian orogeny, whose remains are to be found between Søndre Strømfjord and Disko Bugt, also on the W coast, but further N (A. Berthelsen, 1961).

THE GARDAR PERIOD

The Gardar period is characterized in our area by various phenomena which one may divide into two categories, reviewed in the following order:

a) magmatic activity, including hypabyssal intrusions, pneumatolytic and hydrothermal effects, and mineralizations;

b) faulting tectonics.

One can distinguish three groups of dykes, i.e. in chronological order, lamprophyres (JD), brown doleritic dykes (Brown Dykes: BD), and trachytes (TR). Age relations are naturally based on field observations.

A. Lamprophyres (Pl. 16).

This family is represented by about 15 dykes, practically always vertical, sparsely distributed to the W and with maximum concentration to the NE, N of lakes 470 and 460. They are quite rectilinear, and their general direction is N50–60E, with variations between N45E and N70E. They are usually single but sometimes constitute swarms as, for instance, S of lake 460. Their thickness, in average about 1 m, rarely exceeds 5 m. In adjacent regions several generations have been distinguished; they may exist in ours, but this has been impossible to prove (absence of criteria, mainly of intersections).

These dykes are melanocratic, with a weathered colour which may be black, brown, or reddish. The fresh colour is grey-black to black. The rock is particularly recognizable through the presence of calcite grains attaining 1 cm in diameter, accompanied by abundant lamellae of biotite, varying in length between 1 and 3 mm. Small feldspathic phenocrysts are common and abundant cavities filled or lined with limonite result from the oxidation of pyrite cubes.

On the surface of the rock, the differential weathering of the various constituent minerals locally renders visible to the naked eye the intersertal or sub-doleritic texture.

The grain-size is usually fine, particularly towards the edges, where chilled margins sometimes exist. Alteration is commonly intense, producing gravel. Joints, perpendicular to the walls, and sometimes closely set, tend to form columns (columnar jointing).

These rocks are dense; this is due in particular to their high iron content, which explains their local name of "Jerndiabas", or iron-bearing diabase (JD), but the term is inadequate. If absolutely necessary, one could call them ferro-dolerites, by analogy with ferro-gabbros; but we shall see that for various reasons, and according to several authors, it is quite justified to classify them in the lamprophyre category. This will become apparent in the following detailed examples.

On the E shore of the bay between Angmassivît and Akuliarusiarssuk a lamprophyre, 60 cm in width, N45E in direction, outwardly brown, grey-black when fresh, massive, and rich in feldspathic nests and limonitic cavities, shows, microscopically, a sub-doleritic texture. The plagioclase is represented by laths and needles forming the frame, and also by phenocrysts. It is quite altered and shows twinning and sometimes zoning. Average composition is about 45 $^0/_0$ An. Notable calcite crystals are common and seem to be associated with idiomorphic or sub-idiomorphic grains of nepheline. Small crystals of pink sphene and grains and rods of apatite are abundant. The very fine interstitial material probably includes a monoclinic pyroxene and some biotite.

In the rock appear large amygdules composed of green chlorite, generally surrounded by sericite, both being very finely crystallized. One of these amygdules (Pl. 2, fig. 1) shows a centre formed by a mixture of these two phyllosilicates, enveloped in a rim of magnetite, which forms, moreover, abundant small grains throughout the rock. There also exist veinlets of pyrite about 1 mm wide.

To sum up, the most remarkable feature is the high content of volatile products, particularly CO_2 and H_2O. These substances have even modified the encasing gneiss: as one approaches the contact with the dyke, flakes of biotite become progressively more abundant over the last few cm. H. G. Smith (1946) draws attention to the important role that these gases play in the deuteric transformation of primary minerals; in particular, CO_2 of magmatic origin may carry lime, taken from the plagioclase, from lower to higher levels. This enrichment in lime may, moreover, proceed from the assimilation by the (basaltic) magma of calcareous rocks (I. Campbell and E. T. Schenk, 1950).

In the classification of lamprophyres which is quite variable from one author to another, we place this rock between camptonite and kersantite.

The second example is that of a lamprophyric dyke, 5 m wide, N40E in direction, situated in the valley N of Akuliarusiarssuk. Its grain-size is medium and it displays calcitic phenocrysts, 1 cm long, and some pyrite grains. The sub-doleritic texture is mainly defined by laths of plagioclase, rather sericitized, showing good twinning, and strong normal zoning, from albite to andesine. Frequent, secondary albitic growths are quite in accord with the conclusions of H. G. SMITH (1946) who emphasized the enrichment in soda content of the late-stage residual products. Numerous grains of pyroxene, a pinkish titaniferous augite, are idiomorphic or sub-idiomorphic. The rock tends thereby towards a texture which is considered to be rather characteristic of lamprophyres according to several authors, i.e. a coarse panidiomorphic texture. Calcite forms abundant amygdules. Biotite and chlorite are very well represented; green chlorite in particular also forms amygdules. The opaque minerals include magnetite, limonite, ilmenite, hematite and pyrite. Apatite is ubiquitous.

Here too, the presence of volatile products is remarkable. The rock is in this case a true camptonite.

East of Qerrulik one may observe a JD, superficially reddish, black when fresh, 1 m wide and N45E in direction. It is massive, dense and shows feldspathic phenocrysts between 1 and 3 mm and flakes of mica.

Microscopically, one observes an intersertal, slightly ophitic texture, with two sorts of microphenocrysts:

a) an augitic pyroxene with chloritized edges, cracks and cleavages;

b) a rather sericitized plagioclase, whose alteration sometimes produces quartz grains; it contains small, black inclusions, probably aligned according to the cleavages of the feldspar, and of glassy composition. Anorthite content is about 25 %; it is therefore an oligoclase.

The groundmass is composed of:

c) a very abundant augite, locally slightly titaniferous (pink), often idiomorphic, with frequent twinning. It alters to chlorite, biotite and magnetite, more rarely to epidote.

d) a sodic, pleochroic amphibole (varying between orange-yellow and dark red-brown). It is a barkevikite. This abundant and idiomorphic mineral is the result of uralitization of the pyroxene. Sometimes it contains a core or relics of this mineral.

e) numerous amygdules of biotite-chlorite.

f) a little calcite.

g) abundant ore, especially magnetite.

h) apatite.

The presence of barkevikite is an indication of the enrichment in the soda content of the rock. This mineral is quite characteristic of lamprophyres in general, and particularly of typical camptonite from which this rock is little different. T. F. W. BARTH (1952) is of the opinion that the necessary water for the formation of this barkevikite is taken from the walls, which would bring about the lowering of the temperature of crystallization and the forming of amphibole instead of pyroxene.

As well as chlorite and calcite, in amygdules, there is some epidote, the presence of which is also an effect of pneumatolytic activity.

Apatite is often abundant. Some of it may not be strictly primary, as the residual gases also contain a certain amount of phosphorus.

800 m NE of lake 470 there is a lamprophyric dyke 2 m wide, N65E in direction. The rock is brown and commonly spotted with small patches of calcite (1–2 mm), limonite, and some rare grains of pyrite. The fresh colour is grey-black, the grain-size fine, and the texture micro-granular to intersertal. It contains amygdular grains of calcite, sometimes twinned and frequently enclosed in fine, green and fibrous chlorite. Plagioclase, epidote, titaniferous augite, muscovite and sericite, biotite, zoisite, opaque minerals, uralitic hornblende, quartz, albite and apatite are the other constituents of the rock. The plagioclase is locally quite fresh but more often altered to saussurite, and filled with inclusions. It shows good twinning and zoning, varying between a positive oligoclase and a negative andesine. Epidote which sometimes shows twinning, is slightly pleochroic (golden-yellow to brown); it forms very abundant grains and amygdules. Idiomorphic or sub-idiomorphic crystals of titaniferous augite are also numerous. Muscovite and sericite are ubiquitous; the dark mica is a very ferruginous biotite, in brown or red laths, altering to limonite and magnetite. Occasional small grains of zoisite are probably in relation with the saussuritic mass. Opaque minerals are abundant and mainly represented by magnetite and ilmenite, both idiomorphic. One must also mention some brown, uralitic hornblende, a few quartz grains and possibly a little albite, both associated with amygdules and, as usual, apatite. Some limonitic streaks are bent, indicating that the rock has been submitted to a certain amount of mechanical strain.

The following table summarizes the proportions of the various minerals contained in the three lamprophyric dykes described hereabove. These estimates were obtained through point-counting.

No.	32931	38942	38507	
	%	%	%	
Plagioclase	56	40	44	
Pyroxene (and amphibole)	10	23	19	
Ore	9	8	15	(very high)
Calcite	3	—	3	
Phyllosilicates (of various origins, epidote and apatite)	22	29	19	

Let us remark once again on the presence of these chlorite-, calcite-, and epidote-bearing amygdules, also containing a small proportion of quartz and albite, as well as on the local transformation of pyroxene into hornblende.

The volatile products containing alkaline compounds are therefore extremely important. At an early stage, it is mainly potash that is introduced, taking place in the micas (biotite and muscovite), the increase in soda being a late-stage effect.

Petrogenesis. As to the petrogenesis of these rocks, there is no evidence that they are schizolites (diaschistic rocks), resulting from magmatic scission, nor are they similar to lamprophyres which one may observe in granitic regions, sometimes in radial disposition around a massif. They are much rather transformed basic dykes (C. E. WEGMANN, 1948 b).

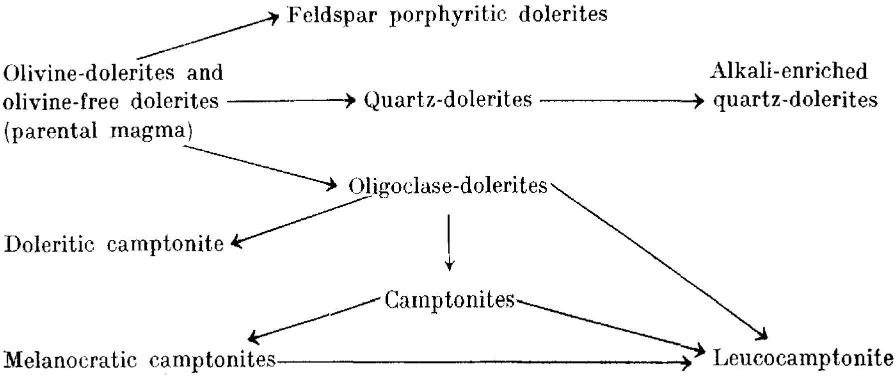
A useful comparison may be established between these dykes and the hornblende-lamprophyres, associated with basaltic rocks, in the Skaergaard region, on the E coast of Greenland. Observed by L. R. WAGER (1947), they have undergone minute laboratory investigations by E. A. VINCENT (1953). Numerous and excellent arguments indicate a transition, from the same basaltic magma, between normal dolerites and camptonites, through oligoclase dolerites. Chemical analyses show a decrease of the proportion of silica for the oligoclase dolerites and camptonites, but an increase in alkalis, mainly in potash. There are little chemical differences between the two last groups, the camptonites resulting from a crystallization at lower temperatures, of a water-enriched magma.

The oligoclase dolerites are composed of a clinopyroxene and a sodic feldspar (generally oligoclase, or oligoclase-andesine). In spite of their basic nature they may contain here and there a little interstitial quartz. The ophitic texture of the dolerites becomes a more panidiomorphic texture (especially in the case of augite). They clearly contain more alkalis than the normal dolerites.

The camptonites are characterized by a brown hornblende and a sodic plagioclase. They may also contain a clinopyroxene and pseudomorphic forms of olivine. Secondary minerals, in particular epidote and chlorite are abundant. The pyroxene is a diopsidic titaniferous augite.

This rock is considered to be the result of fractional crystallization of a primary basaltic magma, to which one must add deuteric transformations (pneumatolytic and hydrothermal, autometamorphic), producing mainly chlorite, epidote and albite. The introduction of volatiles rich in alkalis is a late-stage magmatic phenomenon, according to the author, who is of the opinion that it is superfluous to look for other sources to explain this enrichment.

In the region under study, it seems that the lamprophyres correspond very well either to the oligoclase dolerites or to the camptonites defined by E. A. **Vincent** who sums up the successive differentiations in the following schema. There is, however, a difference between the two areas: on the E coast, the camptonites seem to have been emplaced later than the dolerites whereas, in our region, they precede them.



Two other cases are worth a brief description.

NE of lake 470, 600 m approximately from its shore, and very near to the great N10E mylonite, there is a basic dyke about 1 m wide. It is crushed by a small, parallel fault, N45E in direction, which displaces sinistrally a N30E AD (Fig. 43).

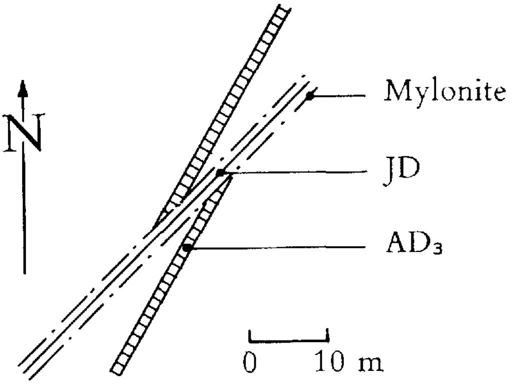


Fig. 43. A lamprophyric dyke coincides with a small fault which displaces sinistrally an AD3. The JD is crushed and acquires a breccia-like aspect. 600 m NE of lake 470.

The small, basic dyke acquires a breccia-like aspect. The rock is fine-grained and shot through by thin, dark veinlets. Locally the surface is shiny or striated, with blue metallic tinges due to a thin film; elsewhere it may be coated with fine calcitic plates.

Under the microscope one observes a cataclastic texture and the following minerals: plagioclase, quartz, limonite, phyllosilicates, calcite and apatite. The plagioclase forms microphenocrysts and is quite fresh; it sometimes contains minute inclusions and shows slight zoning, while twinning is rare. It is an optically negative oligoclase. Quartz is abundant and also microphenocrystalline. One notes, moreover, large grains of limonite (goethite), which are translucent, dull, yellowish-brown, and also needles or streaks. The groundmass is mainly formed of phyllosilicates: greenish chlorite and white mica (sericite-muscovite). These two minerals may also constitute veins in the rock. Calcite is abundant whether in grains or in veinlets, which sometimes intersect the feldspars. Minute crystals of feldspar and quartz compose here and there micropegmatitic associations. Apatite is present in the form of needles.

Although dynamometamorphism partly erases the original characteristics of the rock, the large quantity of phyllosilicates and calcite, a certain proportion of which certainly proceeds from the destruction of the feldspars and the ferromagnesian minerals, induces us to classify it amongst the dykes with a lamprophyric tendency.

Peculiarities of emplacement may occur, such as that observed on the E coast of Qerrulik. A lamprophyre, 50 cm wide, 4 m long, containing pyrite, meanders in a zone of weakness determined by a Kuanitic Dyke.

In our region we did not observe the trace of any very definite tectonic activity between the emplacement of the lamprophyres and of the subsequent Brown Dykes. The mylonite which determines the valley N of Akuliarusiarssuk displaces sinistrally a lamprophyric dyke by about 60 m towards its southern extremity, but towards the N its effect dies out completely before reaching a BD, thus concealing that relationship. It is likely that faulting played an insignificant role between JDs and BDs.

B. Brown Dykes (Pl. 15).

These dykes form the largest group, in number, in volume and in extent, of the whole Gardar suite. They are dolerites with or without olivine, sometimes with a troctolitic, proterobasic or porphyritic tendency. C. E. WEGMANN (1938) already assembled them under the name of Brown Dykes, abbreviated to BD.

Description. Contrasting strikingly with the encasing rock, they may be followed over great distances, their course being quite rectilinear; but they often display various types of irregularities. Their weathering is

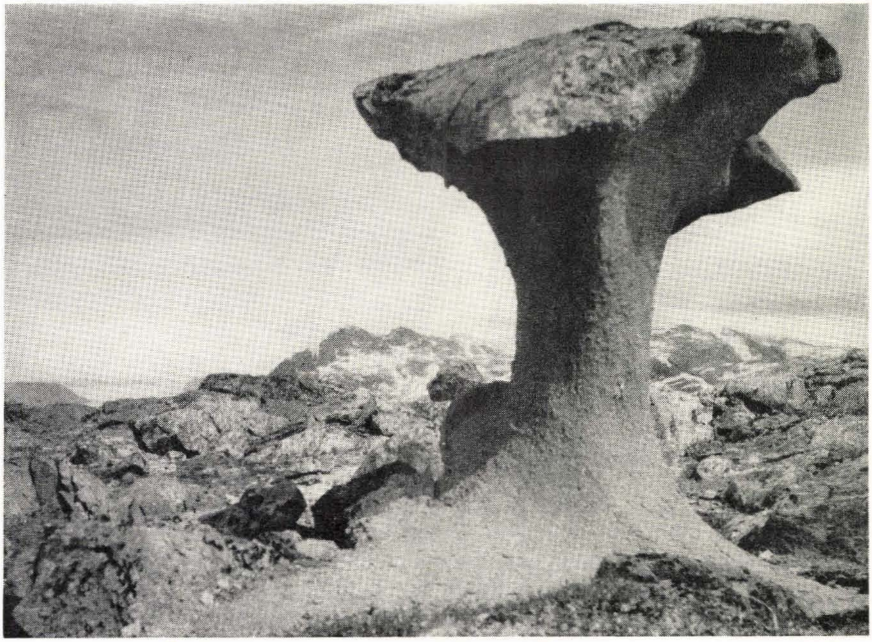


Fig. 44. A curious example of the modelling of a doleritic boulder by eolian erosion. The "mushroom" is about 1.6 m in height. Approximately 2.2 km N of Angmassivît.

typical: they are separated into blocks by three joint systems, two of which are perpendicular to the walls, the other parallel; this is due to contraction, during cooling. These blocks are then transformed into boulders according to the desquamation process described by R. W. Chapman and M. A. Greenfield (1949); finally they disintegrate into sand which may form a bed a few feet thick, in certain cases entirely concealing the fresh rock. R. D. Crommelin (1937) attracts attention to the importance of these sands in which the high titanaugite content is characteristic. Fig. 44 shows a curious example of the modelling of a doleritic boulder by eolian erosion.

When they are wide, these dykes may determine valleys. But the same dyke may form here a depression, there a crest. This may be at least partly due to the angle of the slope. On the other hand those that are only a few feet wide have practically no morphological effect.

They may vary in width between a few cm and two hundred m, the average being between 5 and 20 m.

Three generations have been distinguished, the oldest being ENE in direction, the youngest NE, the second intermediate; this disposition may undergo local variations. We have designated the three groups by the abbreviations BD0, BD1, and BD2.

Fig. 45. Dykes frequently split up into numerous branches, generally due to a system of parallel, pre-existent joints. This occurs mainly as they are about to die out.

One must mention, moreover, that the two last generations were separated by an interval sufficiently long for an important phase of faulting to occur.

Colour. As their name indicates, their superficial colour is generally brown. Here and there it seems possible to differentiate the BD0s from the BD1s; the first are very dark, practically black, the second are orange-coloured, even yellow. The fresh colour is dark grey. As C. E. Wegmann (1938) has already mentioned, a remarkable calciphilous flora grows on these rocks.

Emplacement phenomena. One may enumerate several irregularities in their disposition. First of all they may form small swarms, generally due to a system of parallel, pre-existent joints. Frequently the swarm

Fig. 46. "Pseudo-bayonet" disposition in a BD. The bridge of gneiss has clearly been displaced. As is frequently the case in true bayonet arrangement, the bridge is intersected by numerous little veinlets which link up the two parts.

is but the result of the subdivision of a single dyke, mainly when it is about to die out (Fig. 45).

Bayonet, "pseudo-bayonet" (Fig. 46), and "en échelon" (Fig. 47) arrangements are common, as well as apophyses.

Sudden changes of direction are not easily explained. Sometimes one sees a dyke split up into two parts which join up again further on, probably passing on each side of a more resistant gneissic lens.

The increase in volume due to the dilatation of the fissures intruded by the hypabyssal rocks must be considerable as these occupy a conspicuous proportion of the area.

Grain-size. In the normal and most frequent case, there is a symmetrical variation of granularity in relation to the centre of the dyke, the grain-size diminishing as one goes towards the edges, which are often black and very finely crystallized (chilled margins).

Occasionally the grain-size suddenly increases, forming pegmatitic rocks, known under the name of "gabbro-pegmatites". They have the same mineralogical composition as the rest of the dyke and were probably formed in pockets with a high gas content, which allowed slower crystallization and bigger growth of the crystals.

Flow-lines and whirlpools are to be observed here and there.

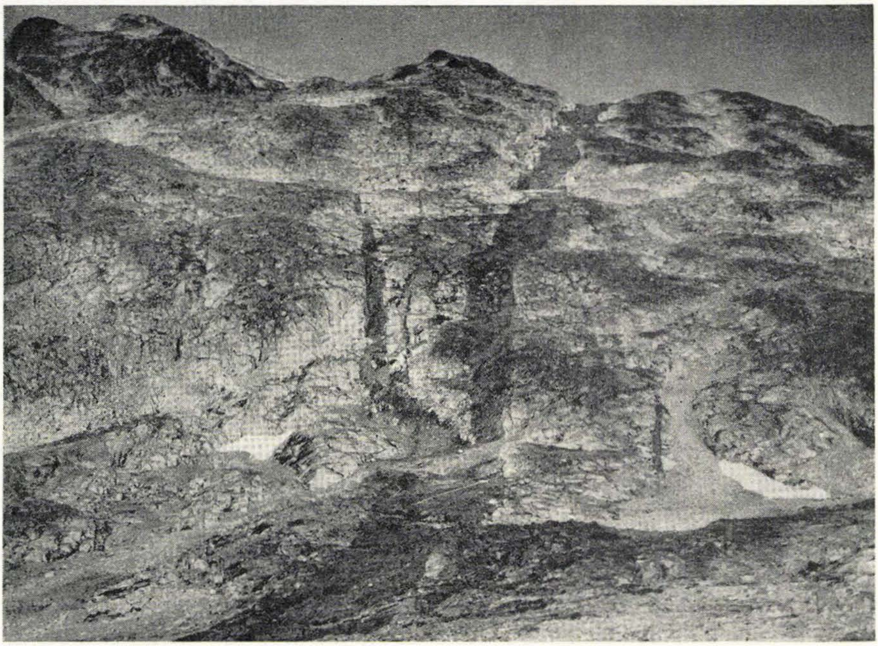


Fig. 47. "En échelon" disposition in a BD. This is a current feature. Sometimes 3, 4 or 5 relays constitute the system. 2 km NW of lake 470.

Texture. It is quite constant for all these dolerites and appears clearly on the weathered surface, as well as under the microscope. The main texture is ophitic (Pl. 7, fig. 2) except in the edges of the dyke where it may become intersertal, pilotaxitic or hyalopilitic. But certain variations have been noted including sub-ophitic, doleritic and sub-doleritic textures; these variations have been summarized in the following table, established by T. KROKSTRÖM in his work on the crystallization of basaltic magmas (1933).

