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Leader: H. I. Drever

THE GEOLOGY OF UBEKENDT EJLAND, WEST GREENLAND

PART I
A PRELIMINARY REVIEW

BY

H. I. DREVER and P. M. GAME

WITH 10 FIGURES IN THE TEXT AND 8 PLATES

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PREFACE

Ubekendt Ejland was visited by the first-named writer (H.I.D.) in 1937 during the course of Mr. J. M. Wordie's Expedition to Ellesmereland and the Canadian Arctic (Wordie, 1938). Specimens of massive and banded gabbro were collected from the cliffs on the southern coast of the island. This was the first gabbro to be recorded from the West Greenland Tertiary Igneous Province.

During the following two summers the island became the base of two expeditions the main objects of which were to examine the gabbro more closely, to collect a representative series of specimens, to obtain evidence sufficient to establish the petrogenesis of all important rock types, and to map, geologically, as much of the island as possible. The wider programme of work of these two expeditions included psychological, meteorological, archaeological and botanical investigations. In 1939 a detailed topographical survey was made of a small area in the south as a basis for more accurate and detailed geological mapping of the gabbro. A summary of all this work has been published [Drever, 1939 (2)].

The second-named writer (P.M.G.), in 1938, devoted most of his attention to detailed work on the lavas and minor intrusions; whereas the first-named writer (H.I.D.), in both 1938 and 1939, investigated the major intrusions. The effect of this division of labour in the field was that the survey was made more rapidly than would otherwise have been possible. Short summer expeditions may often demand somewhat unusual tactics during field-work; the main difficulty is to combine speed with adequate detail.

The geological survey is not yet finished; some mapping has yet to be done, and some critical sections require a more detailed examination.

The two expeditions were made possible through the help and co-operation of many individuals and Societies whose names, in the case of the 1938 expedition, have been given in the general account [Drever, 1939, (1)].

In connection with the 1939 expedition, the first-named writer (H.I.D.) wishes to thank, most sincerely, Major F. George for his detailed topographical survey of the critical section of cliffs on the south coast of the island. Dr. K. A. SWALES and Fl./Lt. K. A. W. PATERSON contributed very valuable assistance and enthusiastic co-operation both at home and in Greenland. Mrs. DOROTHY WRIGHT, when Secretary of the Scott Polar Research Institute, gave this expedition her constant help and encouragement.

The members of the 1939 expedition are indebted to Sir J. C. IRVINE, Principal of St Andrews University, to the Director of the Grønlands Styrelse, to many Danish officials in Greenland and, finally, to Captain (now Ship's Inspector) R. N. TVING (for his forbearance).

The field-work in 1939 was materially assisted by a grant from the Carnegie Trustees for the Universities of Scotland, who also, very generously, met the expenses incurred in the recovery of specimens and equipment after the War.

For the critical reading of the manuscript the writers are indebted to Dr. W. CAMPBELL SMITH.

During the preparation of this paper in the Department of Geology, University of St. Andrews, Mr. R. JOHNSTON has kindly assisted with the photographs and diagrams and has been helpful in many other ways.

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INTRODUCTION

The first map on which Ubekendt Ejland is shown as part of the West Greenland Basalt Formation is that of Rink (1852, and reproduced by Rosenkrantz, Noe-Nygaard, and others, 1942). Steenstrup (1883) was the first to discover acid igneous rocks on the island. Since this early classical exploration there had been no further significant work. There have been, since 1883, various references to the southern part of the island. Koch (1929), for instance, writes: "Of a more recent date than the basalt are a series of dykes and a large volcano with trachyte and tuff on Ubekendt Ejland. This last chapter in the history of the eruptions in West Greenland is still very little known".

Within recent years large areas of the Province have been surveyed by members of Danish Expeditions under Professor A. Rosenkrantz, particularly in the Nûgssuaq and Svartenhuk Peninsulas.

On Ubekendt Ejland the succession of lavas appears to be more complete, and in general the rock suite more diversified, than elsewhere in West Greenland. The island probably represents a critical area in the Province as a whole, and it is particularly in view of this fact that the present publication has been prepared before the work on the island has been completed. It is hoped that it will help in the work of collation and correlation throughout this co-magmatic Region.

Nothing but a very general review is attempted here. A considerable amount of petrological work has already been done, but a further and more detailed examination of certain sections on the island is essential before this work can be published.

Situation and Topography.

Ubekendt Ejland (fig. 1) is a small, roughly pear-shaped, island with its narrow end pointing north. It is a little over twenty miles in length and the greatest width from east to west is fourteen miles. It lies well within the Arctic Circle, in latitude 71°2′ to 71°19′N. and longitude 53°20′ to 54°00′W. between the peninsulas of Svartenhuk in the north and Nûgssuaq in the south. To the east, across a strait seven