Description		*Name*
The pyroxene shows over large areas a uniform orientation.	The plagioclase laths are entirely enclosed within the large pyroxene areas.	Ophitic
	The pyroxene is subordinate in amount and forms a filling in the small interstices between the feldspars.	Sub-ophitic
The pyroxenes of adjacent interstices are of different orientation.	The pyroxene grains are idiomorphic or subidiomorphic.	Doleritic
	The pyroxenes have their outlines determined only by the surrounding plagioclase laths.	Sub-doleritic

Mineralogy of the typical dolerites.

The plagioclase. Its intertwined laths show polysynthetic and complex twinning. Zoning is normal and marked. The composition of a single crystal may vary by 20–40 % An. The minimum that we evaluated is 25 % An, the maximum attaining the limit labradorite-bytownite, i.e. 70 % An. The average composition is situated at about the limit andesine-labradorite (between 45 % and 55 % An.). The plagioclase alters to sericite and/or saussurite, but generally it is surprisingly fresh. Phenocrysts naturally undergo more intense transformation than the microlites. Often the alteration underlines the zoning. When inclusions exist, they are mostly composed of micrographic quartz, as the rock tends towards a quartz dolerite.

The pyroxene. It is mainly a titaniferous, pinkish augite. It is sometimes twinned and alters slightly to chlorite, biotite, and magnetite-ilmenite. A certain amount of uralitization takes place here and there producing a brown hornblende; this last mineral is practically never primary, which renders the existence of proterobasic rocks very improbable, at least in our region. Dispersion is strong. A variably diopsidic composition in a single crystal produces weak zoning. Locally the optic angle (2V) becomes very small and the augite tends towards a pigeonite.

Olivine. When it exists, it forms large grains, either idiomorphic or sub-idiomorphic (Pl. 9, fig. 2). It frequently accompanies the pyroxene crystals. Its alteration begins by the edges, fissures and cleavages, before spreading to the whole crystal. The products of this tranformation are: brown iddingsite, green bowlingite and goethite. The proportion of this peridot varies considerably, probably because it is the first to crystallize; moreover its crystals have a tendency to sink and to form quite dense local concentrations. The plagioclase is formed at the same time as olivine or slightly later, whereas pyroxene appears much later (F. WALKER, 1957).

Sphene is quite rare. Its colourless or pink grains are nearly always associated with leucoxene and ilmenite.

Biotite is generally the transformation product of the ferromagnesian minerals, but may also crystallize in a late-stage magmatic phase. It may itself alter to cryptocrystalline, green or brown vermiculite. Iron content is always high.

Chlorite derives directly from the pyroxene or from the amphibole; it may replace biotite, and is light green.

Apatite. Ubiquitous and fresh, it forms long needles, thick rods or grains and often exhibits hexagonal sections.

Opaque minerals are very abundant and mainly include idiomorphic grains or accumulations of magnetite, ilmenite, limonite, a little hematite, and some cubes of pyrite. It is practically always primary, but may also be part of the final alteration product of the ferromagnesian minerals.

Epidote is not common; it sometimes constitutes small druses containing well-crystallized forms. It appears, like zoisite, through the decomposition of the plagioclase.

Calcite may proceed from the destruction of calcic minerals, or from ulterior metasomatic effects.

Quartz may be interstitial, micrographic or secondary and is always in small proportion.

Rutile is very rare, and sometimes forms inclusions in the biotite.

Zircon also forms sporadic inclusions in the phyllosilicates, producing pleochroic halos.

The proportions of these various minerals vary considerably as we have already mentioned. Not only are these differences noticeable from one dyke to another, they may also be observed in a single dyke in which quite rapid longitudinal or transversal variations may occur (this last case will be examined in detail further on). The following table shows a few examples of these variations.

Mineral *No.*	32847	32848	32910	32911	32943	32945	32949	32957
Plagioclase	60	60	56	51,8	46	60	62	53
Pyroxene	18	13	14	22	22	15	16	25
Olivine		7,7	16,5	2,5		18	13	4
Opaque minerals...	8	4,6	6,5	11	13	4	7	11
Others (primary & secondary phyllosilicates, uralitic hornblende, apatite)....	14	14,8	7	12,7	19	3	2	7

These percentage figures, estimated with a point-counter, are only approximate.

Consequently, in two cases (Nos. 32910 and 32945), the rock has a tendency towards a troctolite, and in the second, it happens to be a gabbro-pegmatite, which may be significant. On the other hand, we have not been able to establish any systematic variation of the proportion of olivine, and in particular of the relation olivine/pyroxene during the course of time. BD0, BD1, and BD2 are dolerites with or without olivine and do not show any evolution from one to another.

Fig. 48. A xenolithic dyke. The margins contain only sparse, small xenocrysts or phenocrysts. The centre, on the other hand, contains up to 40–50 °/₀ of xenoliths and xenocrysts (mainly anorthositic and plagioclasic). They are all of about the same size, and are not oriented in this case. 200 m S of lake 470.

Phenocrysts, Xenocrysts, Anorthositic Xenoliths.

Sometimes these dykes contain big crystals of plagioclase (occasionally accompanied by other minerals). Three cases may occur:

a) they are true phenocrysts formed more or less *in situ*. These idiomorphic crystals, the size of which varies between 1 and 15 cm, their longest dimension averaging between 2 and 5 cm, are generally not oriented; sometimes however, they may be aligned in bands parallel to the axis of the dyke and 10–20 cm in width. Their proportion varies considerably, attaining here and there 40–50 °/₀ of the rock.

b) they may be big crystals which have grown in depth and which have been torn away after their crystallization, and carried up to higher levels by the movement of the magma. In this case they lose their idiomorphism, their outline is worn or broken. They are therefore veritable xenocrysts, which may also be very abundant. Sometimes both sorts of plagioclase coexist and it is difficult to tell whether they have grown where one finds them, or whether they have undergone transportation.

c) there also exist xenoliths, attaining in some cases 30 cm in their biggest dimension, which are either solely composed of big crystals of

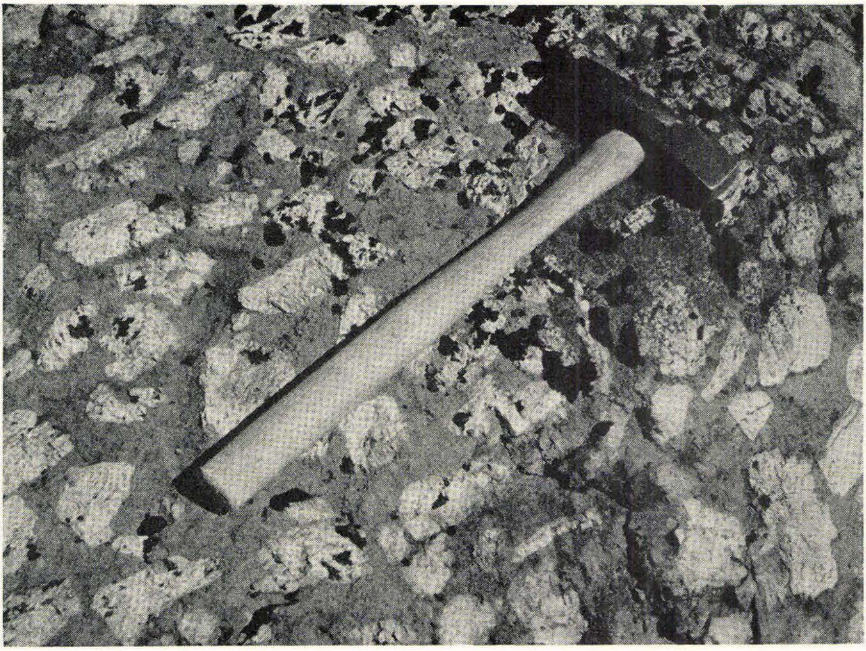


Fig. 49. Detail of the central part of the xenolithic dyke in fig. 48. Some subidiomorphic crystals are to be noted. Most frequently, the xenocrysts have worn or torn edges. Anorthositic xenoliths are also abundant.

plagioclase, or of an aggregate of various minerals (Fig. 50). The first variety forms true anorthosite, and it is the most common. Generally these dykes show the following disposition: the two edges, over approximately 30–40 cm, are practically free from big crystals of plagioclase which, if they exist, do not exceed 1 cm, whereas the centre is rich in xenoliths frequently constituting 40–50 % of the rock. This disposition is sometimes only local; further on the dyke may grade into a common dolerite. Figures 48 and 49 show one of these dykes and the detail of its central part.

Let us rapidly examine the mineralogical composition of a rather typical sample of a xenolithic dyke. Under the microscope the groundmass reveals a sub-doleritic texture. The feldspar shows good twinning and zoning, alters to sericite and saussurite, and contains, moreover, numerous inclusions of glass. It varies between 30–40 % An. The interstices are filled with green chlorite, brown biotite, sericite, sphene, altering to leucoxene, zoisite, some rare relics of pyroxene, some very finely crystallized patches, large grains of calcite and a few grains of quartz, apatite, magnetite and ilmenite. A xenolith which is embedded in this

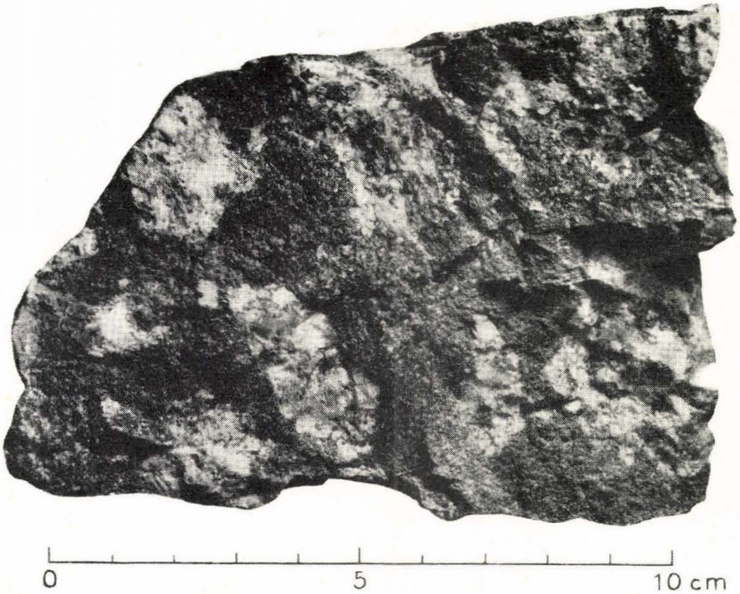


Fig. 50. Xenolithic and phenocrystalline dolerite (BD). The white patches are composed of plagioclase and quartz. (No. 38528). Central part of Akuliaruserssuaq.

groundmass, is composed of numerous and large quartz grains, a weakly-zoned plagioclase at about 45 $^0/_0$ An, containing occasional inclusions (of potassic feldspar?), interstitial calcite, abundant fibrous zeolites, and some phyllosilicates (biotite-chlorite) with a little leucoxene.

This xenolith, separated from the groundmass by a fine margin of phyllosilicates, mainly chlorite, was apparently undergoing digestion.

Elsewhere a yellow-greenish xenocryst reveals numerous glassy inclusions forming a sort of lattice (Pl. 9, fig. 1). It too varies between 30–40 $^0/_0$ An.

The rock of this dyke approaches a quartz doleritic composition, the xenolith, that of a tonalite-aplite, according to the terminology of A. Johannsen (1931). In a general manner these dykes practically all enter into the category of the quartz dolerites; this is also suggested by frequent micropegmatitic associations between quartz and plagioclase.

Let us add that in other regions, on the basis of clearly defined intersections, one or more well-individualized generations of these xenocrystalline dykes, called "Big Feldspar Dykes" (BFD), have been distinguished. In our territory this is not the case: as we have already mentioned, the presence of xenocrysts and xenoliths is always localized in space.

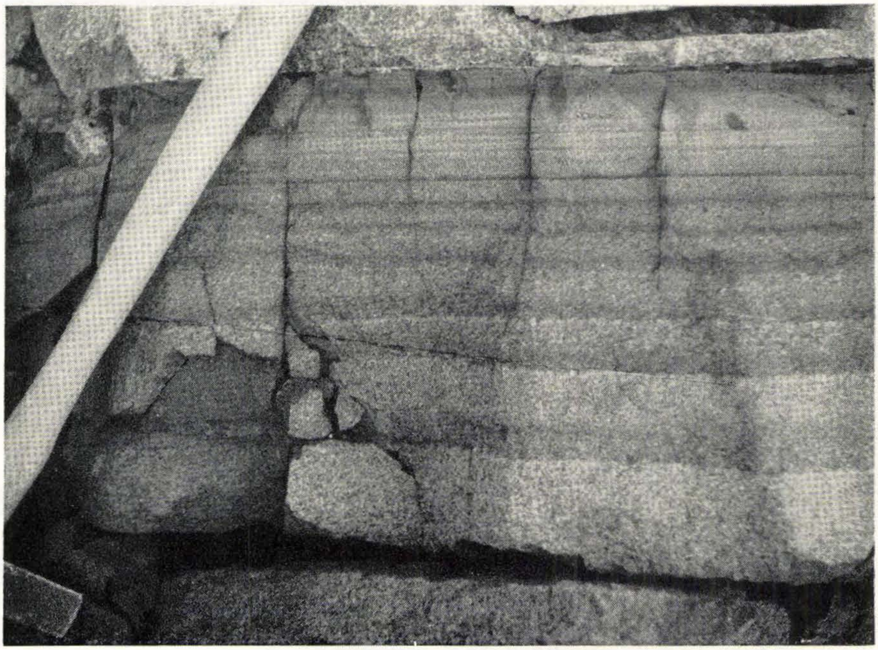


Fig. 51. Igneous banding in a BD. The leucocratic and melanocratic bands are a few mm or cm wide, and succeed each other in an irregular manner. It is nevertheless evident that they decrease in width as one goes towards the edge. The bands are, as in this case, generally vertical and parallel to the direction of the dyke.

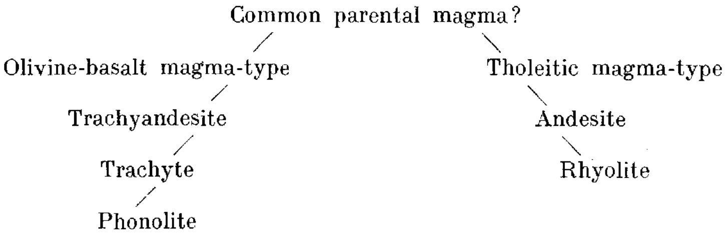
Igneous banding. This phenomenon is often well developed (Fig. 51). The leucocratic and melanocratic bands are a few cm wide and succeed each other in a mainly irregular manner.

Generally the banding occurs in the direction of the dyke, and vertically. Sometimes it is oblique to the walls of the dyke, and inclined by 60–70° towards the N. In one case it takes the form of horizontal beds, in average 0.2 to 1 cm thick. The leucocratic layers, apparently more resistant to erosion than the mafic bands, often form small ridges.

Acid and basic segregations. — "Pegmatitoïdes". In all the generations of dolerites, one may encounter variations which are seemingly more frequent in the BD1s. The products of these variations are mainly composed of interstitial material, the residue of earlier crystallizations, the composition of which depends on that of the initial magma. Among the numerous authors who have made contributions to this problem, W. Q. Kennedy's conclusions (1933) are particularly edifying; they have been summarized in the two following tables:

"Pegmatitoïdes" of olivine-basalt magma.	"Pegmatitoïdes" of tholeitic magma.
Quartz never present.	Quartz always present.
Feldspathoid minerals (nepheline and/or analcite) present.	Feldspathoid minerals never present.
Potash and alkali-feldspars abundant; may be associated with basic plagioclase.	Acid plagioclase is the predominant feldspar; orthoclase subordinate, and occurs mainly as micropegmatite.
Soda-bearing pyroxenes and amphiboles frequently present in addition to titan-augite.	Common augite and, more rarely, amphibole are the characteristic ferromagnesian minerals.
Iron ores common.	Iron ores not conspicuous.

He suggests a common origin of basaltic magmas:



These pegmatites or "pegmatitoïdes" form, in the dyke, spots, streaks, even veins (Fig. 52), hardly exceeding 5 cm in thickness and 40 in length. They are rather uncommon.

Let us examine the case of an acid differentiation product in a BD1 (sample No. 38534).

The dolerite is typical and coarsely crystallized, its texture granular to intersertal, hypautomorphic. Its constituents are: a plagioclase showing good twinning and zoning within the limits of andesine (mainly about 40–45 $^0/_0$ An), altering to sericite, a pinkish titaniferous augitic pyroxene, with distinct dispersion, altering to biotite, vermiculite, chlorite and ore, or uralitized into brown hornblende, some secondary epidote and small amounts of apatite and opaque minerals.

The pegmatite reveals a clouded, grey-brown plagioclase in a much less fresh state. It also shows twinning and zoning but is clearly more acid than that of the dolerite; it is an oligoclase with an average composition of about 20–25 $^0/_0$ An. Micropegmatitic quartz frequently invades the plagioclase; there is also some interstitial quartz. An augitic pyroxene alters to biotite with various colours (green, brown, sometimes blood-red), and sometimes to epidote; uralite easily replaces it. Chlorite, vermiculite and ore are also present, but in insignificant quantities,

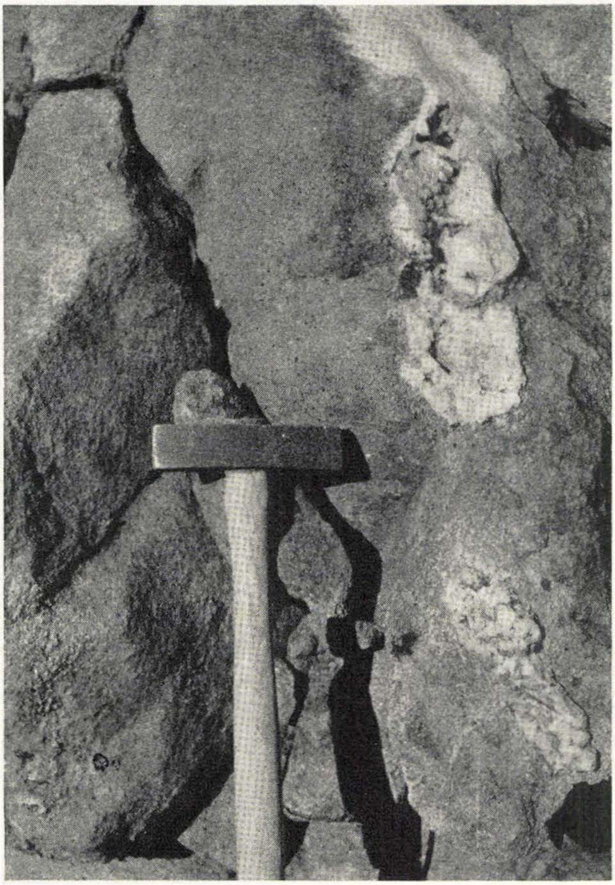


Fig. 52. An acid pegmatite or "pegmatitoide" in a BD1. Patches, spots, streaks or veins of crystallized residual matter may occur. In the case of these dolerites, they are usually of a tonalitic composition. 1 km NE of pt. 812.

whereas apatite is represented by long, numerous and well-developed needles.

The transition between the two parts is rapid but without a definite hiatus: a dolerite gives way to a quartz-bearing microdiorite (approximately a tonalite). The grain-size of the elements increases notably in the segregation.

As compared to the basic part of the dyke, the acid segregations display microscopically the following differences:

1) The plagioclase is much less basic.
2) The ferromagnesian minerals are much more idiomorphic.
3) Quartz is present and even abundant.
4) The quantity of apatite seems to have increased considerably.
5) Epidote is also much more abundant.
6) The texture is much less automorphic.

Chemically, the increase in silica and phosphorus seems to constitute an important characteristic.

Another example (sample No. 32944) reveals large accumulations of quartz, a plagioclase strongly altered to sericite, with weak zoning, graphic aggregates associating these two minerals, a few grains of altered orthoclase, abundant green and brown biotite, a little chlorite, a green amphibole (hornblende) undergoing chloritization, and accessorily, grains of magnetite lined with limonite, apatite, calcite, and sphene associated with leucoxene and ilmenite. The composition of the plagioclase is about 30 $^0/_0$ An.

The decrease in lime, the increase in potash, as compared to the dolerite, the graphic micropegmatites, are all quite characteristic of the dolerite-pegmatites of F. WALKER (1953), or of the "pegmatitoïdes" described by A. LACROIX (1928). The differentiation product is again to be attributed to the family of the quartz-bearing microdiorites.

In certain cases the minerals of the dolerite, while remaining the same, attain an abnormally large size. Amongst the various elements, the only ones to undergo a noticeable increase in proportion are Fe and Ti. Big accumulations (up to 3 cm) of magnetite and ilmenite, closely associated, are formed (Fig. 53). F. WALKER remarks on this occurrence as well; he is, moreover, of the opinion that all these pegmatites constitute late-stage events, when the dolerite is already emplaced, and its crystallization well on its way. At the same time the proportion of volatile elements and iron is quite high.

While the first two cases had a tendency towards a more acid composition, the third may be called a basic segregation. The two phenomena are perhaps, in a certain measure, complementary.

One of these pegmatites (sample No. 38513) forms a layer, 2–4 cm thick, perpendicular to the walls of the dyke, and inclined by 60–70° towards the N. The transition to the dolerite occurs over 2–3 mm, more or less gradually. By its composition, one may situate it between the quartz-bearing microdiorites and the microgranites, since orthoclase is also present; this mineral is frequently idiomorphic, quite altered, and sometimes contains micropegmatitic quartz. There are a few secondary growths around plagioclase crystals, which are occasionally idiomorphic and show weak zoning oscillating around 30 $^0/_0$ An; twinning is complex in practically all crystals; this plagioclase is frequently associated with micrographic quartz. There is also some interstitial quartz. Other constituents are: calcite, chlorite, biotite, sphene and leucoxene surrounding ilmenite, a little apatite.

In one case, we observed a little vein composed of translucent to transparent, well-formed crystals of quartz, averaging about 1 cm in length. This siliceous residue brings us back to the problem summarized

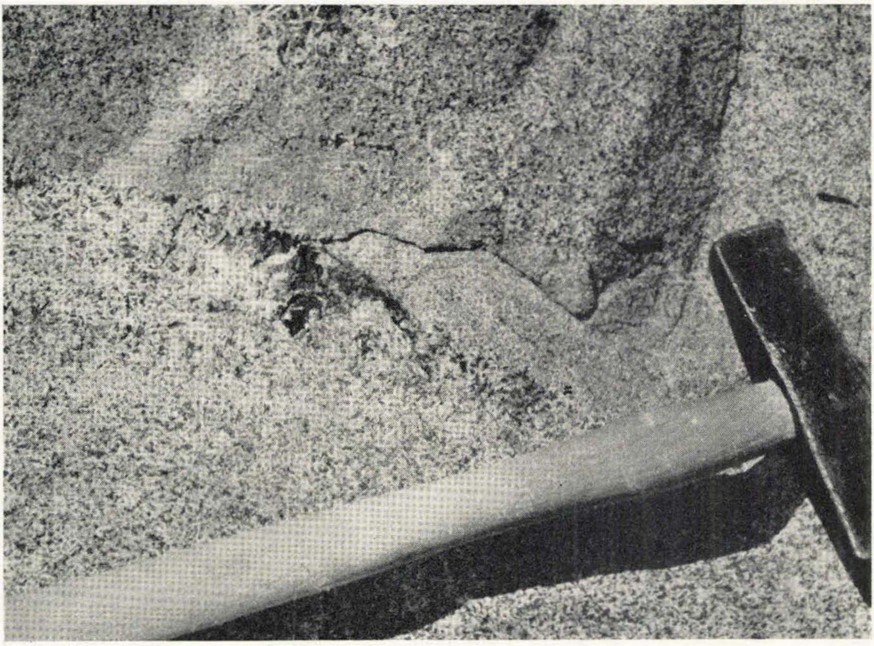


Fig. 53. Basic segregations may also occur, sometimes near the acid pegmatites. They are mainly composed of closely associated magnetite and ilmenite bringing out a local increase in the proportion of Fe and Ti. The two petrographic variations may possibly be, to a certain extent, complementary. 1 km NE of pt. 812.

by W. Q. KENNEDY. On one hand, in numerous dolerites of our region, the proportion of olivine is quite considerable, on the other hand the residue is often quartzous, which would suggest more readily an original magma of tholeitic composition. It is perhaps necessary to postulate a certain amount of contamination in depth by the siliceous gneiss, i.e. a process involving syntexis.