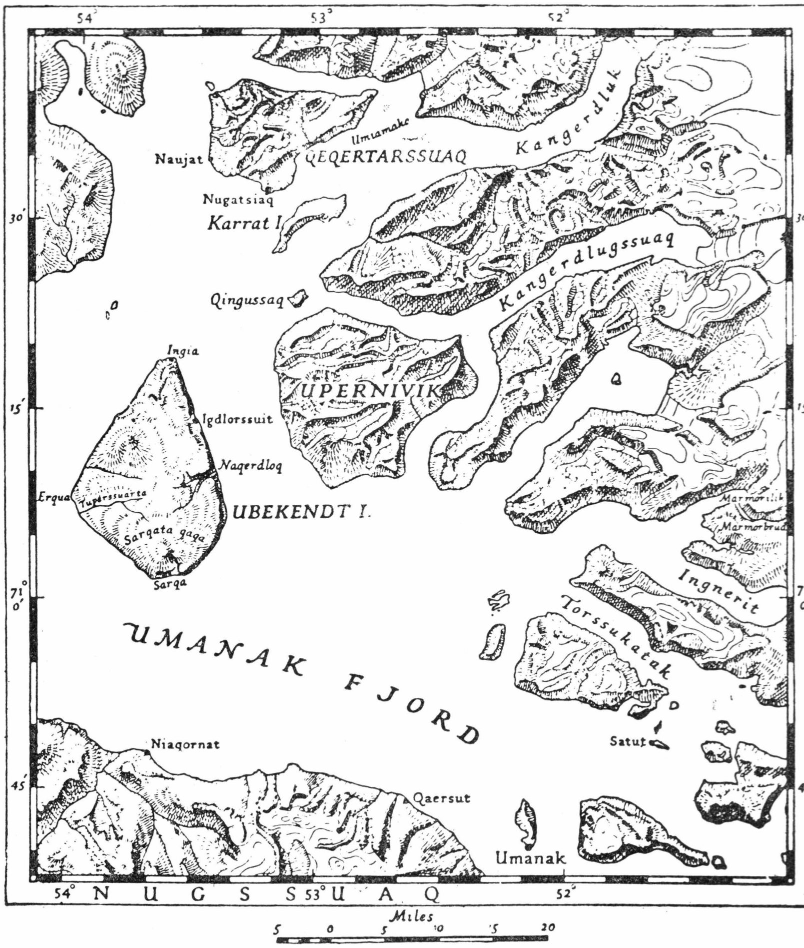

Fig. 1. Reproduced from the general account of the 1938 expedition (Drever, 1939). Originally based on maps published by the Danish Geodetic Survey.

to eight miles broad, lies the island of Upernivik. This Island, the rugged grandeur of which is unsurpassed elsewhere in West Greenland, is mainly composed of Archean gneisses.

The mapping of Ubekendt Ejland was greatly facilitated by the use of maps published by the Danish Geodetic Survey. A number of modifications to detail were made during the course of the geological work.

The island is inhabited, and the small outpost settlement of Igdlorssuit on the east coast served as the main base for both expeditions. Temporary camps were set up at Sarqâ, Erqua, Íngia and Naqerdloq. Tribute must be paid to the help given by the natives, particularly with transport and collecting.

An account of the island's physiography, based on notes by the second named writer (P.M.G.), has already been published [Drever, 1939, (1)].

Remarkably straight coast-lines; a central remnant of a mature, U-shaped valley running across the island from east to west and an elevated coastal plain, dissected by youthful V-shaped valleys, and giving way, very abruptly, to steep cliffs on the actual coast-line are the three most striking features of the island (fig. 2).

The area round Sarqâta qâqâ, the highest point, has been metamorphosed or indurated by plutonic intrusion. To this it owes its relatively greater resistance to weathering.

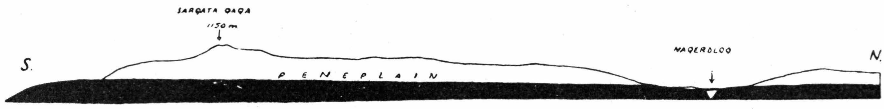

Fig. 2. Granite summit, elevated inclined peneplain, median valley and coastal cliffs (black). Profile after a photograph by P. M. Game taken from the south-west corner of Upernivik Island.

Glacial erratics of Archean gneisses are found all over the island from the lowest to the highest levels. During the Ice-Age it must have been connected with the mainland and covered by the ice-cap.

It is quite clear that the dominant physiographical features were imparted long after the period of vulcanicity.

After the retreat of the ice the island became separated during a period of isostatic adjustment and block-displacement.

In the Svartenhuk Peninsula it has been estimated (Rosenkrantz, A. Noe-Nygaard, A., and others, 1942) that there has been, during the Quaternary Period, an uplift of about 100 m, followed, possibly, by some subsidence. In the case of Ubekendt Ejland there has been a comparatively recent uplift to at least 350 m in the south. Fig. 2 suggests a movement that tilted the island to the north. So far no evidence of recent subsidence has been found.

Koch (1929) has drawn a fault along the line of the east coast cliffs. These cliffs may represents a fault-scarp, and this is supported by the straightness of the coast-line and the existence of a slump-scarp between Igdlorssuit and Naqerdloq parallel to this coast line. No more direct evidence of this fault, however, has been found.

DISTRIBUTION OF ROCKS AND THE GEOLOGICAL STRUCTURE

By far the largest part of the island is composed of a huge pile of lavas dipping to the south-west at angles 20° to 25° (fig. 3). Steeper dips near Igdlorssuit are connected with recent slumping in this area and gentler dips (to the W.S.W.) in the south are probably due to the proximity of major intrusions. Evidence of faulting has been observed in the centre of the northern half of the island but no map has yet been prepared in detail sufficient to show these faults and the extent of the displacement along them. On the whole the writers incline to the view that there is a vast thickness of lavas on Ubekendt Ejland and that displacements due to faulting will not be found materially to alter an estimate of thickness based purely on degree of dip and the horizontal extent of exposure. Noe-Nygaard (1942) has estimated that, in Svartenhuk, the plateau lavas attain a thickness of about ten kilometres. The thickness on Ubekendt Island may be as great as this, and in any event cannot be much less. The base of the succession visible on the Svartenhuk Peninsula is not exposed on Ubekendt Ejland; nor does the basal breccia or pillow lava occur on the island.

The lavas at the top of the succession on Ubekendt Ejland might, therefore, be regarded as the youngest lavas in the West Greenland Tertiary Province, younger even the lavas at the top of the Svartenhuk succession. This is supported by the nature of the lavas on the south-west coast of Ubekendt Ejland which, as a group, are unlike any yet described in West Greenland.

A detailed study has been made of the lavas between Íngia and Igdlorssuit and in the stream named Tuperssuartâ in the south-west. The two suites are referred to, respectively, as the Lower and Upper Lava Groups. The series of lavas between these two groups still requires detailed investigation; but owing to the mantle of drift in the median valley and lack of suitable stream sections, it is considered unlikely that an unbroken succession will be exposed for examination.

The lavas are cut by a large number of basic dykes and, in the south, by acid dykes, sheets and veins which penetrate them irregularly

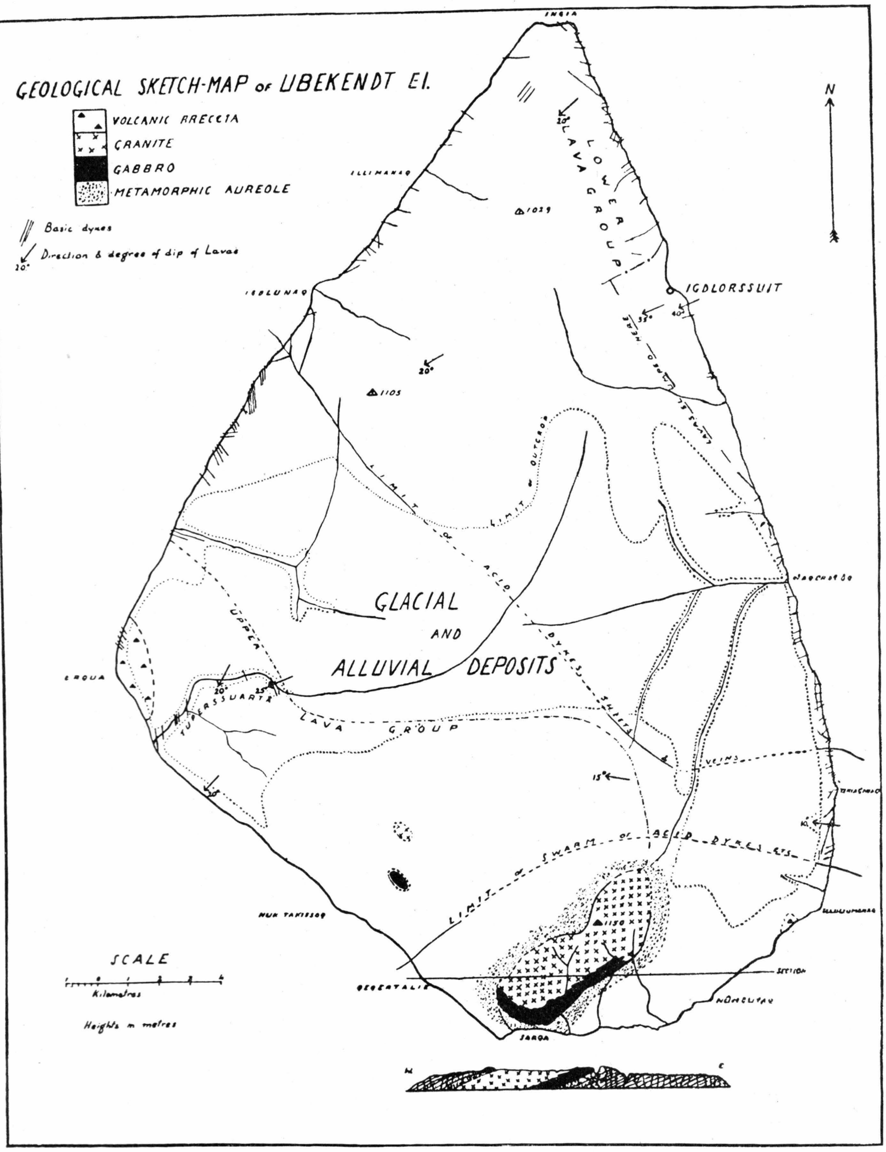

Fig. 3. Based on the map issued by the Danish Geodetic Survey. Modifications of this map have been made and some detail in the southern area has been copied from the survey by F. George (see Appendix).

in all directions (fig. 3-section and fig. 4). The typical basaltic dykes which cut the lower lavas are never found cutting acid minor intrusions gabbro or granite.