Transversal variations. Three cross-sections were sampled in different dykes and studied in an attempt to determine the variations between their margins and centre. More samples were taken near the edges than in the central part.

a) Ten samples in a BD1 (1 km E of pt. 590, in the centre of our region), 40 m wide, N45E in direction, show the following features:

1) The extreme NW edge. The texture is finely sub-doleritic. The plagioclase is fresh, but often contains inclusions which form either aggregates in the centre of the crystal or streaks, more or less parallel to the outline of the crystal, frequently separating zones of different composition (Pl. 8, figs. 1 and 2). This is probably a process involving devitrification, as the inclusions are apparently

mainly amorphous. The interstices contain very finely crystallized material, as well as pyroxene, and well-formed, abundant olivine. In order to shorten this description we will not give the detail of the secondary and accessory minerals if there is no notable variation.

2) 50 cm from the NW edge. The texture is still sub-doleritic. The inclusions in the plagioclase persist. On the other hand, olivine has disappeared.
3) 1 m from the NW edge. The grain-size is already 5–10 times larger than at the edge. The feldspar still contains inclusions. Small, rare and fresh grains of olivine reappear.
4) 10 m from the edge. The grain-size has increased considerably, and the rock takes on a slightly pegmatitic aspect. There are no more inclusions in the feldspar; olivine has again disappeared. Magnetite and ilmenite are so abundant that they form small veins. Amygdules containing mainly chlorite and limonite are common, demonstrating the local importance of the gaseous phase.
5) 18 m from the NW edge. The texture is ophitic. Figures of devitrification and olivine reappear.
6) 15 m from the SE edge. The texture remains ophitic. Little zircons in the phyllosilicates have engendered dark pleochroic halos.
7) 7 m from the SE edge. There are no variations apart from the fact that the texture is locally sub-ophitic.
8) 1 m from the SE edge. A little uralitic hornblende appears. The plagioclase again contains amorphous inclusions.
9) 50 cm from the SE edge. A few phenocrysts are conspicuous. Olivine is still present.
10) The SE edge. Small feldspathic grains are embedded in a very fine groundmass. Hornblende has practically completely replaced the pyroxene, which only subsists in the centre of the grains. There does not seem to be any olivine.

Consequently, it seems that the major variation resides in the fluctuation of the proportion of olivine.

In the samples of adequate grain-size, and which have undergone moderate alteration, estimates of the respective percentual proportions have been made.

Mineral No.	2 (38450)	3 (38451)	5 (38453)	6 (38454)	7 (38455)	8 (38456)	9 (38457)
Plagioclase	56	70	51	68	65	57	56
Pyroxene	21	15	24	12	16	20	22
Olivine		9	15	9	9	8	11
Ore	7	4	6	5	7	7	8
Others	16	2	4	6	6	8	3

b) In a BD1 (about 400 m S of pts. 850), 20 m wide, N50E in direction, the following 8 samples reveal:

1) The extreme NW edge. The texture is intersertal. Olivine is very abundant, its grains well-formed and superior in size to that of the other constituents. Pyroxene is rare, epidote on the other hand is largely distributed, and forms, in particular, inclusions in the feldspar. There are possibly some interstitial, glassy aggregates.

2) 50 cm from the NW edge. The texture is ophitic, and the pyroxene well crystallized.
3) 1 m from the NW edge. There is no variation apart from increase in grain-size.
4) 9 m from the NW edge. The grain-size is about twice that of sample No. 2. Rare amygdules of chlorite-sericite are to be observed.
5) 2 m from the SE edge. There is no notable variation.
6) 1 m from the SE edge. The grain-size diminishes.
7) 50 cm from the SE edge. The grain-size becomes even finer.
8) The SE edge. The texture is finely ophitic. The minerals are all represented and well crystallized. Epidote is again abundant, as in the opposite edge.

Mineral No.	2 (38519)	3 (38520)	4 (38521)	5 (38522)	6 (38523)	7 (38524)
Plagioclase	48	53	60	56	52	55
Pyroxene	25	20	14	18	20	22
Olivine	16	19	18	17	17	13
Ore	7	6	4	5	7	7
Others	4	2	4	4	4	3

This dyke shows a marked constancy.

c) In a BD (1.6 km NNE of pt. 670 at Akuliaruserssuaq), 25 m wide, N45E in direction, 8 samples display the following features:

1) The extreme NW edge. The texture is pilotaxitic to hyalopilitic. Abundant epidote, chlorite, ore and microlites of plagioclase are the only well formed minerals. The interstices are very finely crystallized.
2) 50 cm from the NW edge. The texture becomes sub-doleritic. Epidote, still frequent, is accompanied by a well crystallized titaniferous, pigeonitic augite. There is also a calcitic amygdule. Olivine is absent.
3) 6 m from the NW edge. The texture varies between sub-doleritic and doleritic. The grain-size increases.
4) 11 m from the NW edge. The texture becomes ophitic. A little uralitic hornblende appears. Here and there chlorite forms cryptocrystalline amygdules. The grain-size has suddenly increased and attains 5–10 times that of the previous sample. The presence of minerals rich in volatile hydroxyl radicals is to be noted.
5) 9 m from the SE edge. Rare phenocrysts appear in an intersertal to sub-doleritic texture. Olivine is suddenly present, and forms large but sparse grains. Small zircons have given birth to pleochroic halos in the chloritic patches.
6) 4 m from the SE edge. The texture becomes doleritic. The grain-size clearly diminishes. There are some amygdules of calcite and of orange-golden vermiculite.
7) 50 cm from the SE edge. The texture is intersertal or doleritic. Chlorite forms veinlets.
8) The SE edge. The texture is again pilotaxitic to hyalopilitic. The composition is the same as that of the opposite edge.

Mineral No.	2 (38553)	3 (38554)	4 (38555)	5 (38556)	6 (38557)	7 (38558)
Plagioclase	48	50	59	75	50	50
Pyroxene	24	31	12	11	31	28
Olivine				0.5		
Ore	15	10	9	6	8	15
Others	13	9	20	7.5	11	7

One must note the regular symmetrical increase of the proportion of plagioclase towards the centre of the dyke; this variation has apparently occurred at the expense of pyroxene and ore. The curious apparition of olivine in one lone case must be considered as a local accident. Possibly it has not even crystallized *in situ*.

These examples are sufficient to show that, in order to characterize a dyke, and all the more so a swarm of dykes, sampling must be conducted in a very vast and varied manner in an attempt to eliminate the effect of particular cases.

Considerations on the magmatic chamber. The form of the magmatic chamber constitutes a problem. Indeed, tectonic conditions during the Gardar period exclude a horizontal space of great extent. A. Berthelsen (1958) draws attention to the importance of the "master-dykes" (100–200 m wide) at Ivigtut, which suggest the existence of a "giant-dyke" in depth, such as one may see further S, at Nunarssuit. There the "giant-dykes" measure between 200 and 800 m in width, and could very well constitute entirely or partially the infracrustal magmatic reservoirs. These enormous vertical volumes which are actually occupied by a rock varying between a gabbro and an augite-syenite, could have offered ideal conditions for gravitational differentiation and concentration, by gaseous transfer of volatile alkaline compounds.

Contact phenomena; effects on the country rock; formation of granophyre. The effects on the country rock, produced by the dykes at the time of their emplacement, are generally weak or inexistent. In one case however did we observe some interesting phenomena. They occur in the important group of dykes which passes E of summit 850 and at summits 875 and 760, in the NE part of our region, and which will now be described in detail.

Fig. 54 shows this swarm at the point where it presents these complications.

Two generations, BD0 and BD1, are visible; their directions are practically parallel. The oldest dykes are darker, and their alteration produces a greater quantity of gravel. The BD1s are of a more yellow or orange-brown colour, and contain more pegmatites. These dykes, 2–15 m wide, suddenly, at this point, break up into an "en échelon" or a bayonet disposition. The encasing rock is sporadically brick-red over a few m. When this occurs the contacts are not sharp, but gradual.

Fig. 55 shows the detail of this zone.

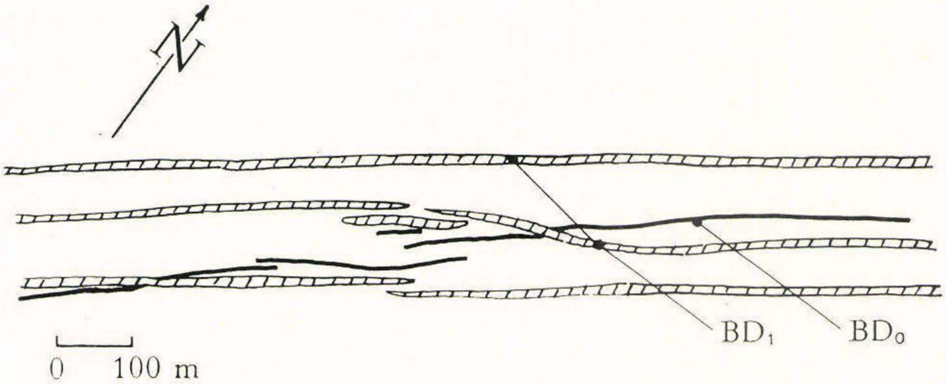


Fig. 54. The swarm of Brown Dykes, where contact phenomena between the dolerites and the encasing gneiss occur. Two generations intersect each other: BD0 and BD1. The effects on the country rock are particularly evident where the easternmost BD1 is "en échelon". 2.5 km NNE of lake 470.

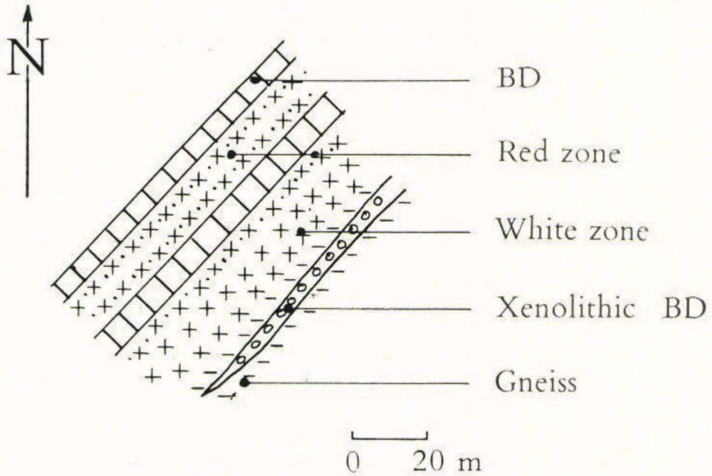


Fig. 55. Detail of the Brown Dykes where contact phenomena occur. Contacts between the dolerites and gneiss are locally gradual, mainly where a red tinge appears in the country rock. 2.5 km NNE of lake 470.

From NW to SE, one notes:

1) A typical BD, 3 m wide.
2) A red zone where the rock is quite compact; but locally vacuoles may appear. The grain-size is medium. Pink feldspars are easily distinguished from the grains of clear or milky quartz, 2–8 mm in diameter; there are also some grains of epidote, limonitic spots and dark minerals.
3) A typical, ophitic BD. 3 m wide.
4) A red zone identical to the previous one.
5) A white zone, where big grains of quartz attain 1 cm in diameter. There are tiny specks of dark minerals. The grain-size of the groundmass is fine. The rock has locally a brick-like appearance.

Fig. 56. The easternmost dyke (BD1) of the swarm, where interesting contact phenomena occur, contains an explosion-breccia, demonstrating the importance of the gaseous phase. Various xenoliths form up to 50–60 % of the rock. Their average diameter is about 10–20 cm. 2.5 km NNE of lake 470.

These first 5 zones grade quite gradually from one to another. Then follows:

6) Practically directly in contact with zone No. 5, or separated from it by a small wedge of gneiss, a BD 2–3 m wide, showing the following particularities:
   a) locally gradual contacts.
   b) a mainly central zone, about 30 m long, containing various xenoliths, which form 50–60 % of the rock. They measure 5–60 cm in width, with an average around 10–20 cm. The aspect is that of an explosion-breccia; its detail will be reviewed further on (Fig. 56).
   c) acid segregations forming either vertical bands one cm wide, parallel to the dyke, or veins without orientation.
   d) gabbro-pegmatites also forming vertical bands, 10 cm wide.

e) aggregates of hornblende, the grain-size of which increases considerably, attaining 0.5 cm. Locally they form veritable hornblendites, consequently basic segregations.

f) geodes, 10 cm in diameter, containing white or yellow, fibrous, idiomorphic feldspars.

7) The gneiss with local red zones.

It therefore seems that the gaseous phase has been extremely important.

As for the red zones, they are very capricious. Their disposition is often symmetrical in relation to the dyke, the rock being tinged over 2–3 m on either side. But sometimes only one edge displays this phenomenon. Longitudinally, the colour may be followed over 50 m before disappearing for a few hundred m, and reappearing further on. We have thus observed it sporadically all along this swarm, over a distance of several km.

Composition of the xenoliths contained in the BD1.

They are of several varieties:

a) Blocks belonging to the white zone (5), with big grains of quartz.

b) Blocks belonging to the red zone (2 or 4), with big grains of quartz.

c) Fragments of foreign rocks which never appear at the surface in this region; these are consequently brought up from the depths. In composition they are either anorthosites (Fig. 57) or olivine gabbros. These xenoliths have been found at two different places in the same dyke, separated by a distance of about 1.5 km.

Microscopic observations — mineralogical descriptions.

The BD1. The texture is ophitic. The plagioclase, generally fresh, shows twinning and zoning, which varies between an optically negative andesine (35 $^0/_0$ An) and a labradorite (60 $^0/_0$ An). The alteration of the pyroxene, a titaniferous augite, produces phyllosilicates (biotite, chlorite). Sometimes a grain of brown or reddish hornblende is formed. In one case, the amphibole contains an inclusion of rutile, while around it, biotite has crystallized, itself enveloped in a chloritic aureole with fine needles of sericite arranged according to the cleavages of the original pyroxene. This aureole passes, further on, to a non-oriented mass of phyllosilicates. Ore forms skeleton-like pseudomorphs of the pre-existent mineral; in a more advanced stage, it forms dendrites. One notes numerous amygdules mainly composed of green chlorite, hydromicas (vermiculite), biotite, sericite and calcite. They are often formed of a single crystal of calcite enclosed in chlorite (Pl. 4, fig. 1); a radial disposition is predominant and grain-size is often cryptocrystalline, certain aggregates

Fig. 57. A large anorthositic xenolith torn up from the depths. It is to be found in the same BD1 as the above-illustrated explosion-breccia and xenolithic zone. 2.5 km NNE of lake 470.

never attaining a position of complete extinction between crossed nicols. Here and there minute zircons form pleochroic halos in the phyllosilicates. Other constituents are: penninite, saussuritic epidote, ore (magnetite-ilmenite-limonite) and apatite (rare). The importance of the gaseous phase is again evident, mainly because of the amygdules which show an abundance of H_20 and $CaCO_3$.

Another interesting fact is to be mentioned. Apart from the amygdules, calcite may occupy the interstices between the laths of plagioclase, without replacing them, like a pyroxene in ophitic texture.

The red zone. The texture varies from granoblastic to granophyric, the latter being predominant. The following minerals are assembled: 1) a plagioclase, generally situated within the limits of oligoclase, is almost everywhere filled with granophyric or micrographic quartz. A certain amount of zoning may exist, and twinning is abundant and complex. Albite with chessboard twinning is sometimes to be observed; it is formed by a fine association of alternating lamellae, themselves composed of either potassic or sodic feldspar; this is characteristic, according to J. D. DE JONG (1941), of late-stage albitization. The plagioclase is tinged in brown (cryptocrystalline iron-oxide), and altered to sericite and/or saussurite. 2) a potassic feldspar is also quite abundant. It is either orthoclase, readily altered to kaolinite and also tinged in grey-brown which gives it a dusty aspect, or microcline, often idiomorphic, it too slightly coloured. Orthoclase generally forms long laths with Carlsbad twinning. Both potassic feldspars are frequently associated with quartz, sometimes in an intimate manner; orthoclase and quartz, in particular, interpenetrate each other here and there in finger-like fashion. Orthoclase and microcline may locally coexist (in the same thin section for instance), but generally only one is present, to the nearly complete exclusion of the other. In certain cases microcline-perthite appears to form. 3) apart from the granophyric quartz, there is some corrosion, secondary and interstitial quartz, the extinction of which is usually undulatory. It is always abundant and possesses numerous inclusions, mainly of apatite and perhaps some gas bubbles. In certain grains one may see an idiomorphic mineral forming rather numerous prisms which have the same position of extinction as the quartz. They seem to be minute crystals of orthoclase in full growth. 4) chlorite is abundant and forms either long lamellae, fibres or needles, slightly green in colour, or spherulitic radiated aggregates (amygdules) in which sericite is also abundant. Long lamellae of distinctly dispersive muscovite are also common. 5) biotite only exists as an accessory. 6) epidote may be primary or proceed from the decomposition of the plagioclase; it forms yellow or brown grains with very pronounced optical anomalies. 7) big grains of calcite are frequent. 8) one notes occasional pseudomorphs of the potassic feldspar by opaque minerals (mainly magnetite, ilmenite, limonite). 9) other constituents are: sphene-leucoxene-ilmenite, apatite and hematite.

Consequently, this rock corresponds to the approximate composition of a granophyre.

The white zone. The texture is again granophyric to granoblastic, the feldspar still an oligoclase (about 15 $^0/_0$ An), showing slight zoning, twinning, filled with granophyric quartz and strongly altered to sericite with a little saussurite. The quartz grains contain inclusions which are arranged in a haphazard manner. Sericite is the main constituent of the fibrous, very abundant and more or less round spherulites. Orthoclase is distinctly more tinged than the plagioclase. Epidote, chlorite, ore (limonite-magnetite), apatite, and a little green or brown biotite make up the rest of the rock.

The anorthositic xenoliths. Their texture varies: locally it is microgranular, practically equigranular, elsewhere slightly intersertal. The rock is formed of a hypautomorphic to xenomorphic-granular plagioclase, showing twinning and zoning between 25 and 60 % An, the average being situated around a positive andesine. The dark minerals never exceed 5 % of the total composition of the rock; this is already evident by its colour. They are either rare aggregates of phyllosilicates (green or yellow chlorite, yellow-brown vermiculite, biotite), or yellow or green cryptocrystalline masses. An augitic to pigeonitic pyroxene (2V near to 0°) is rarely to be found in the middle of these patches, to which ore is also related. A few grains of calcite, as well as flakes of sericite, may form dendrites; they proceed from the destruction of the feldspars.

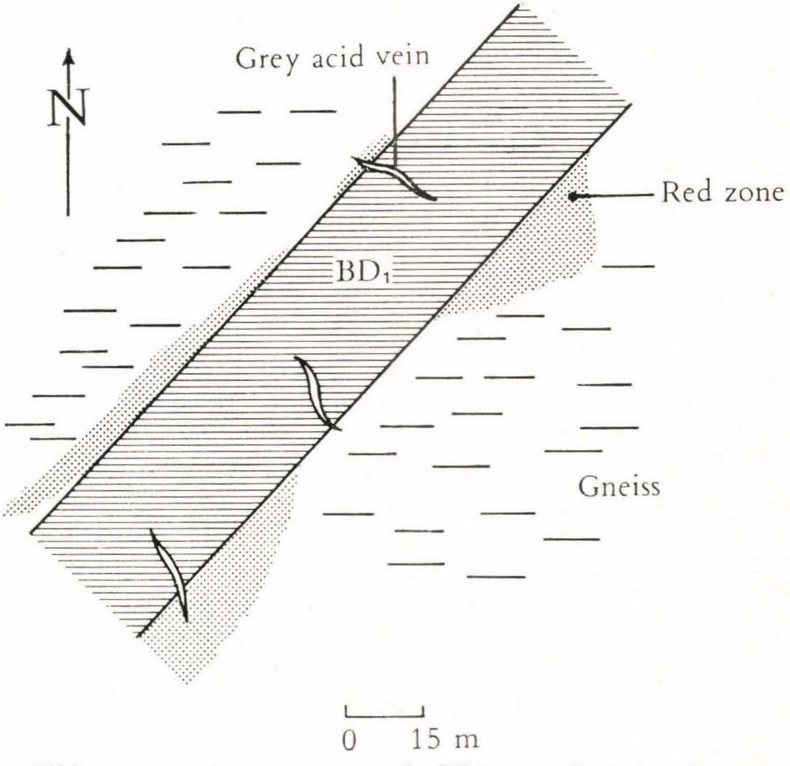


Fig. 58. White or grey acid veins may cut the BD1 perpendicularly, while red zones continue to appear sporadically in the encasing gneiss. As it shall be stated further on, the remobilized gneiss probably back-veins the dolerite. 1 km N of lake 470.

The gabbroic xenolith. The rock is very coarse-grained, the texture hypautomorphic-granular or slightly intersertal, even sub-doleritic. The plagioclase, generally fresh, sometimes altered to sericite, shows twinning and zoning varying between 55 and 80 % An. Mostly, it is an optically negative bytownite. In its cleavages saussurite may develop with abundant streaks of epidote, as well as phyllosilicates (chlorite, biotite, sericite), ore (magnetite, ilmenite, hematite, limonite), even a titaniferous augite and a less calcic feldspar. One observes a progressive decrease in lime around the inclusions, which are, moreover, frequently oriented in a single crystal. This variation gives an impression of zoning. Amongst the inclusions one must also mention olivine.

Between the feldspars, big xenomorphic grains of ferruginous olivine alter to goethite, iddingsite and bowlingite. There is also a small amount of pyroxene, a pink titaniferous augite, displaying evident dispersion. Secondary phyllosilicates (sericite, chlorite, biotite, vermiculite), epidote and not very abundant ore make up the rest of the rock which is a typical olivine gabbro. (The proportion of apatite may be considered to be nil).

Before considering the petrogenesis of these rocks, we are going to describe a case which occurs in the same dyke, three km to the SW. There, as shown in Fig. 58, the red zones reappear and form capricious and discontinuous tongues. Moreover, small veins 20–50 cm wide, grey in colour, cut the dyke perpendicularly. They start from the red zones or from the non-tinged gneiss, and are short-lived, as they penetrate but a few m into the BD1.