The basic dykes were mapped as accurately as possible, but on certain coastal sections, particularly along the West coast, their position

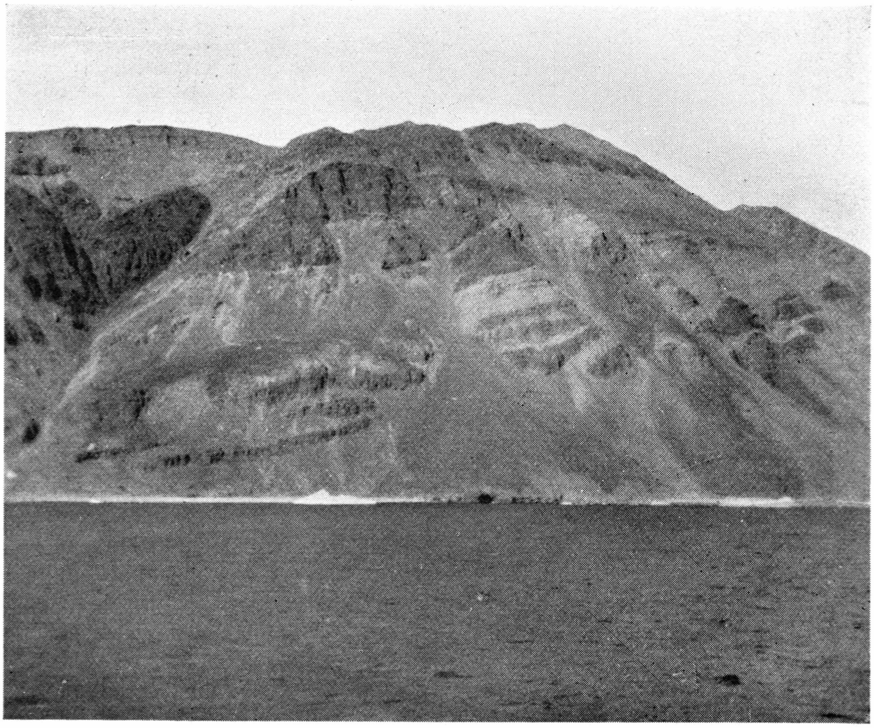

Fig. 4. Acid sheets on the right of the central gully through the southern cliff. Gabbro is exposed in the gully behind the ridge.

was obtained only by dead-reckoning from a motor-boat. In such cases the directions as shown on the map (fig. 3) are liable to some error. Insufficient mapping has been done in the interior to establish a very definite regional trend but the evidence collected along the coast, and from a rapid reconnaissance south-west of Igdlorssuit, does suggest that the majority of these dykes show a rough parallelism in an ENE-WSW direction. A small minority run approximately perpendicular to this direction.

Both in nature and in numbers there is a marked contrast between the dykes of the east and west coasts i. e. the dykes that cut the Lower Lava Group and those that cut the Upper Lava Group.

The acid dyke-and sheet-swarm, which is such a conspicuous feature of the south coast, is clearly linked with the intrusion of plutonic rocks (fig. 4). A similar association is characteristic of the British Tertiary Igneous Province. KOCH (1929) refers to this southern part of the island as an area of 'central eruption'. No detail is offered and nothing less vague has been added since.

The only indisputable eruptive centre is found on the extreme west of the island at Erqua. Here there is a large remnant of a volcanic neck exposed as a coastal cliff. Necks have not been previously recorded in West Greenland. The position of this neck at the junction of two remarkably straight coast lines is an obviously suggestive feature if, as is quite conceivable, these coast lines mark lines of faulting or fissuring. The rock of which the Erqua neck is composed is a hard acid explosion-breccia with a few large basic volcanic bombs and is cut by one or two later basic lamprophyre dykes. Associated with the Erqua neck are acid flow-breccias, tuffs and acid pitchstones. Another smaller and less clearly defined area of explosion-breccia is exposed on the south-east coast near Nûngutaq.

The major intrusions (fig. 3), comprising a mass of granite above a banded gabbro, might be regarded as a single composite intrusion in which the acid member is the later. The structure is that of a complex laccolithic sheet enclosing massive 'rafts' or relics of metamorphosed basaltic lava.

The gabbro is best exposed in deep drainage clefts in the southern cliffs. The whole line of cliffs on the southern coast represents one of the finest of geological sections. It is, indeed, a wonderful section which will repay the most detailed investigations however arduous the work involved.

Many of the rocks in the vicinity of the major intrusions, particularly the lavas of the southern coastal section, are considerably altered probably by volatiles derived from the intrusive magmas. This alteration, which resembles the widespread alteration in Mull (Bailey, Thomas, and others, 1924), includes the effects of albitisation, serpentinisation and propylitisation.

LAVAS, FLOW-BRECCIAS AND TUFFS

Lower Lava Group.

From the lowest flow exposed near Íngia to a height in the succession of 1638 m (5375 ft.) a very detailed examination was made. In the representative series of specimens that was collected the average gap between each sample was 20 m. (66 ft.). These lavas are perfectly exposed in very steep and high cliff sections (fig. 5) to work on which is arduous owing to the looseness of the rock.

The whole succession is so welded together that it is often impossible to ascertain the top and bottom limits of individual flows. The occurrence of thin beds of red bole proclaims their sub-aerial origin, and only where these are found can separate flows definitely be discriminated. No tuffs occur and no columnar jointing. A striking feature of many flows is the development in them of remarkable vesicular flow-banding which extends long distances in a very uniform manner. The late stage minerals include analcite and at least five members of the zeolite group.

The lavas of this lower group are, characteristically, extremely rich in olivine, the average type varying between olivine-rich basalt and picrite-basalt. The group contains, probably, the greatest known development of picrite-basalt. No group of lavas known to the writers is at the same time so thick and so rich in olivine. The olivine is, characteristically, forsteritic (Game, 1942). No olivine-free lavas have been observed in this succession although the whole group was examined very carefully.

A detailed examination has yet to be made of the series of lavas between those mapped as the Upper and Lower Groups (fig. 3). The practical impossibility of filling this gap completely has already been mentioned. Reconnaissance trips have confirmed that there should be little difficulty in examining a considerable upward extension of the lower (Íngia-Igdlorssuit) section, and have established that the olivine-rich lavas probably continue for several thousand feet above the 5375 ft. (1638 m.) already measured, and are the predominant rocks in the succ-

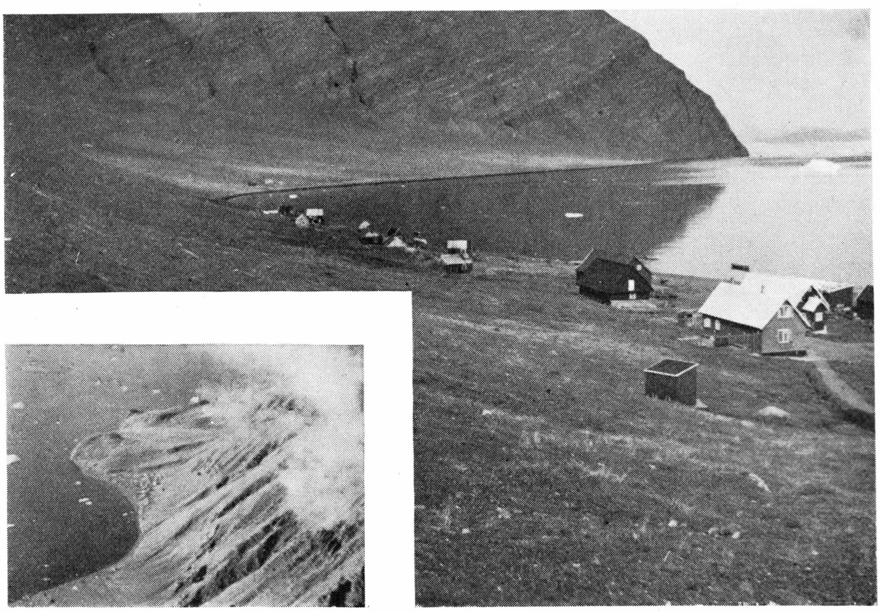

Fig. 5. The outpost-settlement of Igdlorssuit flanked by high cliffs of vesicular, olivine-rich lavas dipping south-west. Inset: The same from above.

ession as a whole. Lack of outcrops, on the other hand, will almost certainly prevent the examination of a continuous extension downward of the upper series of lavas exposed in the Tuperssuartâ section. Here, below the lowest flow, the gap is likely to lie.

The Upper Lava Group.

In all, 3730 ft. (1139 m) of lava flows have been examined in detail in the section along the line of the stream known as Tuperssuartâ. Although there are some gaps in the lower part of this succession the greater part of it is displayed in the middle and lower reaches of the stream. This is fortunate because, so far as is known, the Tuperssuartâ section is the only representative section through the Upper Lava Group.

The group includes porphyritic tholeiite (with plagioclase phenocrysts), rhyolite, biotite-trachyte, trachy-basalt, monchiquitic basalt and a few beds of volcanic breccia. Picrite-basalts do not occur and olivine-basalts are found only at the very bottom of the succession. There is a frequent development of calcite as a secondary or hydrothermal mineral.