These small, grey veins reveal, under the microscope, a microgranular texture; big grains of slightly zoned plagioclase (in average about 20 $^0/_0$ An) and quartz with undulatory extinction are conspicuous. One notes grains of sphene associated with leucoxene and ilmenite, chlorite, sometimes forming amygdules, a little biotite, ore (magnetite, limonite), apatite and epidote. Interstitial quartz is abundant. This composition allows one to attribute this rock to the family of the quartz-bearing microdiorites.

Petrogenesis. We eliminated quite rapidly the hypothesis of a composite-dyke, with differentiations and segregations, in order to adopt that involving rheomorphism of the encasing gneiss, under the effect of thermal metamorphism, with introduction of material in gaseous form, by a process similar to that described by D. REYNOLDS at Slieve Gullion, in Ireland (1948).

There, a Caledonian granodiorite is transformed into Tertiary granophyre under the effect of a doleritic ring-dyke, constituting the skeleton of an important volcanic edifice. The transformation is gradual and takes place over more than 300 m. The ferromagnesian minerals are altered, and a potassic feldspar develops at the contact between grains of plagioclase and quartz which it progressively replaces, often in finger-like fashion, a phenomenon to which we have drawn attention in the above descriptions. A corrosion micropegmatite is formed and the rock becomes a granophyre. The transportation of material results in an increase of potash and silica whereas iron, lime and magnesia diminish. But the introduction of new elements is not very considerable.

During the discussion following the presentation of this article, P. GEIJER remarked that similar observations have been made concerning large, doleritic dykes in the Pre-Cambrian of Scandinavia. There, the encasing rock often takes on a porphyritic aspect, in which the "phenocrysts" are composed of grains of quartz and feldspar, non-transformed relics of the encasing rock. This reminded us of an example observed in the same swarm of dykes, where one sees a dolerite divide into two branches which join up again a few m further on. The lens thus determined takes on a porphyritic aspect, with very big "phenocrysts" of feldspar, while the composition does not seem to undergo any change. The contacts between lens and dolerite are, moreover, gradual.

P. ESKOLA's remark, also following D. REYNOLDS' article, is another important contribution to the thesis, according to which remobilization or anatexis of the pre-existent rocks has occurred with formation of a palingenetic magma.

In a later article D. REYNOLDS (1954) described in more detail the process which seems to her to be mainly responsible for this remobilization; it is known in industry under the name of "Fluidization", the principle of which is the following: a stream of gas is sent through a bed of very fine, solid particles in order to facilitate mixture and chemical reactions. At a slow rate of flow, only percolation occurs, without agitation of the solid phase; the bed expands and the particles are separated. If one increases the rate of the flow, bubbles are formed and rise through the bed, creating violent agitation. If the gas flows even faster, the bubbles increase in quantity, take hold of the solid particles, and finally carry them away. D. REYNOLDS mentions several geological phenomena in which this process might very well intervene.

We have already insisted on the importance of the gaseous phase in the case with which we are concerned, and it undoubtedly played a capital role in the transformation of the encasing gneiss; the necessary introduction of thermal energy was produced, most probably, by a very long extrusion of lava.

As for the little grey veins described above, which cut the BD1 perpendicularly to its edges, they have the same composition as the gneiss (which varies petrographically between a quartz diorite, a granodiorite and a calco-alkaline granite). We believe that in this case rheomorphism has produced an occurrence of back-veining, the remobilized gneiss sending veinlets into the dolerite. This reminds one considerably of the palingenetic dykes and veins described by A. KAHMA (1951) in SW Finland; there, an olivine diabase remobilizes all sorts of encasing rocks. Micrographic texture is almost characteristic of this process.

E. B. BAILEY (1959), without being completely in agreement with the mechanism suggested by D. REYNOLDS, confirms these remobilizations of acid material by a basic magma (moreover, it is likely that rheomorphism may only occur when the fusion points of the elements concerned are quite different, as in the present case). He also mentions other remobilizations of granophyre, and quotes the following remark of D. REYNOLDS: "Any acid magma so formed would remain fluid longer than the gabbro. Indeed, acid magma may actually have been forming, whilst the gabbro solidified."

It is probable, as stated by E. B. BAILEY and W. J. MCCALLIEN (1956) that, as well as fluidization, a certain amount of fusion has occurred.

Significance of the xenoliths of anorthosite and olivine gabbro. As mentioned above, the rocks to which these xenoliths belong never crop out in this region. We have therefore precious indications on the composition of very deep levels, and one must conclude that there exists a massif of olivine gabbro, of which the dolerites probably constitute the hypabyssal manifestation. It is not rare that numerous crystals of plagioclase assemble at the roof of such a massif, which would be the source of the anorthositic fragments. Let us also mention that these xenoliths are little or not digested by the magma which has transported them.

C. Trachytes (Pl. 16).

Towards the end of the Gardar period, following the emplacement of the Brown Dykes (BD), a new magmatic activity takes place forming rocks of a more acid and alkaline composition. This group of dykes is distributed throughout the whole area but its density varies greatly from one place to another. The term of "trachyte" is a field appellation including different sorts of rocks. It is only under the microscope that the presence, in the region of Ivigtut, of undersaturated, saturated and oversaturated, alkaline and calco-alkaline types has been able to be determined. In order to give a few names of species one must mention true trachytes, phonolites, hedrumites, tephrites, tinguaites etc. Quite extensive variations have been observed in a single dyke.

In our territory, trachytes are only represented by a few dykes strictly concentrated in the NE part. They are always thin, never exceeding 1 m in width. They appear and disappear suddenly; one cannot follow them over long distances. They run in a sinuous manner (they rarely follow a truly straight line); their general direction is nevertheless about N60–70E. The grain-size is fine and quite frequent phenocrysts (feldspar, pyrobole or other) are to be observed. They are practically always strongly jointed; this phenomenon is seemingly to be put rather on the account of cooling than on that of later tectonic movements, which are, however, not to be neglected. Locally, they may present apophyses, restricted in number; they may also be disposed in swarms, sometimes "en échelon". Their age is well established through intersections: they are cut only by Post-Gardar dykes and seem to belong to a single generation.

Their colour is curious. The same dyke may be light grey, light brown, brick red, dark red; the transitions from one tinge to another are sometimes extremely sudden. In the small group of dykes passing to the SE of the long lakes 180 and 155, the colour goes from grey to brick-red and again to grey, the transitions taking place over 20–30 cm. We will see further on that these variations in colour correspond clearly to petrographic modifications, but the cause of these phenomena still remains mysterious.

Let us examine in detail the above-mentioned dykes; the group includes one member, 1 m in width, and two others of about 0.5 m.

A first thin section was sliced in a sample of grey, fine-grained rock. It reveals a fluidal texture in which the microlites of fresh, idiomorphic albite neighbour long twinned laths of orthoclase with a rather dusty aspect. They are accompanied by a feldspathoid, a very fresh nepheline, which exhibits numerous square sections. In the interstices between these minerals there is probably a clinopyroxene generally altered to a brown, uralitic hornblende, which is more easily recognizable. There is also some epidote in long needles, some finely crystallized phyllosilicates (sericite and green biotite), some apatite and a little iron-oxide, the latter being a secondary product.

One may therefore classify this rock in the phonolite family.

Three km to the E, near summit 760, one may see a very sudden change of colour. Under the microscope, the grey part shows a microgranular texture in which three sorts of phenocrysts are to be distinguished: a) a basaltic hornblende, light brown to red-brown, strongly pleochroic, idiomorphic and fresh. Blue or blue-green spots, grading to light brown through distinct pleochroism, appear in these hornblendic crystals, particularly in the cleavages. This represents a transformation into a sodic amphibole, approaching riebeckite. Rarely one may see slight zoning due to an increase in iron content during crystallization. b) a titaniferous pinkish augite, non-pleochroic, containing small quartz inclusions, and grading, on its edges, into a uralitic amphibole. c) a garnet which is black macroscopically but colourless under the microscope. It is enclosed in an alteration border composed of fibrous chlorite. This garnet is an andradite called schorlomite or melanite because of its dark colour.

The size of the phenocrysts is in average 2–3 mm, the garnet attaining 1 cm. There are two different feldspars: anorthoclase and finely-twinned albite, both rather fresh, idiomorphic, microphenocrystalline, and abundant.

In the matrix the concentration of aegyrine needles may be very high; they show a pleochroism varying from light or dark green to pale brown. These needles are generally distributed in a haphazard manner, but show here and there a distinct orientation. They are partially transformed into biotite and separate grains of leucite, more or less altered to sericite and pseudoleucite.

Elsewhere aegyrine diminishes, seemingly to the advantage of epidote in small yellow grains, accompanied by a little zoisite.

Apatite is a rare accessory.

This mineral assemblage permits one to classify this rock among the leucite-bearing tinguaite porphyries (Pl. 4, fig. 2).

Let us now take the brick-red part 40 cm distant from the previous thin section. Its texture is mainly microgranular, but locally, feldspathic laths elongated according to a well-defined direction determine a more fluidal texture. Two feldspars and a feldspathoid are present: a) a potassic feldspar, probably sanidine, perthitic in aspect; its soda content situates it quite near to anorthoclase. Long laths nearly always show Carlsbad twinning. In appearance it is quite "dusty", with a slightly pink colour. b) idiomorphic albite-oligoclase, generally sericitized, sometimes quite fresh. c) scattered throughout the rock there are typical square or hexagonal sections of nepheline showing weak zoning (variation in potash content). It is slightly altered.

The groundmass is composed of a brown ferruginous mass in which the minerals are not easily distinguishable. One may, however, recognize a few augitic, titaniferous pyroxenes, the borders of which alter to leucoxene-ilmenite, and some green biotite and chlorite in very small quantity. The phyllosilicates are frequently enclosed in a brown, cloudy mass due to the exudation of ferruginous and titaniferous minerals. Amongst the minerals forming the rest of the groundmass, one must mention: apatite, magnetite and sphene (accessory minerals), sericite and kaolinite (alteration minerals), as well as possible glassy residues.

The red colour is doubtless due to a very fine pigmentation of secondary hematite, common in these rocks.

The petrographic classification of trachytes is complex; it varies from one author to another, which does not facilitate the denomination of these rocks.

In the case of the rock described hereabove, it may be called an undersaturated trachyte, approaching a keratophyre, or a phonolitic trachyte, or still a phonolitic latite (nepheline-bearing), when the proportion potassic feldspar/sodic feldspar varies, tending towards 1.

If one compares the grey and red parts, it appears that the alkaline elements have undergone a different distribution according to very local conditions. Moreover, the red part is probably richer in iron. Unfortunately, we lack precise chemical analyses which would help us to determine the process of transition, the rapidity of which remains its most mysterious characteristic.

In the NE region, on the shore of Sermiligârssuk, a small trachytic dyke, 50 cm in width, meanders through a big Brown (doleritic) Dyke. The direction of the trachyte is N60E, its grain-size fine. It contains small, white feldspathic phenocrysts between 2 and 4 mm in diameter, black, non-oriented needles 1–5 mm in length, sometimes in aggregates, as well as small grains of pyrite (and chalcopyrite ?), undergoing limonitization.

Through the microscope one observes a microgranular, locally equigranular texture, with the following minerals: orthoclase, plagioclase, quartz, hornblende, biotite, chlorite, opaque minerals and apatite. 1) orthoclase is abundant, sometimes fresh, generally altered to sericite or kaolinite. It contains various small inclusions, mainly needles of apatite. It is, moreover, heterogeneous, perhaps perthitic; flame-like lamellae reveal the soda content (tendency towards anorthoclase). It constitutes the phenocrysts. 2) a plagioclase accompanies the potassic feldspar. Most frequently it is sericitized, or slightly saussuritized and rich in inclusions. It shows good twinning (Carlsbad, albite, pericline), and slight zoning, its composition varying by approximately 10 $^0/_0$ of anorthite in the neighborhood of the boundary albite-oligoclase. 3) quartz is present in the form of small, interstitial grains, and is also associated with orthoclase in micropegmatitic associations; here and there it is more vermicular, tending towards myrmekite. 4) green hornblende (pleochroism: dark green–light brown), in small, idiomorphic or sub-idiomorphic crystals, is associated with a mainly idiomorphic, uniaxial biotite, blood-red in colour, and slightly pleochroic. Locally the latter loses its colour, tending towards a brownish orange or yellowish tinge. Being very ferruginous, it alters to limonite or hematite. Sometimes it is to be found in the centre of the amphibole crystals; this is due to a late-stage reaction of the magmatic phase rather than to alteration. This biotite is itself altered to finely crystallized vermiculite, varying between orange, yellow and brown.

One must also mention a little green chlorite and some grains of very dispersive penninite. Opaque minerals are quite abundant, sometimes idiomorphic, and include magnetite, ilmenite and limonite. There is also some apatite, in small needles.

Another thin section cut in a rock not very distant from the previous one, displays, moreover: muscovite, amygdules of pumpellyite, colourless or slightly greenish ($2V = 50–60°$, positive), and perhaps some epidote.

A little further on, the dyke becomes extremely thin (20 cm) with a pilotaxitic, even hyalopilitic, locally intersertal texture.

As the proportion potassic feldspar/plagioclase may vary slightly, this rock falls either into the category of oversaturated trachytes with free silica (in the form of quartz), or in that of quartz-bearing latites. In the case of the second thin section which we have just described, quartz is sufficiently abundant for one to call the rock a calco-alkaline rhyolite.

Of all the Gardar dykes, these acid rocks are the most radioactive, which is what is normally to be expected.

Petrogenesis of the trachytes. It seems that a normal process of differentiation is sufficient to explain the genesis of these rocks. The case is very similar to that of the trachytes associated with olivine basalts in certain islands of the Pacific (E. E. WAHLSTRÖM, 1950). There, the trachytes have come up through the same channels as the basalts. They constitute apparently a late-stage manifestation of volcanic activity and the result of differentiation in depth of a basaltic magma. The nature of the "trachytes" varies with the primitive composition of the original magma. Trachyandesites and latites, associated with the trachytes, are probably intermediate products of the same source.

In the case of these islands there does not seem to have been any contamination (syntexis). Indeed, an olivine basaltic magma may normally produce a trachytic rock. Without contamination, only a tholeitic magma may lead to an oversaturated rock; it is therefore probable that a certain amount of digestion of acid rocks by the basalt has taken place in our region, since, starting from a magma quite rich in olivine, the final product in certain cases is a rhyolite.

D. Gardar Faulting (Pl. 17).

Fault movements often separated the emplacement of two different sets of dykes, through the alternation of phases of tension and compression.

Two fault systems played a particularly important morphological role. Indeed, one has only to look at the map to note two principal fjord directions, the most important being approximately WNW, nearly E-W, the other NNE.

The WNW system.

At various moments during the Gardar period considerable movement took place along these faults which have been followed over more than 200 km. It is supposed that they continue under the ice-cap and form the rectilinear, narrow fjords of SE Greenland.

These faults determine depressions which may attain several hundred m in width and are frequently invaded by the sea. The rock is generally crushed, even mylonitized.

It is possible that vertical displacements exist in numerous cases but the lack of well-defined correlating horizons renders their observation difficult. It is however certain that the most important movement took place horizontally; these features are therefore mainly transcurrent horizontal faults. Displacements of several km are common; this is the case of Sermiligârssuk and Tigssalûp ilua. If one adds up the various displacements of this fault system in the region of Ivigtut, the total offset is not far from 25 km.

This faulting constitutes one of the last manifestations of this period; in any case, these faults moved later than the emplacement of the most recent Gardar dykes.

It is to this category that one must ascribe the big WNW fault which passes on the southern shore of lake 470, displacing all dykes (excepting TDs) by 140 m.

The NNE system.

The map of our region also reveals the effect of these faults. Indeed, they determine a set of small, parallel, lateral fjords which are generally prolonged by a valley. Fig. 59 shows the fault which determines Qerrulik.

At Eqaluit, the situation is slightly different. First of all, the direction of the fjord is less clearly defined; in fact it is a bay. Moreover, the fault creates but a faint depression in the topography.

The effect of most of these faults becomes weaker as one goes towards Sermiligârssuk. Here too the repercussion on the topography is evident. The N coast is much less jagged than the S coast.

In these depressed zones, often 10–20 m wide, the rock is generally crushed; mylonitization causes, in extreme cases, a remobilization of siliceous material which forms quartz veinlets. Fault-planes are rarely visible; they show slickensides, generally related to the last movement of the fault. A dark, thin film occasionally covers these surfaces; it is composed of phyllosilicates (mainly chlorite) and some iron-oxides which, if they are in sufficient quantity, may give the rock a red tinge. Veins of muscovite also occur (Pl. 3, fig. 2).

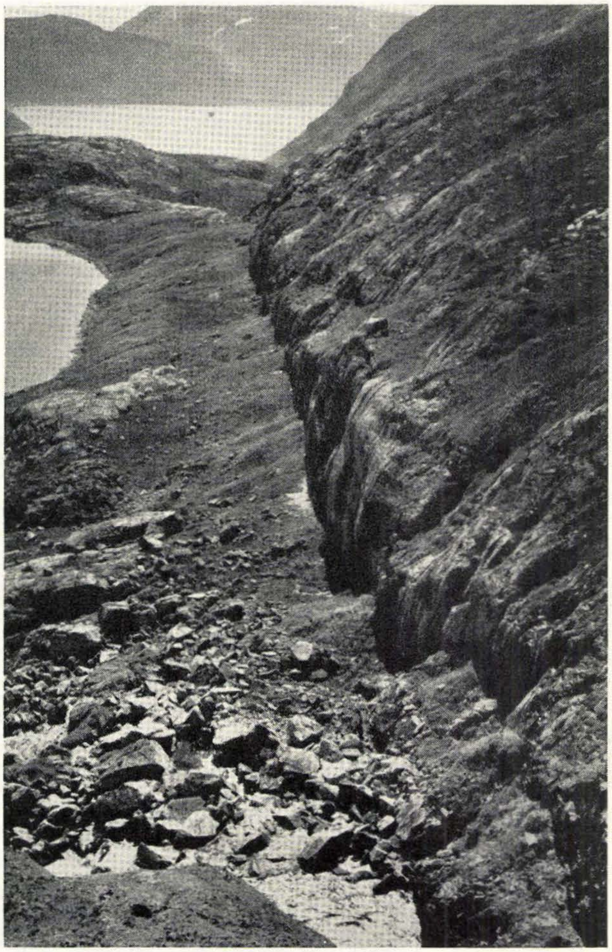


Fig. 59. The big NNE fault which determines Qerrulik.

The age of these faults has been precisely determined since they occurred between the emplacement of the BD1s and that of the BD2s; this important feature is valid for the whole region. Indeed, the same system is to be found all over the territory around Ivigtut and can be followed far to the S in the region of Nunarssuit-Qagssimiut.

In general, the direction of the dislocation is rectilinear: it is a narrow zone caused by a sudden and clean rupture. But in some cases, the foliation is distorted by the fault; this is shown by the microfault in Fig. 60. Moreover, dykes are frequently sheared, drawn out and boudinés in the tear zone. In the case of BDs, the plagioclase becomes less basic, the pyroxene, rarely preserved, is transformed into biotite or into hornblende through uralitization.

Fig. 60. Drags in a microfault affecting greenschists. This phenomenon may also occur on a very large scale. In gneissic areas, the foliation is frequently bent up against the fault. If the dislocation is quite important, this may take place over a few dozen m.

The displacement appears to be mainly horizontal and always dextral, except in one case. Here and there a vertical component is suggested by slickensides on fault-planes, but it is of small extent.

We shall now review these faults, from W to E.

1) The first starts at Eqaluit and crosses the whole territory right to Sermiligârssuk. The displacement increases from 350 m in the S to 500 in the N. Small fractures of moderate importance accompany it.

2) The valley N of Akuliarusiarssuk is caused by a fault which displaces a lamprophyre by 60 m.

3) At Kangerdlugssuaq there are two NNE faults separated by a distance of about 400 m. They do not reach the N coast. Their displacements are respectively 20 and 60 m.

4) The great fault of Qerrulik is the most curious. It determines all the way along its course an important depression marked by numerous

small lakes. Its displacement varies considerably and very suddenly. Where it penetrates into the territory mapped by M. Weidmann the displacement is 50 m. To the NE of lake 470 it is 80 m. Near the SE point of the same lake it increases rapidly and reaches 680 m. One km further S it is reduced to barely 50 m, whereas at the embouchure of the valley, it effects a large BD1 by 760 m. These estimates leave little doubt as to their correctness, as a number of dykes on each side of the fault allow correlation.

How to explain such rapid variations in the displacement? It seems in any case that the movement occurred in an irregular and complicated manner. An attractive hypothesis in order to explain the shortening of the displacements along the fault is that which suggests folding of the fault-blocks. This phenomenon has been brought to light by the measuring of axial variation in the folds of the region mapped by N. HENRIKSEN, W of Ivigtut (N. HENRIKSEN, 1960). Unfortunately, folds formed in this way would have, in our case, an axial direction identical to that of the Ketilidian folds, thus rendering a distinction between the two extremely difficult.

To explain the features observed in our territory, one must imagine that certain parts of the SE compartment of the fault continued to advance towards the SW under the effect of compression, whereas other more resistant parts came practically to a stop. Through the formation of small folds in the more plastic zones, the energy was absorbed and the volume of the displaced rock apparently reduced. It is possible that small folds were created simultaneously in the other compartment. In spite of the lack of sufficient proof of such a process, this hypothesis is the one which best explains the observed facts. C. A. COTTON (1956) refers to these "buckling" phenomena in connection with the tectonics of New Zealand.

5) In the SE corner of the region, at the northern extremity of the valley where two long lakes are to be found, a N–S to N10E fault displaces several dykes, but sinistrally, the displacement being about 20 m. It is the only example of a contrary movement observed in this territory.

Apart from these, there exist numerous small faults belonging to the same category, with displacements not exceeding 30 m.

Another category of faults, post-BD1 in age, may be distinguished. They seem to represent movements compensating states of slight instability due to the major system; they are of small extent and effect; sometimes displacement is nil, the rock only crushed. The general direction of this group is NNW.