Exposed on the shore 4 kilometres south east of the Erqua neck are a series of rhyolites, acid pitchstones, monchiquitic or calcitised lava, flow-breccias (fig. 6) and tuffs. A dark pitchstone occurs as a flow

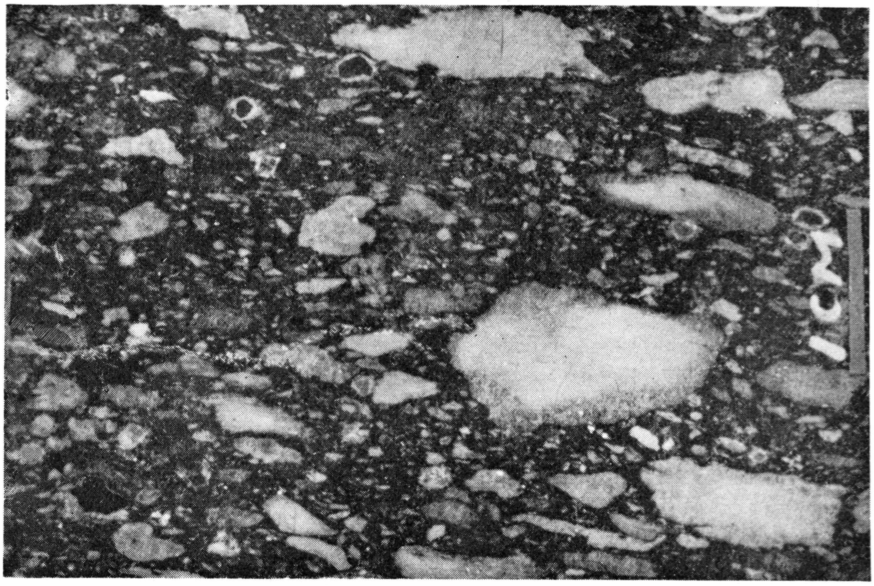

Fig. 6. Polished specimen of acid flow-breccia from a point on the west coast 4 kilometres south east of the mouth of Tuperssuartâ.

about 8 metres thick. It contains numerous small aligned fragments and is really a glassy flow-breccia. Other flow-breccias may have either a glassy or a pale grey, devitrified, rhyolite base. These glassy flows are found between beds of acid breccia. Much of the lava in this area is highly calcitised and resembles 'white trap'. One of the dykes which cuts these lavas has been identified as a nepheline-basalt. The whole group can probably be correlated with the youngest rocks exposed in the Tuperssuartâ section. To what extent, if any, the group is directly related to the vent at Erqua has not yet been established. So far no discordance has been noted between this latest series of rocks and the lower rocks of the Upper Lava Group.

There is no doubt that the lavas and associated pyroclastic rocks on the west coast of the island represent the latest known manifestations of Tertiary vulcanicity in West Greenland. Their position at the top of the huge pile of lavas, their relatively small amount, extreme diversity and narrow localisation all suggest that they are the products of the last waning phase.

THE DYKE SWARM

These dykes fall naturally into three groups defined by geographical distribution, geological relationship and by the nature and number of the dykes in each group. The three groups are:

(1) The East Coast Group.
(2) The West Coast Group.
(3) The Southern Group.

The East Coast Group.

The dykes and transgressive sheets of this group cut the Lower Lava Group but do not appear cutting the Upper Lava Group on the west coast. Characteristically they are picrite-basalts, olivine-basalts and tholeiites. They may show considerable variation in direction and inclination, but normally they are straight-sided and vertical. Most of them have been carefully mapped along the coastal section.

Along the first 7.5 kilometres of the east coast, south of Íngia, 25 dykes outcrop. The average spacing here is, therefore, 0.30 kilometres. The mean width of these dykes is just under 2 metres, and the variation is from $^1/_2$ to 3 metres. Proceeding south, only 6 dykes (5 close together) were counted in the next 8 kilometres, but this relative scarcity may partly be due to poorer exposures and the slumping of the cliff mass. Nevertheless some decrease in intensity seems to be established along this median sector of the east coast. The mean dyke-width is here increased to just under 3 metres with limits of $1^1/_4$ to $4^1/_2$ metres.

Again going south, the next 8.9 kilometres of cliff-section show 27 dykes, which have therefore an average spacing of 0.33 kilometres-almost the same as that for the first described zone. The average thickness is $2^3/_4$ metres and the variation from 1 to $10^3/_4$ metres. The latter thickness is, however, unique, a more representative maximum being $4^1/_2$ metres.

The percentage of dykes containing plentiful olivine (compared with tholeiitic types in which olivine is sparse or lacking) decreases in a southerly direction. Between Íngia and Igdlorssuit olivine-bearing dykes form 50 % of all dykes. In the 16 kilometre stretch south of Igdlorssuit the percentage falls only slightly (to 44 %); but thereafter the proportion of dykes with olivine dwindles rapidly, becoming nil beyond Illuliumanaq.

In the three instances observed in the field of one dyke cutting through another, the later dyke is tholeiitic, the earlier olivine-rich. This has been confirmed microscopically. The same relationship between olivine-bearing and olivine-free dykes has been observed by Dr G. W. TYRRELL (1928) in Arran.

The West Coast Group.

The dykes of this group cut the Upper Lava Group and the Erqua volcanic neck. Characteristically they are basic lamprophyric types (including nepheline-basalt) (Plate 1, fig. 1). No dykes of olivine-rich basalt or tholeiite have been observed. They are well exposed in the Tuperssuartâ stream section and in the cliffs at the north end of the volcanic neck. They show a definite trend which is nearly N—S in the stream section (a few dykes run NNW—SSE) and swings slightly to the west in the cliff where the average strike is between NW—SE and NNW—SSE.

Ten dykes outcrop in the Tuperssuartâ section where the average spacing works out at 0.43 kilometre. The swarm is considerably denser at the north end of the volcanic neck, where 5 dykes outcrop in a distance of about $^1/_3$ kilometre.

At both exposures the majority of dykes have vertical dips. A smaller proportion (30 %) show steep easterly dips of from 70°—80°. The characteristic width of these lamprophyric dykes is from $^2/_3$ to 1 metre. More rarely they attain thicknesses of from 2 to $3^1/_2$ metres. A dyke about 10 metres wide outcrops 100 yards from the mouth of the Tuperssuartâ stream.

The association of a group of lava flows with dykes similar in composition is an observational fact which has recently been reiterated by NOE-NYGAARD (1942) in his research on the Svartenhuk Peninsula. Here the dyke swarm is confined to the group of lavas which occupy a relatively low position in the succession. The evidence, as NOE-NYGAARD has pointed out, is in favour of the conception of eruption of West Greenland lavas along fissures now occupied by the dykes. The extrusion of lava by fisssure eruption (TYRRELL, 1937) is very strikingly supported by the evidence on Ubekendt Ejland. In fact it only remains to find a dyke, or dykes, actually passing into flows for the island to supply spectacular evidence of fissure eruption. Unlike the East Greenland and

British Tertiary Provinces there appears to have been in West Greenland no late regional dyke swarm, which might tend to confuse the relationships of earlier dykes.

The Southern Group.

The dykes, transgressive sheets and injection-veins of this group are almost confined to the southern half of the island (fig. 3). They are associated with the major intrusions with which they contribute to the impressive complexity of the southern coastal section. The intensity of this swarm is in proportion to proximity to the major intrusions with which their origin can confidently be linked. The swarm is very dense in the contact aureole surrounding the major intrusions.

The members of this group are characteristically acid, and they may vary from small veins to sheets 15 metres in thickness. They are described in the later section on minor intrusions.

In spite of the predominantly acid character of the south coast dyke swarm, dykes of basic composition do occur in this section also, and are described in a later part of this paper.

Very few dykes cut the gabbro, and no dykes of any kind have yet been found cutting the massive granite rock of Sarqâta qáqâ, which is, however, not very well exposed.

MINOR INTRUSIONS AND VOLCANIC NECKS

In addition to the dykes and transgressive sheets already mentioned there are a few exceptional types which are best treated under a separate heading. These include members of all three groups of dykes. Some dykes and veins are described in a later section.

The East Coast Group.

What appears to be an olivine-dolerite sill is associated with the lowest lavas exposed on the shore at Ingia. No chilled margins have been observed, but the rock is massive, relatively coarse-grained, and less rich in olivine than the associated lavas. It is traversed by acid segregation veins. Apart from this possible instance no other sills have so far been noted on the island. Some of the acid sheets on the southern coast are concordant over considerable distances but, typically, they are transgressive.

Collection and field examination of about 50 dykes between Íngia and Iluliumanaq suggested that at least 4 of these might be composite and 4 multiple. Petrographical examination of the 4 multiple dykes revealed no marked petrological differences between their component members.

The first of the four composite dykes is exposed in the cliff $1^1/_2$ km south of Íngia. The second cuts the lavas on the shore $2^1/_2$ km south of Igdlorssuit. The other two outcrop between Teriangniaq and Iluliumanaq within $^1/_2$ km of each other. All four dykes consist of an ultrabasic central member without chilled margins, sandwiched between less basic components. The contrast is greatest in the second and the most southerly members. The relative arrangement of components is thus the reverse of that in Skye (Harker, 1904).

The Íngia dyke is $3^1/_2$ metres wide with a central band one metre thick containining up to $50\,^0/_0$ olivine. The third dyke also has an ultrabasic core and the marginal rock in the case of both dykes is ophitic olivine-dolerite.

The 'dyke' south of Igdlorssuit is really a steeply inclined sheet about a metre in width. Centrally the olivine occurs in closely packed grains. The top margin of the sheet, unlike the lower margin which is ophitic olivine-dolerite, is a relatively fine grained layer grading within about two inches (5 cms.) into the olivine-rich portion. This fine-grained rock has platy jointing perpendicular to the margin. The actual contact selvage is fine-grained with phenocrysts of olivine set in a very fine-grained basaltic groundmass with a second generation of olivine. The ultrabasic central part of this sheet has an average width of about $^1/_4$ metre. To submit an explanation of the origin of this sheet would be to anticipate, without sufficient evidence, the detailed examination it obviously deserves and would repay.

The most southerly dyke is $4^1/_2$ metres wide with a core of picrite-basalt, 3 metres thick, between outer layers, $^2/_3$ and 1 metre wide, of an equigranular, ophitic, olivine-free basalt containing primary analcite.

The West Coast Group.

A dyke 10 metres broad cuts across the Tuperssuartâ gully within 100 metres of its mouth, striking north to south and dipping east at 80°. It contains 5 components. An augite-rich lamprophyre with a well-developed flow-structure forms the central and side members, which are relatively broad. Flanking the central member are two relatively narrow doleritic dykes with tabular phenocrysts of plagioclase and with feebler flow-structure and coarser grain-size than the lamprophyre. Calcitisation has affected the groundmass of both types sometimes completely replacing original pyroxene.