In one of these faults, we came upon a magnificent fault-breccia (Fig. 61), which is an uncommon occurrence. The matrix is in variable

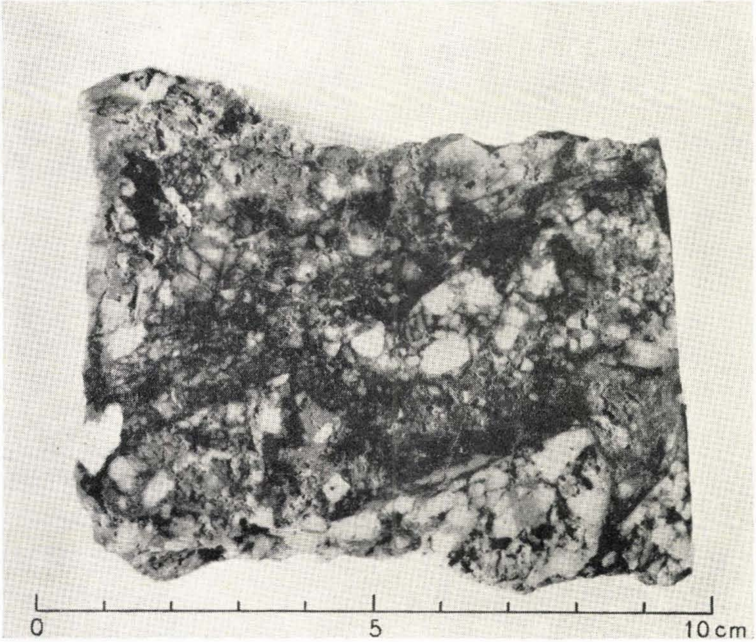


Fig. 61. Fault-breccia. The matrix is composed of phyllosilicates. The coarse elements are grains of oligoclase, quartz and epidote, and big cubes of rusty pyrite. (No. 38539). Central part of Akuliaruserssuaq.

quantity (between 10–15 $^0/_0$ of the rock), and essentially composed of phyllosilicates: very pleochroic biotite, in large plates, sometimes in fibrous clusters, light green chlorite, sericite and muscovite (with slight dispersion) and some antigorite. Limonite replaces the biotite plates. In this matrix are embedded large grains of plagioclase (an oligoclase with about 15 $^0/_0$ An), small grains of quartz with wavy extinction, sub-idiomorphic epidote with a yellowish tinge, tending locally towards piedmontite (red tinge), some zoisite, and big cubes of pyrite, with edges from 1 to 3 cm, more or less transformed into limonite.

Mineralizations. It was mainly towards the end of the volcanic evolution that large quantities of volatile material escaped and reached high levels. The courses that they followed are many and various: zones of weakness in a general manner, in other words, joints, fissures, faults, mylonites and dykes. One observes, especially in the dykes, great variations in the lateral and vertical distribution of the mineralizations depending above all on the age, composition and the tectonic deformation of these channels.

According to A. Berthelsen (1958), most of these deposits have been destroyed by erosion.

What is left of these mineralizations allows us, nevertheless, to define the character of the emanations. In the main fault-zone, near Ivigtut, where this phenomenon attained maximum intensity, the principal components were H_2O, CO_2, F, Cl, and S. Moreover, local concentrations of radioactive minerals show a fair amount of Th.

This pneumatolysis has had but little effect in the region under study, situated at quite some distance from this zone of maximum intensity. As for the particular components only the action of CO_2 merits attention. This caused the formation of calcite (other carbonates are nearly absent), especially in the great crush-zones, in some dykes, sometimes elsewhere. Here and there, in certain mylonites, a small amount of iron accompanies it, generally in the form of hematite. Moreover, we observed rare traces of sulphides (pyrite), and it is not impossible that small veins of tourmaline are also related to this phase, but as we have already stated, the genesis of this boric mineralization is mainly prior to the Gardar period; it is more or less synchronous with the formation of the Discordant Amphibolites (Kuanitic Dykes).

Radioactive minerals, prospected with a Geiger counter, appear to be totally absent from our region.

E. Summary and conclusions of the Gardar period.

The Gardar period begins by the emplacement of lamprophyric dykes. A comparison is established between these dykes and the hornblende-lamprophyres of the Skaergaard region on the E coast of Greenland. In both cases they derive from a basaltic magma enriched in volatiles (mainly alkali-compounds and H_2O).

The Brown Dykes constitute the most important group of the hypabyssal complex of the Gardar period. Three generations are distinguished, solely on the basis of their direction, which varies between ENE and NE, the first being that of the oldest dykes (BD 0), the second, that of the last (BD 2). Intrusion phenomena are noted: swarm, bayonet, "en échelon", disposition etc. Moreover, one observes variations of grain-size (chilled-margins, gabbro-pegmatites etc.), of texture (mainly ophitic), and of petrology (acid, basic segregations, "pegmatitoïdes", transversal variations; in composition, they range from quartz dolerites to troctolitic dolerites). They contain phenocrysts, xenocrysts, gneissic or anorthositic xenoliths. A few considerations on the very unlikely existence of a magmatic chamber with great horizontal extent are followed by the description of contact phenomena with effect on the encasing rock, a homogeneous gneiss, which is locally transformed into granophyre; the process is described with some detail.

Last manifestation of the hypabyssal complex, the group of the trachytes displays a quite wide diversity. In fact this field denomination includes types going from undersaturated (phonolite, tinguaite) to oversaturated (calco-alkaline rhyolite). While a process of differentiation readily explains the petrogenesis of most of these dykes, in the case of a rock with free silica, a certain amount of contamination must have occurred.

Faulting played a very important part in this period. Two main fault-systems determine the great WNW and the lateral NNE fjords. The displacements of the major system are considerable. Moreover, there exist numerous other fractures of smaller extent.

Some rare pneumatolytic mineralizations are reviewed.

THE POST-GARDAR PERIOD

The only important phenomenon which takes place during this period is the emplacement of a swarm of doleritic dykes more or less parallel to the coast. Their disposition is similar to that of the famous dyke formations, on the W coast of Scotland.

A. Description of the Trap dolerites (Pl. 18).

Direction. Most are NNW and belong to the same generation. Only one example of a younger dyke running approximately N–S has been observed, and its relative age determined through intersections. Moreover, they are diversely inclined towards the SW; generally the dip is about 75°, in some cases the angle may decrease to 45°. These variations in dip are observable from one dyke to another, or along the same dyke. Further inland, the inclination seems to increase.

Emplacement phenomena. Usually rectilinear, they may in certain cases meander (this depends on the adopted fissure); N of Qerrulik one of the NNW dykes leaves its course to follow, over a distance of about 400 m, the great N10E mylonite, before turning aside (see Fig. 40). Another, at Akuliaruserssuaq, follows the margin of a large AD, then clearly penetrates into the interior of this dyke, before leaving it towards the SE. The two dykes are in contact with each other over approximately three km. They may also display an "en échelon" arrangement, and possess apophyses. One of them splits up into two equal branches before reaching the sea on the S coast of Akuliaruserssuaq.

Distribution. Quite common to the W, they become more and more rare towards the E, and almost completely disappear at the eastern limit of our region.

Width. Some are 40 m wide, the average being about 10–15 m. The rare dykes in the eastern parts are only about 1 to 2 m, even 0.2 to 0.5 m wide. Consequently, their width, like their frequency, diminishes from W to E.

Fig. 62. A Trap dolerite (TD), about 10 m wide, forming a small crest above the encasing gneiss. Its course is slightly sinuous. Central and western part of Akuliarusserssuaq.

Erosion. They are mainly characterized by their "steps" which are the result of horizontal and vertical joint-systems (columnar jointing), most probably a direct consequence of cooling. These "steps", generally 0.5 to 1 m high, and other features too, justify the use of the term "Trap Diabase" (TD), in connection with these dykes. Weathering loosens the blocks, and rounds off their corners, transforming them into more or less spherical boulders which finally crumble into gravel. The dykes generally form crests above the encasing gneiss (Fig. 62). Like the Brown Dykes, they are more resistant than the country rock to glacial erosion, but less resistant to weathering.

General macroscopic aspect. These dykes bear a considerable resemblance to the Gardar dolerites and without field criteria (intersections, directions), it would be practically impossible to distinguish between them. Their superficial colour, however, often seems to be redder than that of the Brown Dykes. The rock is massive and the texture (mainly ophitic) appears clearly on the brown or grey-brown weathered surface. The fresh colour is generally dark grey. The grain-size is variable; the edge of a big dyke may be very fine, even glassy (chilled-margins), the centre being very coarse.

Fig. 63. Igneous banding in a Trap dolerite (TD). The acid segregation is vertical, parallel to the direction of the dyke, and about 5 cm wide. Its longitudinal extent is only about a few m. 2.5 km NNE of Angmassivît.

One may observe, as in the case of the Brown Dykes, zones rich in phenocrysts, where the crystals of plagioclase are in average a few cm long, sometimes attaining 8 cm. Here and there augite also stands out conspicuously, but its size does not exceed 0.5 cm. Xenoliths are rather rare; they are always enclaves detached from the walls.

Igneous banding may be locally developed (Fig. 63), the segregations being rectilinear with a more or less sharp contact; they form vertical bands a few cm wide (5 at the most), but which are not of great longitudinal extent.

Petrology. Under the microscope these dolerites vary but little. The texture may be ophitic (this is the most frequent case, Pl. 5, fig. 1), sub-ophitic, doleritic or simply intersertal.

The plagioclase is generally very fresh. Twinning is always frequent and often complex. Normal zoning shows a variation of plus or minus 10–15 % of anorthite with an average composition of about 50 % An: one notes, therefore, zoned crystals which vary between an optically negative andesine and a labradorite with 60 % An. It is sometimes brownish due to an exudation of cryptocrystalline hematite. Elsewhere it may be strongly sericitized, saussuritized or altered to zeolites. In the two last cases, the transformation is the result of late-stage magmatic, pneumatolytic activity.

The pyroxene often exists in two forms, monoclinic and orthorhombic.The first is an augite, commonly diopsidic, pinkish and titaniferous. Its alteration, generally weak, produces biotite, chlorite, sphene, leucoxene and ilmenite. Twinning is rare. A brown uralitic hornblende sometimes replaces the pyroxene, appearing along its cleavages, then spreading further. The second pyroxene is a light-coloured bronzite, in big grains, optically negative, with parallel and often undulatory extinction. Its alteration is similar to that of olivine, its refringence lower than that of the monoclinic pyroxene; uralitization and twinning are less frequent. Both pyroxenes are commonly and closely associated; one (mainly augite) may even exist as an inclusion in the other. Both display occasional idiomorphic forms. Quite often only augite is present, bronzite being totally absent from the rock.

Olivine is never very abundant and may be sometimes completely lacking. It is colourless and alters readily, beginning from the edges and along fissures, to iddingsite, bowlingite and limonite.

Biotite, as well as being the alteration-product of ferromagnesian minerals, may also be primary, but in insignificant quantity. It is brown, orange, sometimes very red, and forms patches which are often very finely crystallized, even cryptocrystalline. The proportion of iron is always very high. When it undergoes alteration, either orange vermiculite or a green chlorite is formed.

Opaque minerals are ubiquitous and abundant. They include mainly magnetite, ilmenite, limonite, sometimes hematite and pyrite. They are either primary or alteration products of the ferruginous minerals.

Apatite is always present and forms idiomorphic, more or less thick rods. Hexagonal sections are frequent.

Sphene is quite rare and commonly associated with leucoxene and ilmenite.

Micrographic quartz. These micropegmatitic associations (Pl. 5, fig. 2), although not always present, are in some cases magnificently developed, the quartz forming numerous hieroglyphs in the plagioclase.

This shows that the residual liquid is sometimes slightly quartzous, the rock having a tendency towards a quartz dolerite.

Zeolites. Very commonly one comes upon these white, fibrous minerals, with parallel or slightly oblique extinction. Generally formed at the expense of the plagioclase, they may themselves be sericitized. They are caused by late-stage magmatic, gaseous activity and are either intimately associated with the rock, or appear in amygdular druses. Sometimes they grow on a joint-plane. An X-ray diagram revealed stilbite.

Sericite-muscovite appears through alteration of the plagioclase; a few more important lamellae may possibly have developed during the last phase rich in volatiles.

The following table shows the percentual proportions of the different minerals.

	No. 32903	No. 32927	No. 32947	No. 32948	No. 32951	No. 32952	No. 32953	No. 32955	No. 32969	No. 33000
Plagioclase	44	60	54	58	47	48	70	52	56	60
Pyroxene M	26	24	28	28	6	2	20	30	24	22
Pyroxene O	..	..	..	..	39	44	..	..	..	..
Olivine	..	..	6	5	..	..	7	..	..	..
Ore	10	8	7	5	3	1	2	10	12	8
Others (Phyllosilicates, apatite, sphene)	20	8	5	4	5	5	1	8	8	10

B. Petrogenesis of the Trap dolerites.

The fresh state of these dykes, the fact that they are never faulted, their disposition, strongly suggest a close relationship with the Plateau basalts further N. Their age would therefore be Upper-Cretaceous or Tertiary. Moreover, L. R. Wager and W. A. Deer (1938) have described a similar swarm of dykes on the E coast, inclined towards the continent, i. e. in the same sense as in our region.

In both cases it seems that basaltic lavas have come up through more or less parallel fractures caused by a Tertiary coastal flexure.

C. Summary and conclusions of the Post-Gardar period.

A great lapse of time separates the end of the Gardar and the emplacement of two generations of dolerites, more or less parallel to the coast. These hypabyssal rocks are to be compared to a similar swarm on the E coast. They are probably related to the Plateau basalts further N and came up through parallel fractures, caused by a (Tertiary?) coastal flexure.

GENERAL CONSIDERATIONS ON THE EVOLUTION OF THE KETILIDIAN OROGENY

The geological history of the Ivigtut region is a very instructive example of the complete evolution of an orogenic cycle. The following summary of the succession of events brings this to light:

a) a geosyncline comes into being during a preorogenic stage. Sedimentation takes place in a zone of subsidence. Thick deposits are formed through the erosion of the neighboring continent; they are accompanied by ophiolitic and spilitic intrusions and effusions. This accumulation of material corresponds, in our region, to the Sermilik and Arsuk groups. The lowest levels undergo the early effects of regional metamorphism.

b) folding begins, accompanied by the rise of cordilleras. The role played by metamorphism and migmatization becomes gradually more important. This corresponds, *grosso modo*, to the N–S to NNE deformation.

c) the main features of this stage are intense folding, strong metamorphism and increasing migmatization ending in the formation of an anatectic granite. At the same time, a serpentine belt becomes individualized, indicating the zone of maximum orogenic activity (H. H. Hess, 1939). This corresponds to the major Ketilidian tectonic events.

Thus a mountain chain has risen, and now begins the ascent of deep-seated material.

d) while deformation still continues, syn-tectonic granites are emplaced, preceded in time and space by the various stages of migmatization.

e) fracturation occurs which allows the emplacement of basic magma in the form of dyke-systems, represented in our region by the Kuanitic Dykes.

f) the next phase is characterized by a rise of the thermal front, probably accompanied by a certain degree of subsidence. Diffuse post-tectonic granitic bodies are emplaced. Deep levels are reactivated, and the basic dykes metamorphosed. This is the Sanerutian period, which ends by the intrusion of post-tectonic potassic granites "circonscrits" into the upper levels. This particular period may be considered to be a repercussion of the Nagssugtôqidian orogeny which gave birth to a mountain chain further N, in the vicinity of Disko Bugt. The correlation is based solely on absolute age determinations and would tend to detach the Sanerutian period from the Ketilidian orogeny.

g) erosion has never stopped being active, and at this stage, where the last orogenic movements have come to an end, the mountain chain is slowly destroyed. A peneplain is left, on which are deposited arkosic and molassic sediments: the Igaliko sandstones, which are preserved only in a graben further S, in the vicinity of Narssarssuaq. They mark the beginning of the Gardar period, whose main feature is an alternation between states of tension and compression corresponding respectively to the intrusion of igneous rocks and fault-movements. Volcanic activity is intense; numerous generations of various hypabyssal rocks are separated by dislocations of more or less great extent. To the S of our region, various large syenitic massifs are emplaced at the beginning and at the end of the period.

h) after a long interval, continental flexure allows basaltic magma to extrude. This forms the Plateau basalts and the Post-Gardar dolerites (TD).

i) from this point on, only the weathering action of the elements and glacial abrasion affect the rigid shield.

RÉSUMÉ

Dans le cadre des recherches menées par le G. G. U., l'étude d'un terrain situé au NW d'Ivigtut, entre les fjords de Tigssalûp ilua et Sermiligârssuk, a été entreprise. Cette pénéplaine, où les effets d'érosion quaternaire, particulièrement glaciaire, ont été importants, fait partie, géologiquement, du bouclier canado-groenlandais. Depuis la reconnaissance de C. E. Wegmann (1938), l'histoire géologique de cette région a été divisée grossièrement en une phase orogénique, pendant laquelle est née la chaîne des Kétilides, et une phase de tension avec fractures et mise en place de filons (période de Gardar). Les études récentes ont mis à jour deux périodes intermédiaires: la période kuanitique, où se sont mises en place des dolérites, et la période sanérutienne pendant laquelle des transformations des roches préexistantes ont eu lieu, grâce à une remontée du front thermal.

Pendant la période kétilidienne, une chaîne de montagnes s'est constituée, où l'on peut distinguer une infrastructure migmatisée et une suprastructure comprenant une série d'ectinites. Les différences principales entre ces deux unités sont d'ordre structural et lithologique. La pétrographie macroscopique et microscopique de ces roches est passée en revue.

La suprastructure se compose de schistes pélitiques, basiques, quartzo-feldspathiques, ferrugineux, et magnésiens, qui ont recristallisé dans les deux premiers sous-faciès des schistes verts, selon F. J. Turner et J. Verhoogen (1960). L'infrastructure est caractérisée par des gneiss divers (rubanné, à schlieren basiques, homogène), dont un seul membre sort de la banalité, soit les gabbro-anorthosites; l'origine de ces roches curieuses est fortement débattue. L'apparition d'un grenat dans ces gneiss suggère un faciès métamorphique légèrement plus profond. L'ensemble représente probablement la transformation des roches de la série d'Arsuk (C. E. Wegmann, 1938).

Des zones rouillées ("rust-zones") peuvent avoir plusieurs origines. Dans les schistes verts, il s'agit probablement de bancs sédimentaires pyriteux transformés. Dans les gneiss, elles sont plutôt liées à des zones de broyage.

Les pegmatites sont surtout du type simple, quartzo-feldspathique. Un certain zonage, une structure en "pinch-and-swell", des plissottements ptygmatiques, sont phénomènes courants. Les pegmatites complexes, contenant des minéraux d'origine pneumatolytique ou hydrothermale, sont moins fréquentes. La plupart de ces filons se sont probablement formés par remplacement, grâce à une lente diffusion de matériel acide dans les zones de faiblesse.

Soit dans l'infrastructure, soit dans la suprastructure, il existe des lentilles de roches ultrabasiques, surtout sous la forme de serpentine, ou de talcschistes. Des phénomènes de réaction, au contact d'une pegmatite, sont décrits. Plusieurs arguments sont avancés en faveur de l'hypothèse d'un sill mis en place dans les sédiments frais et gorgés d'eau du géosynclinal.

Toutes ces roches ont subi des déformations intenses que l'on peut diviser en trois phases:

1) une phase pré-migmatique N–S à NNE.
2) une phase majeure migmatique WNW.
3) une phase surtout post-migmatique NE à ENE.

Il n'y a pas d'indication d'un arrêt considérable entre les diverses phases.

Durant la première phase, des plis petits et raides se sont formés, dont le style suggère une prédominance de matériel schisteux.

La deuxième est caractérisée par la formation d'une suprastructure en forme de synclinal et par la montée de dômes migmatiques composant l'infrastructure, où de grands plis, plus ou moins couchés, sont séparés par des synclinaux pincés et profonds.

Aux endroits où ces deux premières phases ont été très actives, on assiste à des phénomènes de "crossfolding" (tectoniques superposées) et de "wild-folding". L'emploi du canevas de Wulf s'est avéré très utile pour éclaircir ces problèmes; des exemples sont donnés.

Les effets de la troisième phase ne sont pas très visibles dans cette région, puisqu'il s'agit de déformations (plissements et torsions) à très grande échelle. Le laminage de la suprastructure en a peut-être été le principal résultat. Une certaine microclinisation semble également en être une des manifestations.

L'aboutissement de la tectonique kétilidienne est l'individualisation d'une suprastructure et d'une infrastructure, généralement séparées par une discordance structurale.

Le caractère polymétamorphique des roches kétilidiennes est résumé, les diverses transformations par métamorphisme sont succintement décrites, et la relation étroite entre migmatisation et métamorphisme régional affirmée.

La migmatisation et son rapport avec la tectonique révèlent d'intéressants phénomènes. Un front migmatique complet peut être suivi de l'infrastructure à la suprastructure. L'association étroite entre sa mise en place et les plis WNW est tout-à-fait évidente. La distribution des faciès migmatiques dans l'anticlinal couché, au NNE d'Angmassivît, démontre ce fait de façon particulièrement claire. La migmatisation et la seconde phase de plissement sont nettement contemporaines. Où il existe des barrières résistantes (horizons quartzitiques), le front migmatique arrêté est concordant avec la stratification primaire de la suprastructure.

La migration d'éléments et le métasomatisme sont passés en revue. Il est démontré que le sodium a migré plus loin que le potassium, qui reste cantonné dans les zones profondes. La migration du calcium est grandement responsable de la formation d'oligoclase basique, amphibole, calcite et épidote.

Des veines et pellicules hydrothermales sur la surface des diaclases sont fréquentes. Elles se composent principalement de magnétite, biotite et chlorite.

Pendant la période kuanitique, trois générations de dolérites tholéitiques se sont mises en place dans trois directions distinctes. Leur largeur et densité de distribution peuvent varier considérablement.

Une remontée du front thermal caractérise la période sanérutienne. Toutes les roches préexistantes subissent un métamorphisme assez faible. En particulier, les filons kuanitiques sont transformés en métadolérites selon les processus décrits par J. Sutton et J. Watson (1951). L'apport migmatique et métasomatique est très réduit. Plusieurs systèmes de dislocation et zones de broyage ont été distingués.

Des déterminations d'âge absolu suggèrent une corrélation entre la réactivation sanérutienne et l'orogenèse nagssugtoqidienne, dont les traces subsistent entre Søndre Strømfjord et Disko Bugt, également sur la côte W, mais plus au N (A. Berthelsen, 1961).

La période de Gardar commence par la mise en place de filons lamprophyriques. Une comparaison est établie entre ces dykes et les lamprophyres à hornblende de la région de Skaergaard, sur la côte E du Groenland. Dans les deux cas, ils dérivent d'un magma basaltique, enrichi en substances volatiles contenant alcalis et eau.

Les "Brown Dykes" constituent le groupe le plus important du complexe filonien de la période de Gardar. Trois générations se distinguent uniquement par leur direction, qui va de ENE à NE, la première direction étant celle des filons les plus vieux (BD 0), la seconde, celle des derniers (BD 2). Des phénomènes de mise en place sont relevés: disposition en "swarm", "baionette", "échelon", etc. En outre, on note des variations de la taille du grain ("chilled-margins", gabbro-pegmatites etc.), de la texture (surtout ophitique), de leur pétrographie (ségrégations acides, basiques, pegmatitoïdes, variations transversales; en composition, ils varient entre dolérite quartzique et troctolitique). Ils contiennent phénocristaux, xénocristaux, xénolithes gneissiques ou anorthositiques. Quelques considérations sur l'existence peu probable d'une chambre magmatique, étendue dans le sens horizontal, sont suivies de la description d'un phénomène de contact avec effet sur la roche encaissante, un gneiss homogène, qui est transformé localement en granophyre; le processus est décrit avec quelque détail.

Dernière manifestation du complexe filonien, le groupe des trachytes montre une assez grande diversité. En fait, cette dénomination de terrain comprend des types allant du sous-saturé (phonolite, tinguaïte) au sursaturé (rhyolite calco-alcaline). Si un processus de différenciation explique assez aisément la pétrogenèse de la plupart de ces dykes, dans le cas des roches à silice libre, un certain degré de contamination a dû avoir lieu.

Les manifestations de la tectonique cassante ont été très importantes pendant la période de Gardar. Deux grands systèmes de failles déterminent les fjords majeurs WNW, et les fjords latéraux NNE. Les rejets du système majeur sont considérables. En outre, il existe quantité de cassures de moindre importance.

Quelques rares minéralisations pneumatolytiques sont passées en revue.

Un grand laps de temps sépare la fin du Gardar de la mise en place de deux générations de dolérites plus ou moins parallèles à la côte. Ces roches hypabyssales sont à comparer à un essaim semblable de la côte E. Elles sont probablement liées aux basaltes des plateaux, plus au N, et auraient emprunté des cassures parallèles, causées par une flexure côtière (tertiaire ?).

КРАТКИЙ ОЪЗОР

Исследование территории расположенной к северо-западу от Ивигтута, между фиордами Тигссалупилуа и Сермилигарссук, производились как часть исследовательской работы Г. Г. У. Этот пенеплен, где эффект четвертичной эрозии является очень важным, особенно ледниковая абразия, принадлежит геологически к Канадо-Гренладскому щиту. Со времени исследования произведенного **К.Е.Вегманом** (1938 г.) геологическая история этой области была разделена на орогеническую фазу, во время которой формировалась кетилиданская цепь, и фазу напряжений с блоктектоникой и осаждением дейков (гардарский период). Последние исследования выявили два промежуточных периода, куанитный период, во время которого произошло внедрение долеритов, и санерутианский период, во время которого произошла трансформация предсуществующих пород в результате увеличения термического фронта.

Во время кетилиданского периода формировалась горная цепь в которой можно отличить мигматизированную инфраструктуру и супраструктуру состоящие из эктинитовых серий. Принципальная разница между тыми двумя формами заключается в структуре и литографии. Рассматривается макроскопическая и микроскопическая петрография этих пород.

Супраструктура включает в себе пелитовые, основные, кварцо-фельдшпатовые железистые и магнезиальные сланцы, которые перекристализировались в двух первых зелено-сланцевых субфациах согласно **Ф.Ж. Турнер** и **Ж. Вергуген** (1960 г.). Супраструктура характерна различными гнейсами (полосчатыми, чешуйчатыми, гомогенными) из которых оден член строго отличается, а именно, гарбоанортозиты. Произхождение этих пород обсуждается очень строго. Появление в этих гнейсах указывает на немного глубшие метаморфические фации. В общем эти породы представляют, по видиму, трансформацию арсукской группы (**К.Е. Вегманн**, 1938 г.).

Рустовые зоны являются различного произхождения. В зеленых сланцах они, по видиму, имеют осадочные пласты содержающие пирит. В гнейсах они чаще всего относятся к зонам раздавливания.

Пегматиты являются главным образом кварцо-фельдшпатного типа. Зональность, структура роздувов и пережимов а также птигматические образования микроскладок являются текущим явлением. Комплекс пегматитов содержащие минералы пневматолитового или гидротермического происхождения встречаются реже. Большинство этих жыл формировались, по видиму, путем медленной диффузии кислотных материалов в слабых зонах.

Инфраструктура как и супраструктура содержат линзы ультраосновных пород, особенно серпентиниты или тальковые сланцы. Описывается явление реакции с пегматитом в контактных зонах. Обсуждаются аргументы в пользу гипотезы осаждения интрузивного пласта во свежих и водонасыщенных осадках геосинклинали.

Все эти породы подвергались складыванию которое можно разделить на три фазы:

1. Домигматическая фаза распространяющаяся от северо-юга к северо-северо-востоку.
2. Большая западно-северо-западна мигматическая фаза.
3. Послемигматическая фаза распространяющаяся от северо-востока к востоко-северо-востоку.

Нет признаков большого сброса между отдельными фазами.

Во время первой фазы формировались небольшие крутые складки, форма которых указывает на преобладающий сланцеватый материал.

Вторая фаза характерна образованием синклинальной супраструктуры и мигматических роздувов в инфраструктуре, в результате чего появились большие складки опрокинутые в большой или меньшей степени и отделенные крутыми синклинальями. Метаморфоз достигл максимальной интенсивности.

В местах, где обе фвзы были очень активны, произошли косые и безпорядочные складки. Дается пример использования сети Вульфа для решения этих вопросов.

Эффекты третьей фазы не очень видны в этой области, так как они относятся к полупластичной вторичной складчатости, кручению и изгибам большого масштаба. Главным результатом этого может быть сдвиг супраструктуры. Микроклинизация, по видиму, также относится к этой фазе.

Результатом кетилиданской тектонической деятельности является индивидуализация супра и инфраструктуры обычно отделенных структурным разрывом.

Обсуждается полиметаморфный характер кетилиданских пород а также дается краткое описание различных преобразований в результате метаморфизма и подтверждение связи между мигматизацией и областным метаморфизмом.

Мигматизация и ее отношение к тектонике показывают некоторые интересные особенности. Дается возможность проследить ввесь мигматитный фронт от инфраструктуры до супраструктуры. Близкая связь между его местонахождением и складками в направлении З-С-З является вполне явной. Распределение мигматитных плоскостей в опрокинутой антилинали, С-С-В от Ангмассивит, лемонстрирует этот факт особенно хорошо. Мигматизация и вторая фаза складывания являются явно одновременными. В местах где существуют устойчивые барьеры (кварцитовые ярусы), неразвитый мигматитный фронт согласовывается с первичным нижним слоем супраструктуры.

Производится обзор элемента мигрирования и метасоматизма. Показывается что натрий мигрировал дальше чем калий остающийся локализированным в глубоких зонах. Мигрированием кальция обусловляется образование основного олиглклаза, амфибола, кальцита и эпидота.

Часто встречаются гидротермические жылы и пленки. Их главные составные части следующие: магнетит, биотит и хлорит.

Во время куанитового периода осадились три генерации толеитных долеритов в трех легко отличаемых направлениях. Их ширина и плотность распределения меняется в большой степени.

Повышение термического фронта характеризует санерутьянский период. Все предсуществующие породы подвергаются небольшому метаморфизму. Особенно, куанитные дейки превращаются в метадолериты в соответствии с процессом описанным **Ж. Суттон** и **Ж. Уотсон** (1951 г.). Мигматитное и метасоматное внедрение материала незночительно. Отмечено несколько сбросов и зон разрушения.

Абсолютное определение эпохи указывает на соотношение между санерутьянским восстановлением и нагссугтоквидьяской орогенией, остатки которых можно найти между Сондре Стромфиорд и Диско Бугт а также на западном побережьи но более к северу (**А. Бертелсен**, 1960 г.).

Гарданский период начинается посадкой лампрофирных дейков. Приводится сравнение между этими дейками и амфибол-лампрофирами скаергардской области на восточном побережьи Гренландии. В обоих случаях они происходят от базальтовой магмы обогащенной испарениями (главным образом щелочыми соединениями и H_2O).

Дейки Браун составляют главную группу гипабиссального комплекса гардарского периода. Отличается три генерации исключительно на базе их направлений, которые меняются от В-С-В и С-В, первое из них будучи наистаршим дейком (БД$_0$), а второе, последним (БД$_2$). Наблюдаются следющие явления внедрения: ползучесть, эшалонность, расположение, и прочее. Кроме этого наблюдается изменение размеров зерна (затвердевшие окраины, габро-пегматиты, и т.п.) структуры (главным образом офитовой) и петрографии (кислоты, основные энтогенные включения, »пегматитоиды«, поперечные изменения; в составе они меняются от кварцовых долеритов до троктолитовых долоритов). Они включают в себе фенокристы, ксенокристы, гнейсовые или анортозитные ксенолиты). Обсуждается очень невероятное существование магматической полости с большой горизонтальной протяженностью и дается описание контактного явления заключения пород и однородного гнейса, который в местах превращен в гранофир. Процесс описывается с некоторыми подробностями.

Наимолодший член этого гипабиссального комплекса, а именно, группа трахитов, проявляет очень большое разнообразие. На самом деле, класс поля включает в себе типы от недонасыщенных (фонолит, тингуаит) до перенасыщенных (кальцио-щелочный риолит). Тогда как диференциация об'ясняет петрогенез большинства этих дейков, в случае пород содержащих свободный кремнезем произошло некоторое загрязнение.

Сбросовая деятельность играла в этом периоде очень важную роль. Большие фиорды З-С-З и поперечные фиорды С-С-З определяют две главные системы сброса. Перемещения главных систем значительны. Кроме этого существуют многочисленные трещины небольшой протяженности.

Обсуждаются некоторые редкие пневматолитические минерализации.

Конец гардарского периода и осаждение двух генераций долеритов, расположенных более-менее параллельно к побережьи, отделены большим промежутком времени. Эти гипабиссальные порды сравниваются с подобной серией землетрясений на восточном побережьи. Они, по видиму, относятся к плоскогорью базальтов расположенных севернее и проникших сквозь параллельные трещины обусловлены (третичной?) радиальной складкой побережья.

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N. B. M. o. G. = Meddelelser om Grønland.
G. G. U. = Grønlands Geologiske Undersøgelse.

Færdig fra trykkeriet den 18. juni 1963.

PLATES

Plate A.

The region between Tigssalûp ilua, in the right foreground, and Sermiligârssuk. In the distance, the ice-cap. Copyright: Geodetic Institute, Copenhagen.

Plate 1.

Fig. 1.

Microcline – microperthite in gneissic schists. (No. 38500). S coast of Sermiligârssuk. 45 ×. Crossed nicols.

Fig. 2.

Epidote with a core of allanite and radial cracks in a banded gneiss (No. 38527). Centre of Akuliaruserssuaq. 90 ×. Plain light.

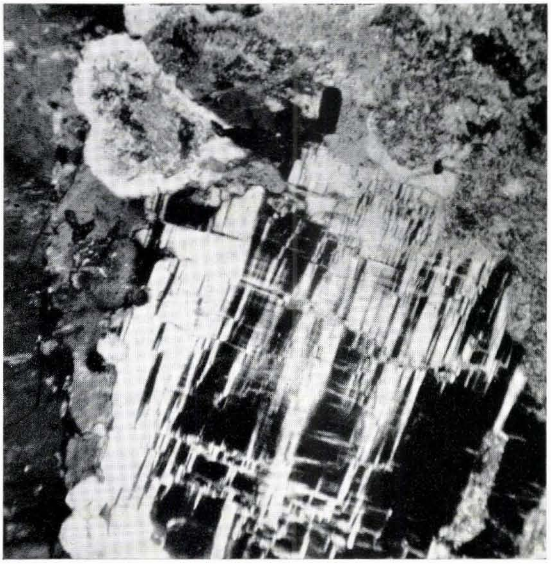


Fig. 1.

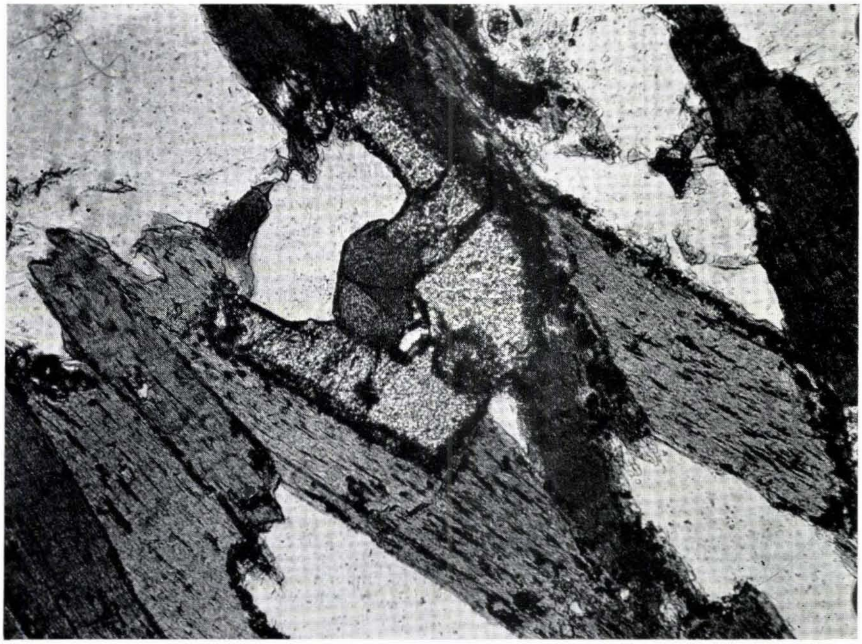


Fig. 2.

Plate 2.

Fig. 1.

Amygdule in a lamprophyric dyke (JD). The centre is composed of chlorite-sericite, the dark rim of ore. (No. 32901). Akuliarusiarssuk. 45 ×. Plain light.

Fig. 2.

Sphene replacing ilmenite, the cleavages of which are quite distinct. Banded gneiss. (No. 32991). Angmassivît. 45 ×. Plain light.

Fig. 3.

Magnetite crystals embedded in a matrix composed of finely crystallized talc. Ultrabasic lens. (No. 38420). SW coast of Eqaluit. 30 ×. Plain light.

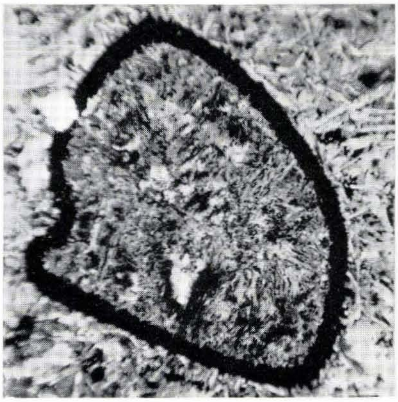


Fig. 1.

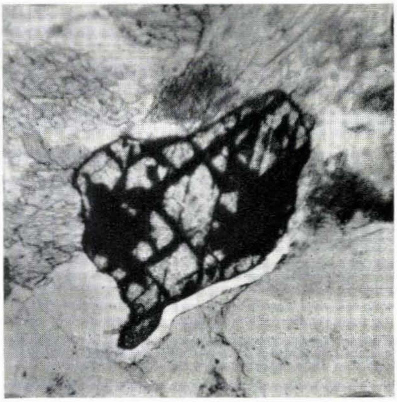


Fig. 2.

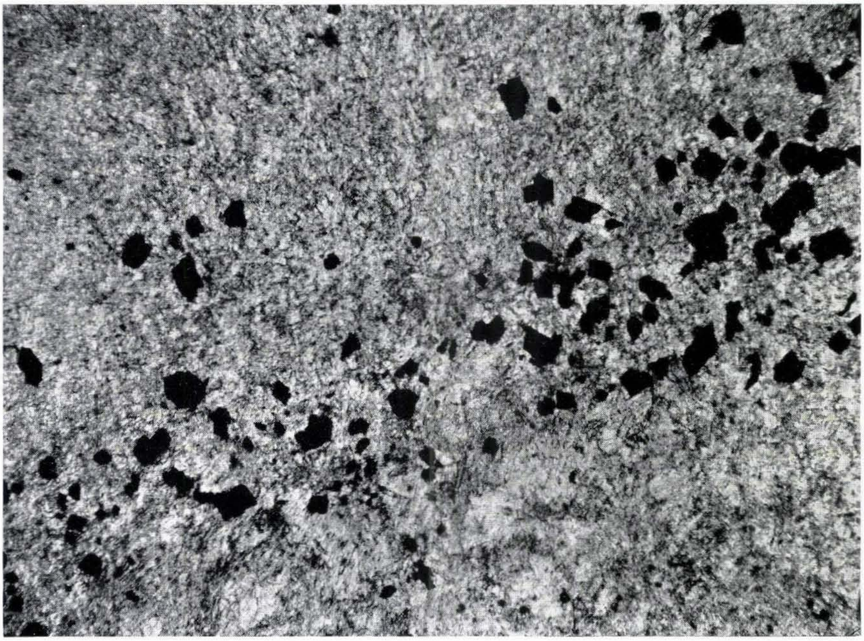


Fig. 3.

Plate 3.

Fig. 1.

Vein composed of tremolite fibres. Ultrabasic lens. (No. 38418). SW coast of Eqaluit. 22 ×. Plain light.

Fig. 2.

Muscovite in a mylonitic zone. (No. 38543). Centre of Akuliaruserssuaq. 30 ×. Plain light.

Fig. 1.

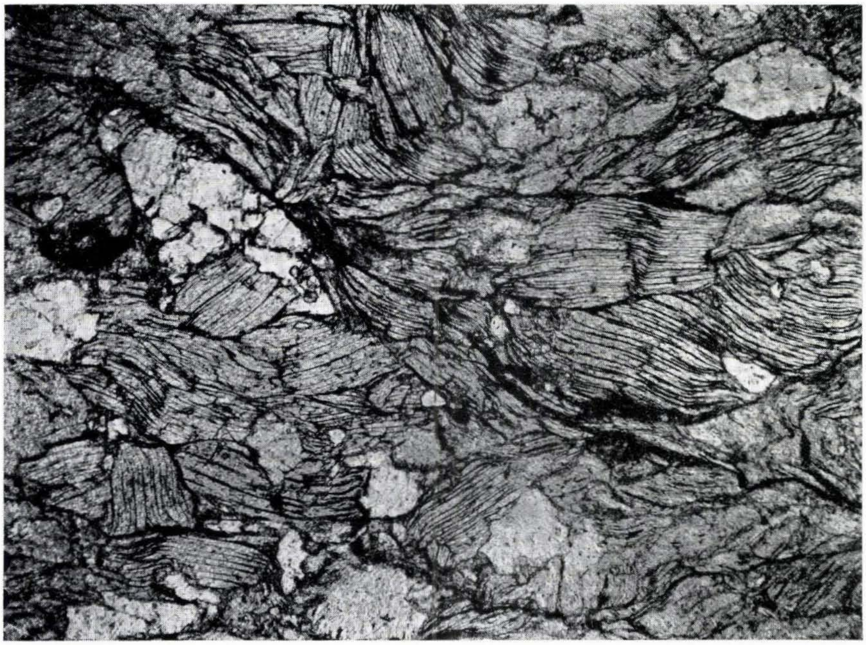


Fig. 2.

Plate 4.

Fig. 1.

Amygdule composed of a crystal of calcite and a rim of chlorite. This occurs in a dolerite (BD1). (No. 38481). SW of summit 890 (crest overlooking Sermiligârssuk). 22 ×. Plain light.

Fig. 2.

Leucite-bearing tinguaite porphyry. In the lower right-hand corner, a crystal of brown hornblende, and in the upper left-hand corner, a microphenocryst of melanite. The groundmass is composed of leucite, pseudoleucite and needles of aegyrine. (No. 38503). 1 km N of summit 890 (crest overlooking Sermiligârssuk). 30 ×. Plain light.

Fig. 1.

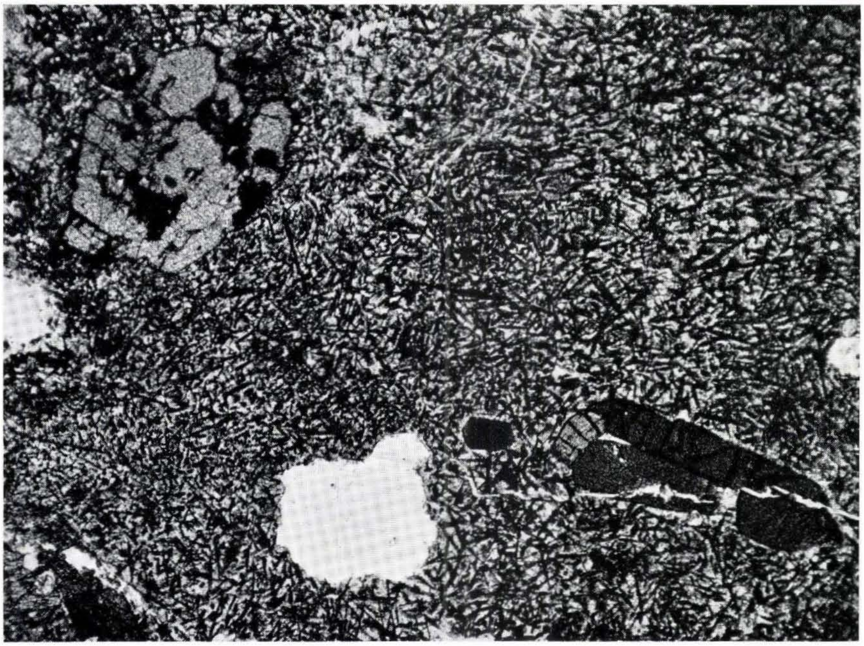


Fig. 2.

Plate 5.

Fig. 1.

Post-Gardar olivine-bearing dolerite (TD1) with ophitic texture. (No. 32947). W coast of Qerrulik. 45 ×. Plain light.

Fig. 2.

Micrographic associations in a Trap dolerite (TD) containing two sorts of pyroxene (monoclinic and orthorhombic). (No. 32951). SE point of Akuliarusersuaq. 45 ×. Crossed nicols.

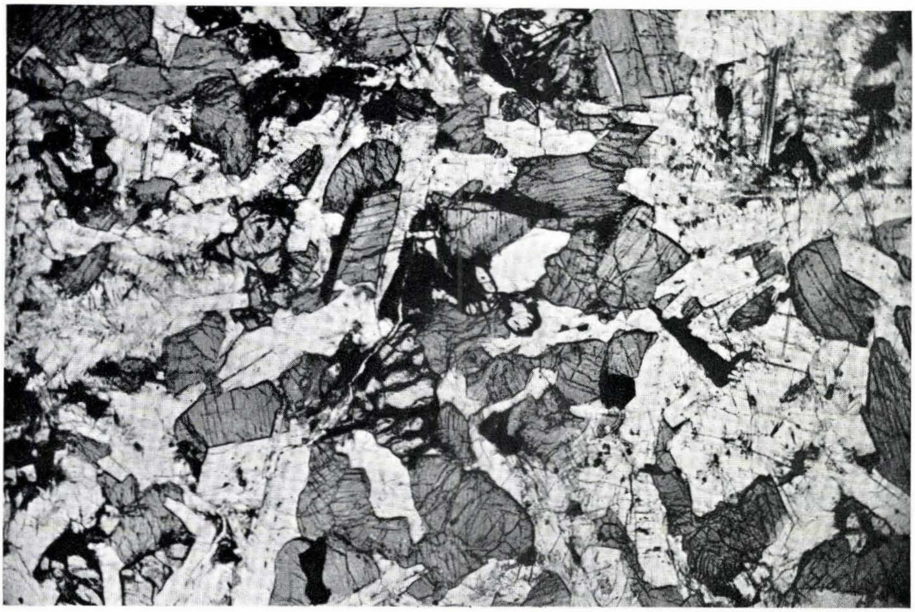


Fig. 1.

Fig. 2.

Plate 6.

Fig. 1.

Crocidolite in a crushed banded gneiss. (No. 38541). E part of Akuliaruserssuaq. 90 ×. Plain light.

Fig. 2.

Micrographic arrangement in a Kuanitic Dyke. Note the grains of ilmenite surrounded by sphene. The groundmass is made up mainly of phyllosilicates. (No. 32930). 400 m S of lake 280. 45 ×. Crossed nicols.

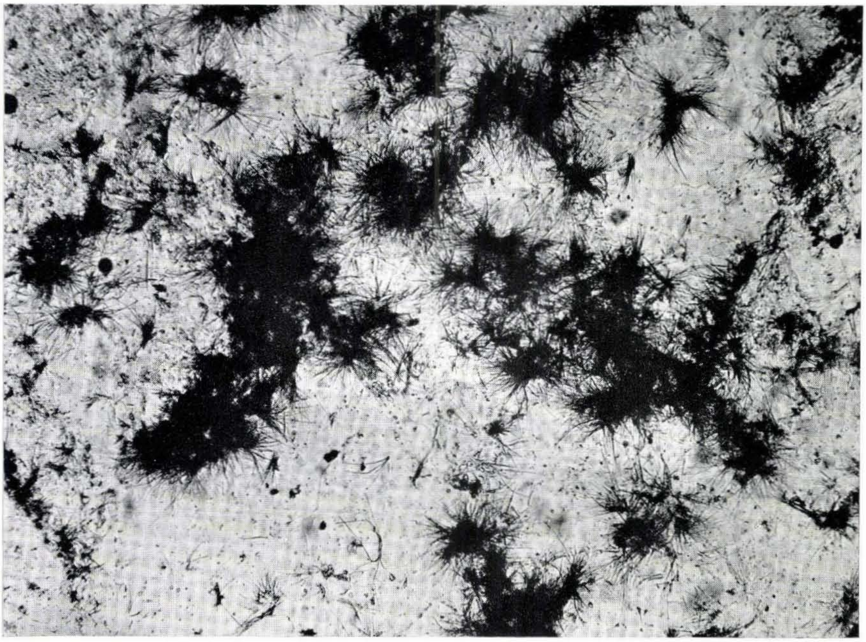


Fig. 1.

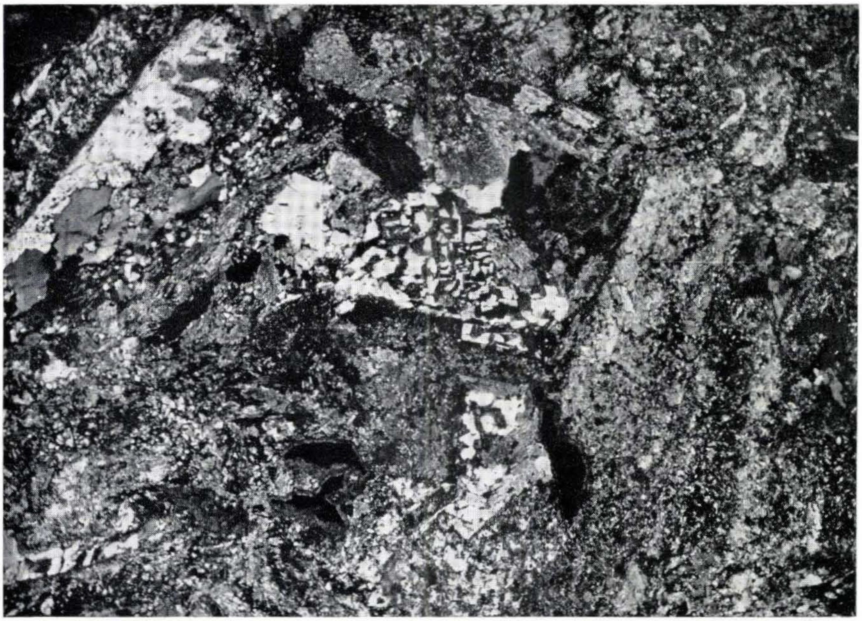


Fig. 2.

Plate 7.

Fig. 1.

Magnetite replacing amphibole in a Kuanitic Dyke. A light green chloritized hornblende is the main mafic mineral. (No. 32958). S coast of Akuliaruserssuaq. 45 ×. Plain light.

Fig. 2.

Typical ophitic texture in an olivine-bearing dolerite (BD1). (No. 32848). Peninsula 25 on the S coast of Sermiligârssuk. 45 ×. Crossed nicols.

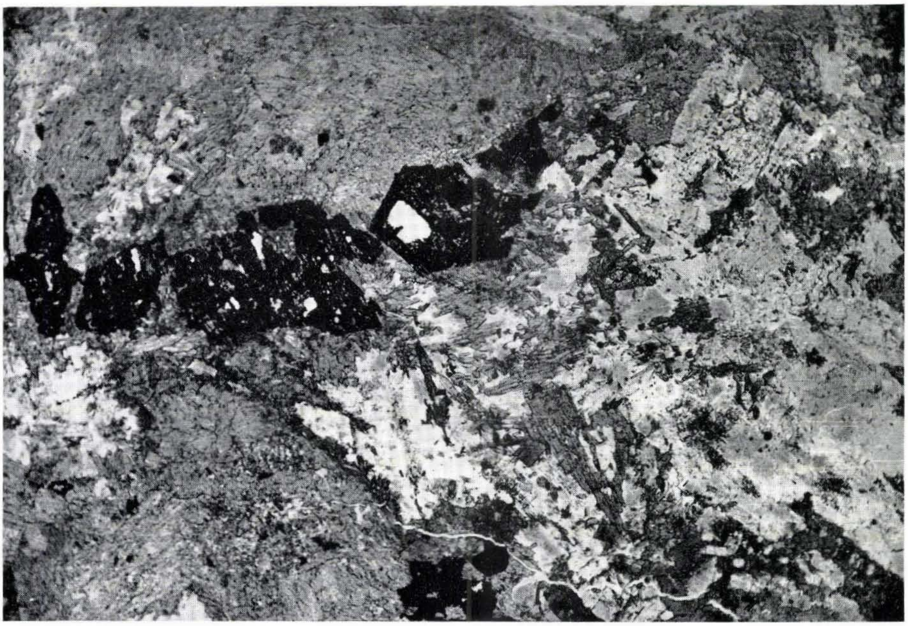


Fig. 1.

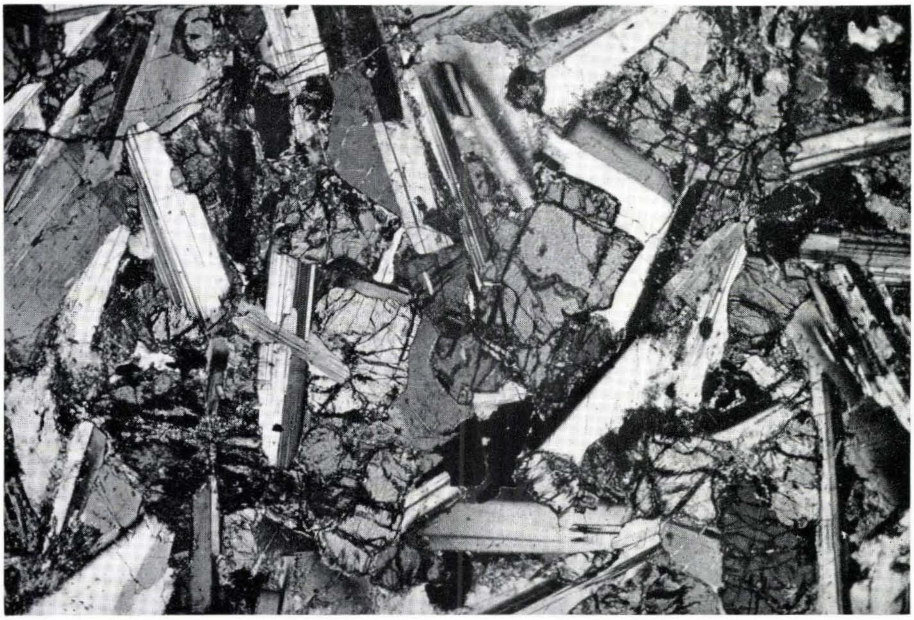


Fig. 2.

Plate 8.

Fig. 1.

Minute inclusions in the central part of a microphenocryst of plagioclase. This occurs in the finely crystallized edge of a large dolerite (BD1). (No. 38449). Valley N of Akuliarusiarssuk. 30 ×. Plain light.

Fig. 2.

Minute inclusions arranged in a zonal disposition in a microphenocryst of plagioclase. Observed in the same slide as Pl. 8, fig. 1. 30 ×. Plain light.

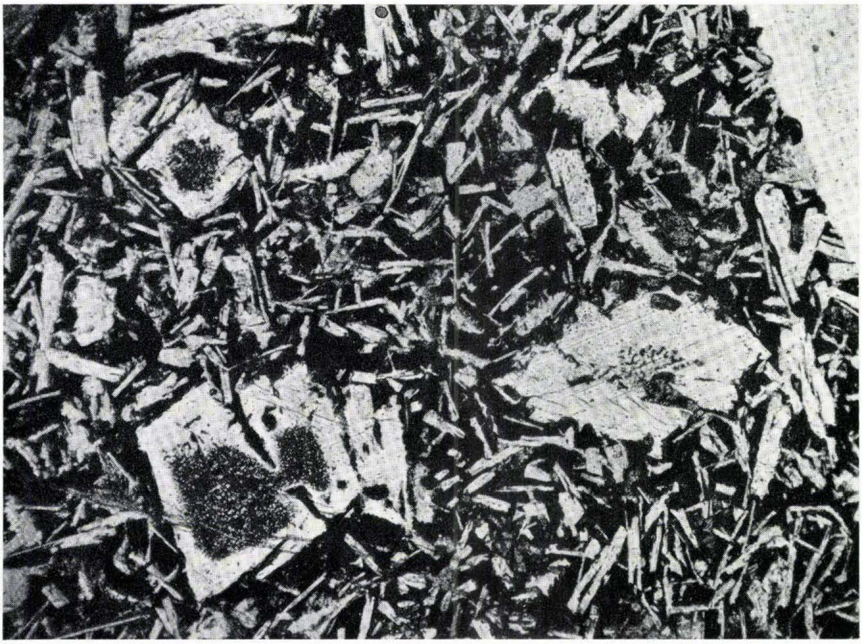


Fig. 1.

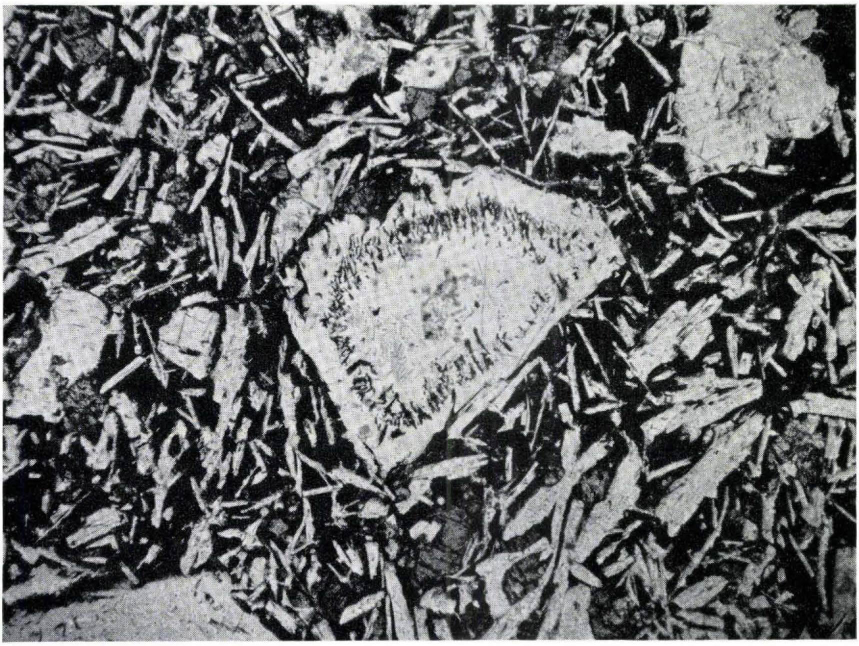


Fig. 2.

Plate 9.

Fig. 1.

Xenocryst of feldspar in a dolerite (BD1). Numerous small inclusions form a sort of lattice which disappears towards the centre. (No. 38528 b). Central part of Akuliaruserssuaq. 30 ×. Plain light.

Fig. 2.

Microphenocrysts of olivine in a finely crystallized dolerite (BD1). (No. 32907). SW tip of Akuliarusiarssuk. 45 ×. Crossed nicols.

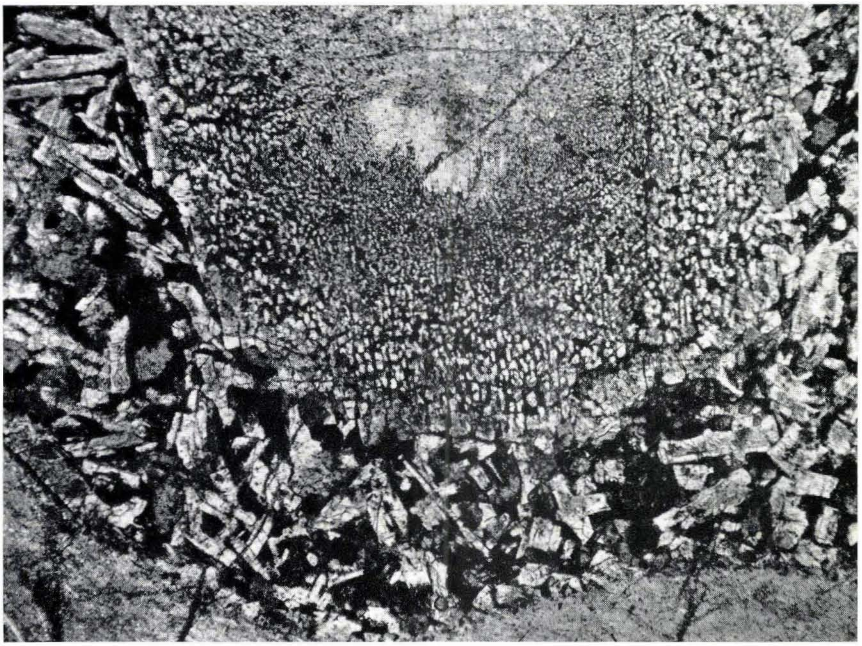


Fig. 1.

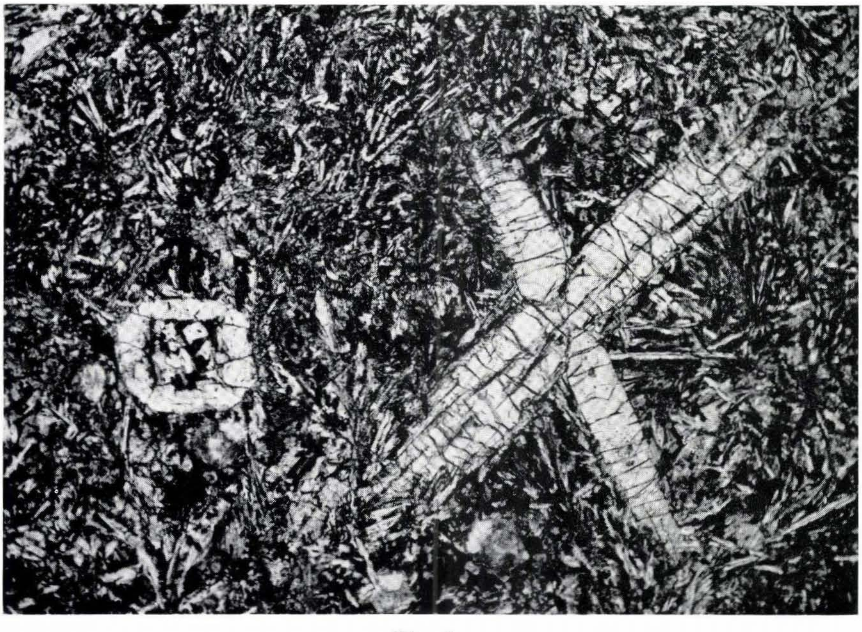
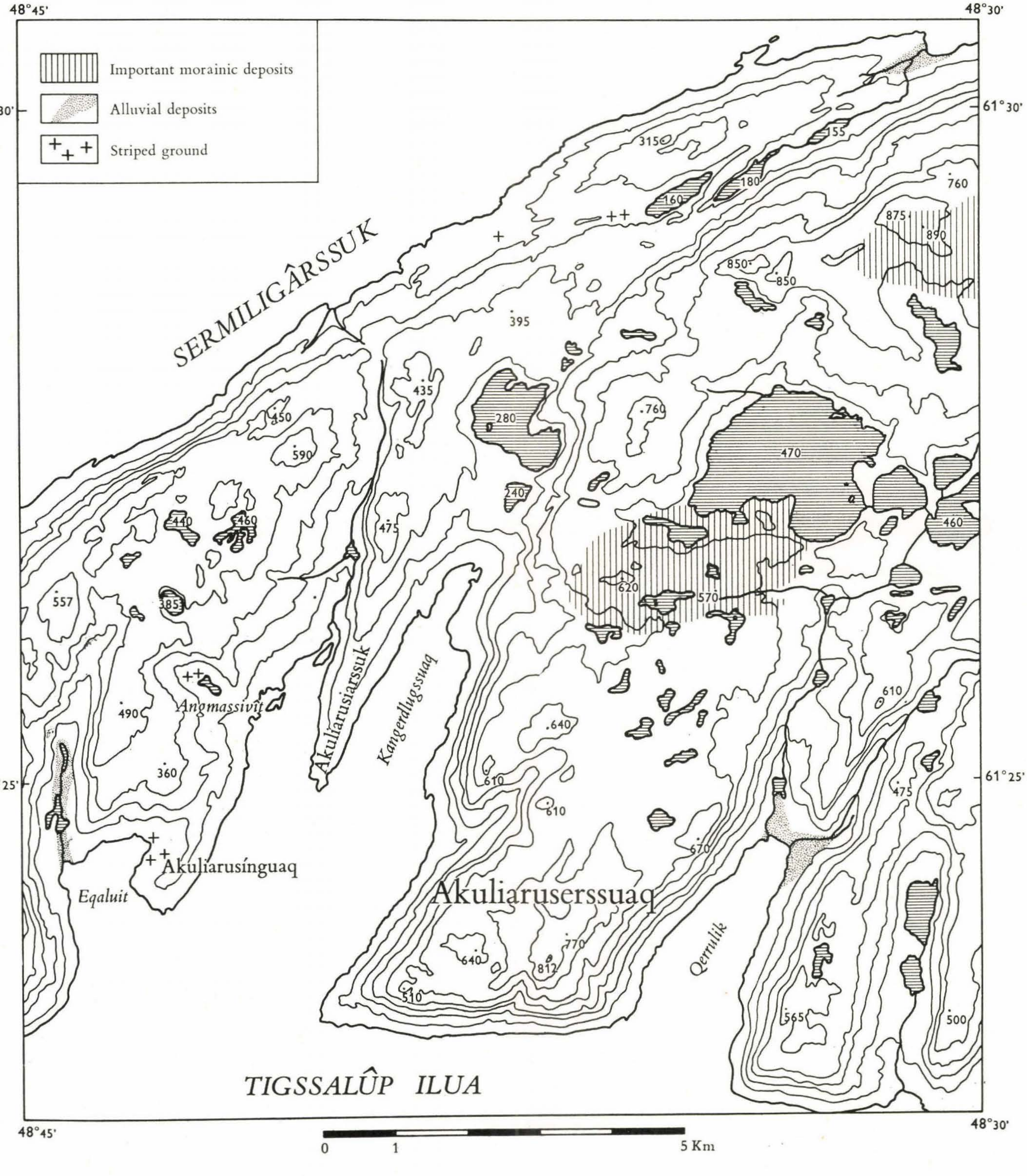


Fig. 2.

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

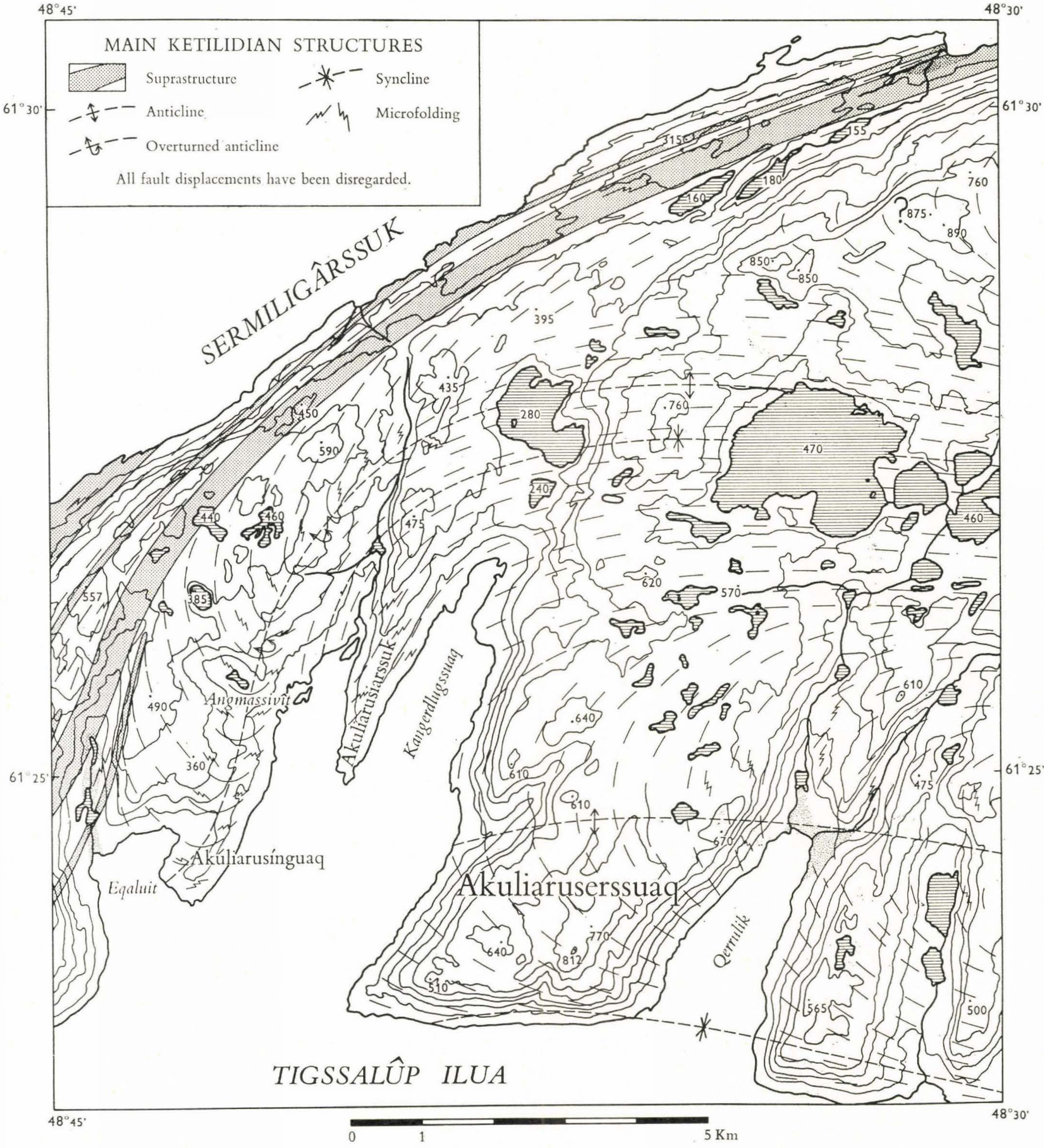
PLATE 10.



GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

PLATE 11.



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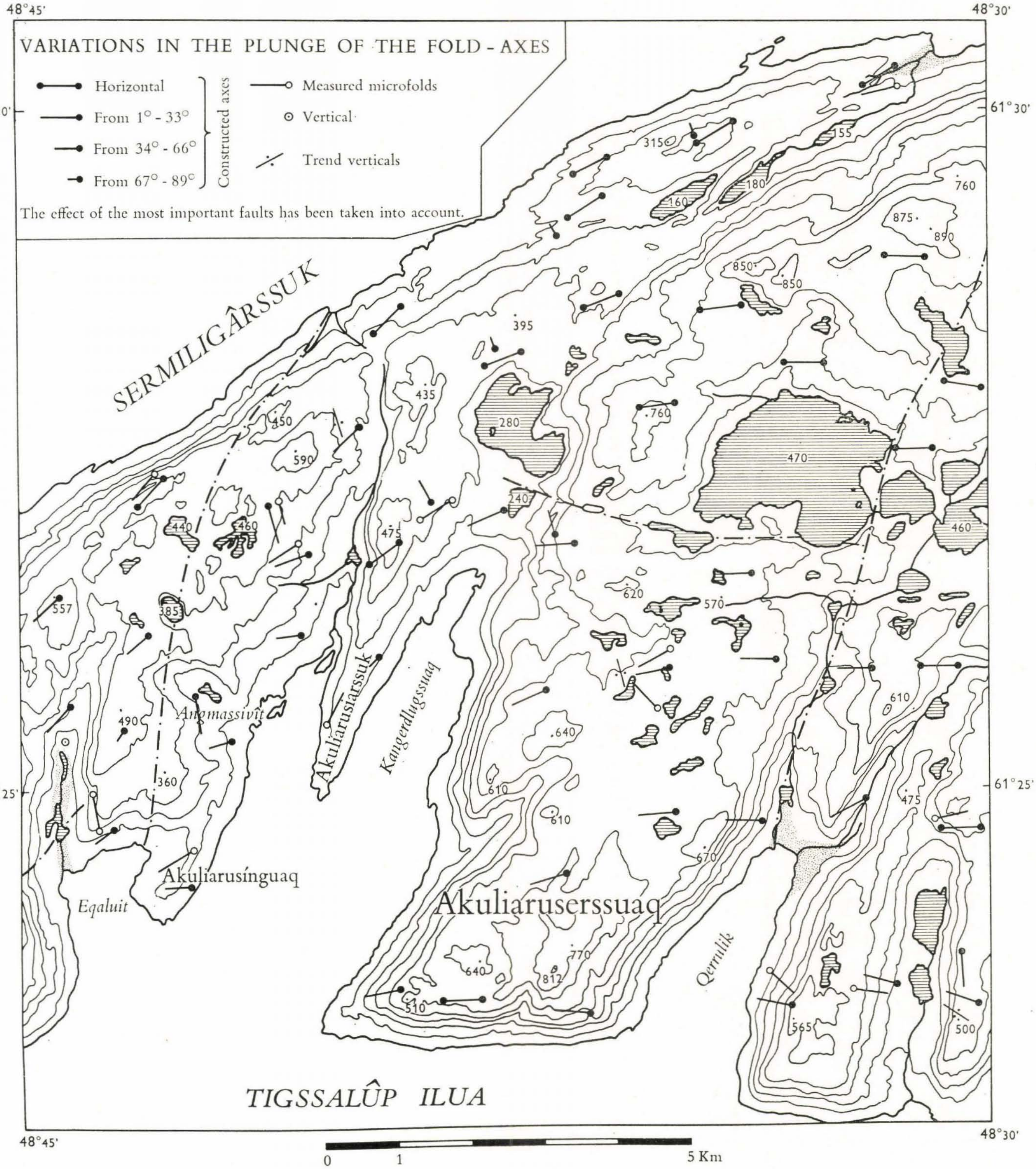
THE GEOLOGICAL SURVEY OF GREENLAND

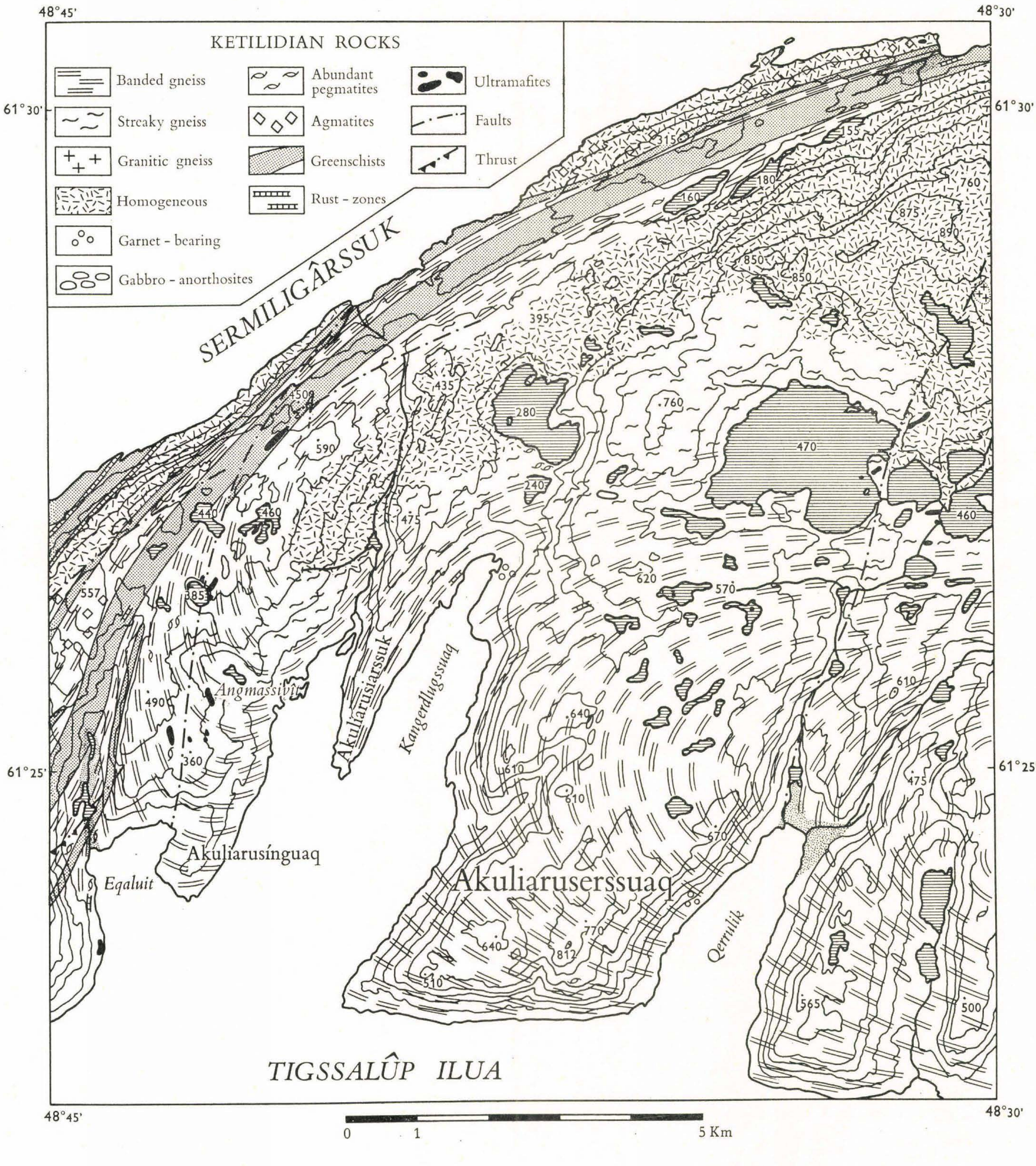
MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

PLATE 12.



GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

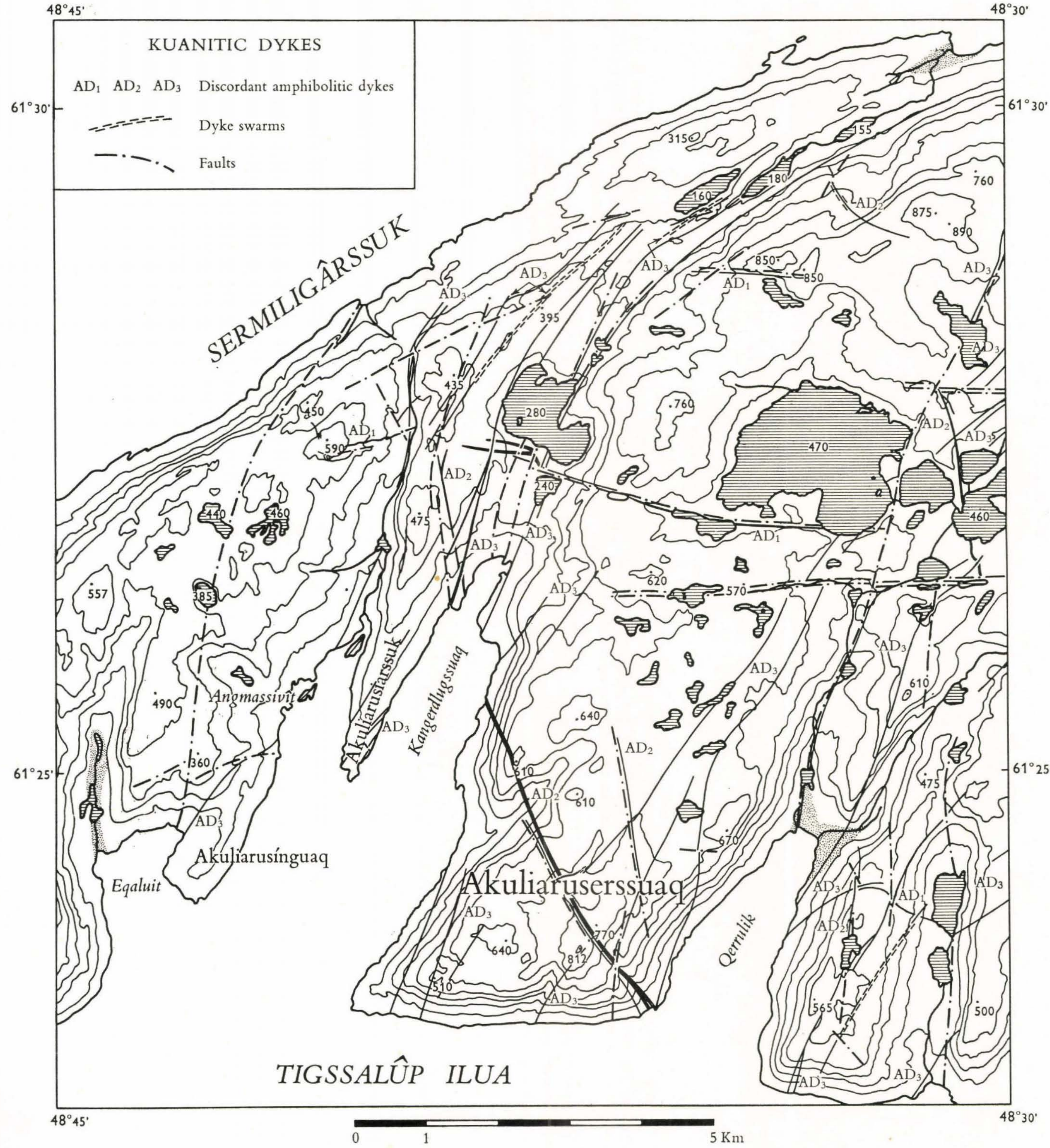
MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON). PLATE 13.



GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

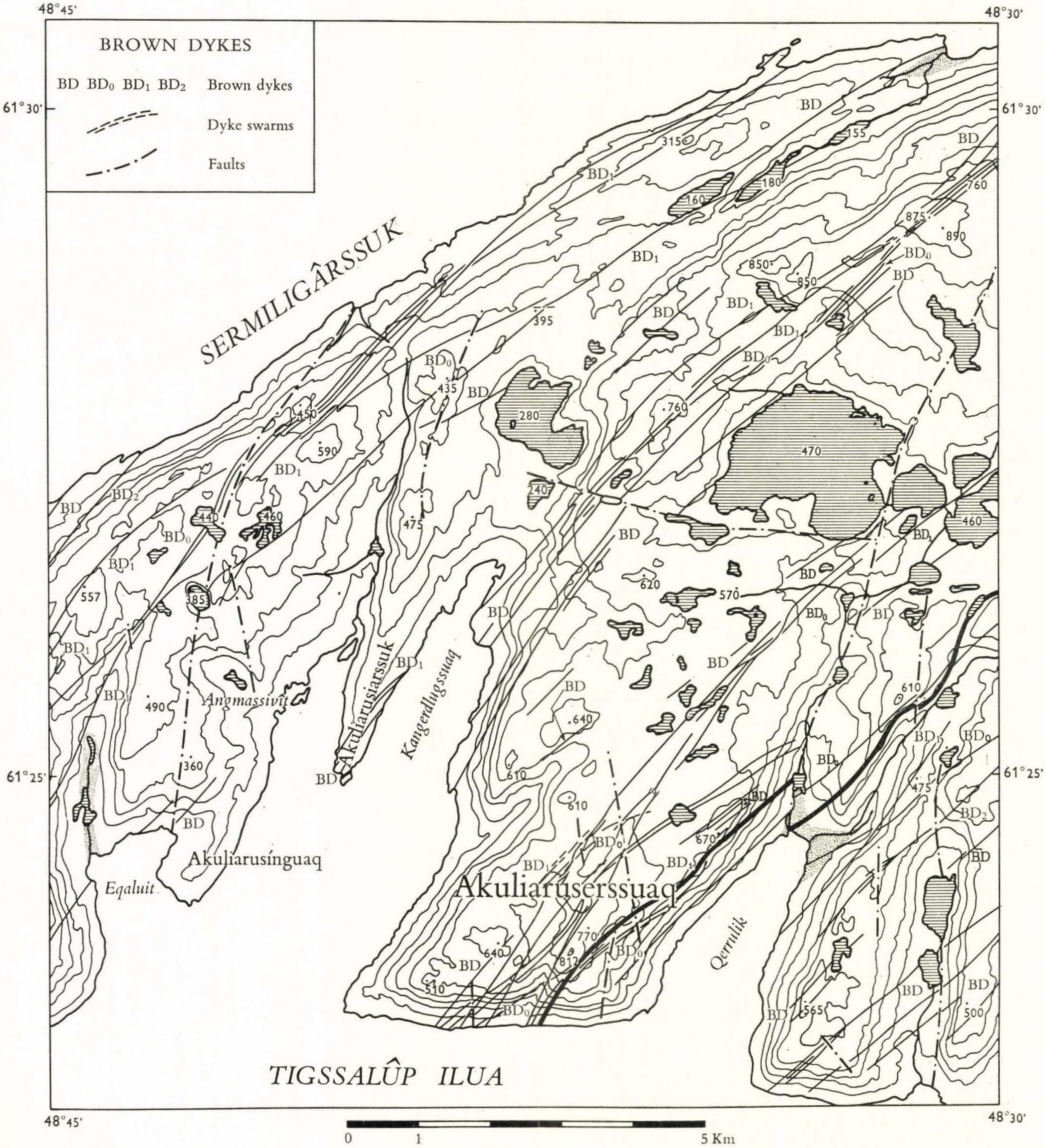
PLATE 14.



GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

PLATE 15.

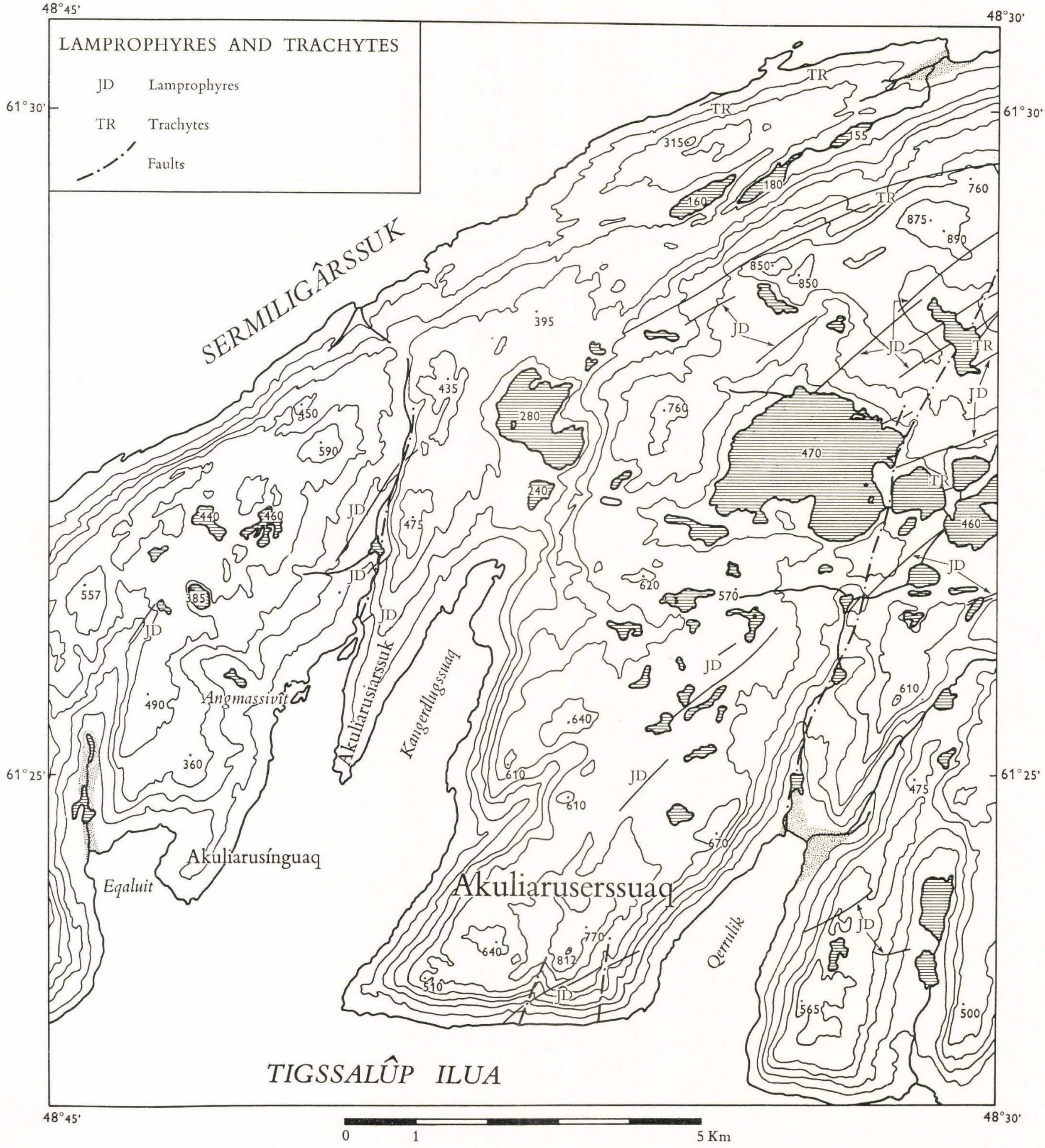


GRØNLANDS GEOLOGISKE UNDERSØGELSE

THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

PLATE 16.



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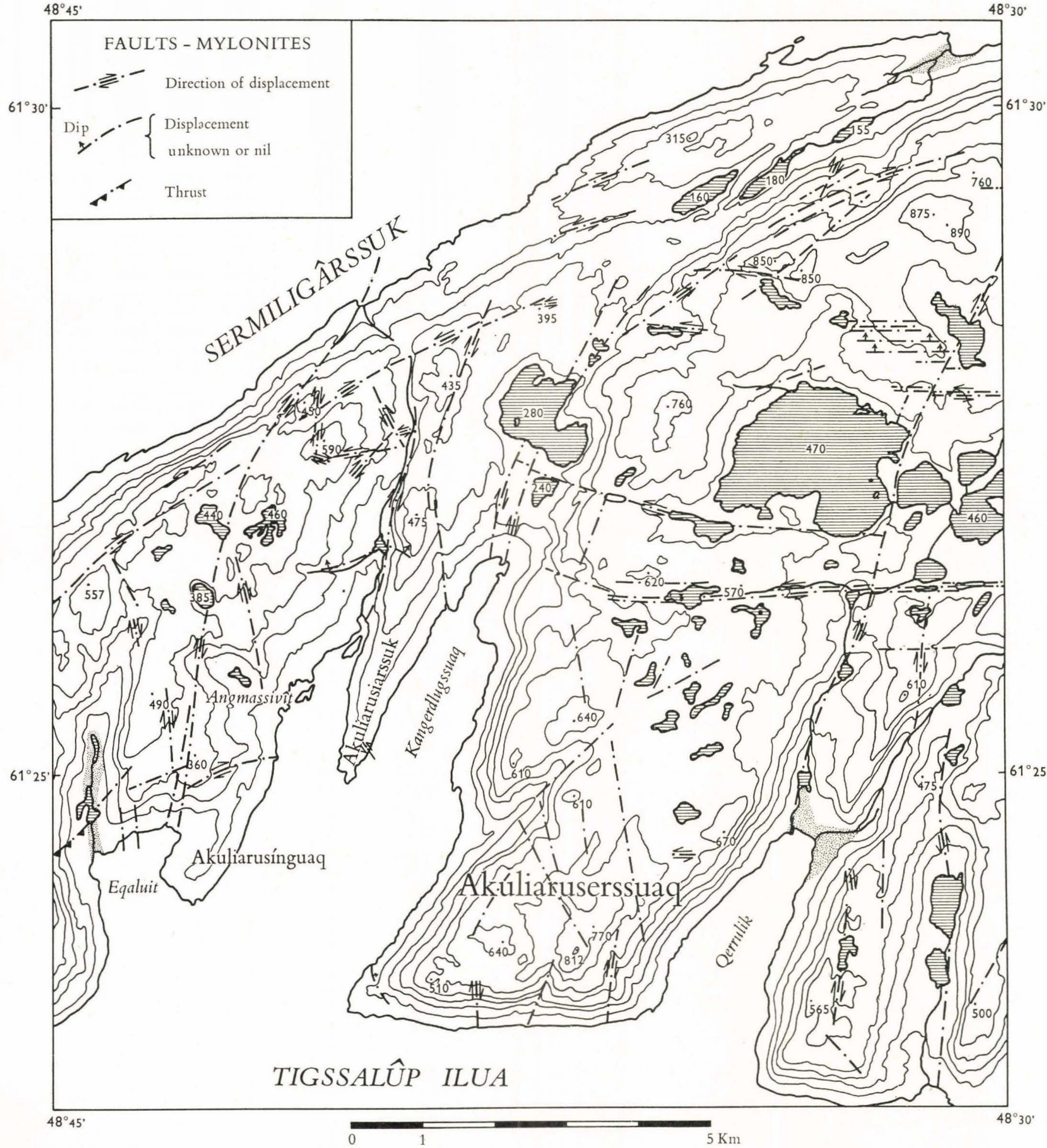
THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

PLATE 17.



GRØNLANDS GEOLOGISKE UNDERSØGELSE

THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNL. BD. 167 NR. 3. (STEPHEN AYRTON).

PLATE 18.