The Southern Group.

In this group felsites, microgranites and microsyenites may form a very complex and intricate network of dykes, sheets and veins. Pyroxene-fayalite-porphyry dykes and transgressive sheets are usually found as much more regular and clean-cut intrusions. In two separate localities a sheet of pyroxene-fayalite-porphyry is cut by a later sheet of microgranite, but the reverse has not been observed. On close examination some of the dykes and sheets were found to be composite. In an acid dyke, $1^1/_2$ miles (2.4 km) north-east of Sarqâta qáqâ quartz-dolomite veins were observed. As these veins, owing to the removal by solution of some of the dolomite, showed unusually striking lamellar cavities, some specimens were collected and photographed (Plate 8, figs. 1—4).

Between the middle and eastern ravines, on the southern cliffs about 180 m. above sea-level, two basic dykes can plainly be seen cutting through a thin acid sheet (fig. 7).

On close examination the acid sheet (which may be concordant) was found to be of variable width and composite in character. It has two basic fine-grained margins and a light coloured, feldspathic central

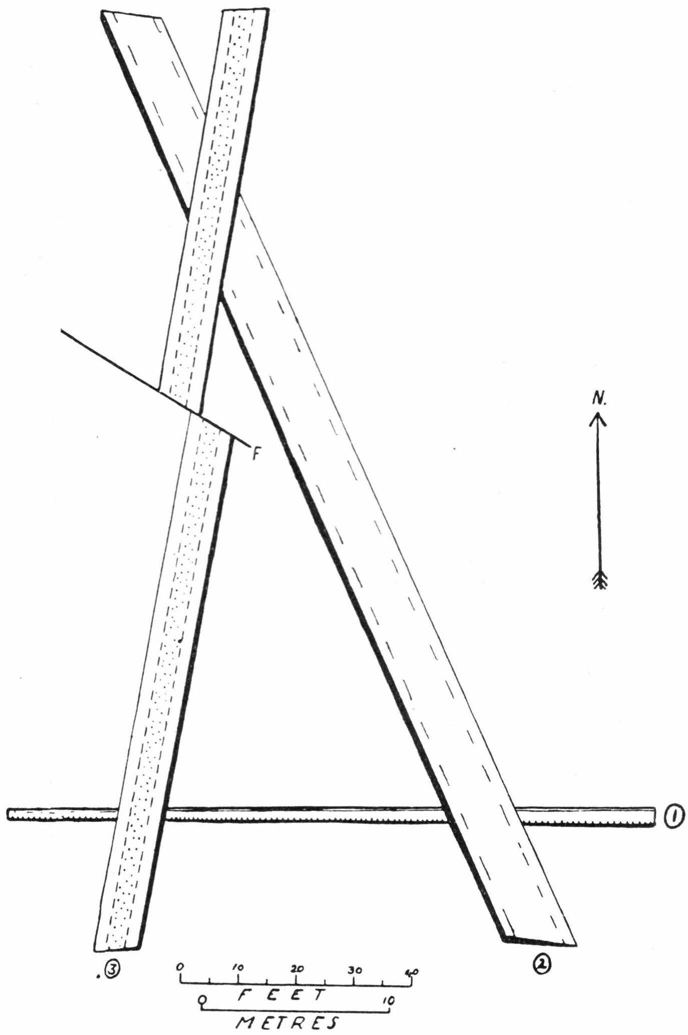

Fig. 7. Diagrammatic sketch of two vertical dykes cutting a thin sheet which is gently inclined to the north. (1) to (3) is clearly the order of intrusion. (1) is composite; (2) and (3) have clearly marked central portions but are not 'composite'. Ocelli of analcite occur aligned parallel to the length, and confined to the central part, of dyke (3).

portion which is very much altered, possibly by weathering. The upper margin is rather sharply differentiated from the acid centre and is about 5 inches ($12^1/_2$ cm) thick. The lower margin is a little thicker and merges

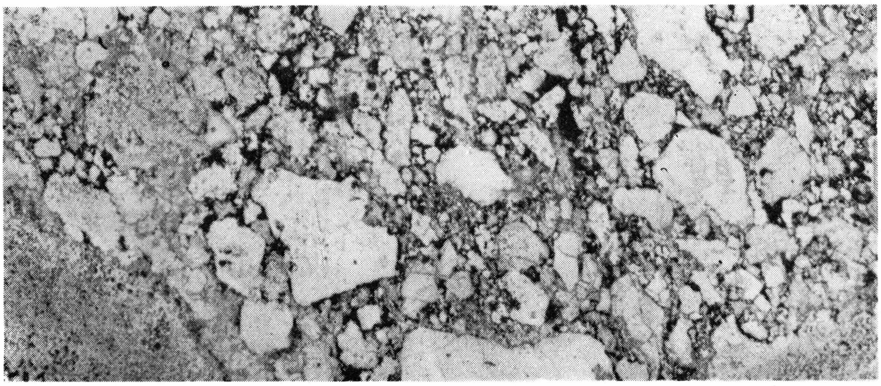

Fig. 8. Polished section of acid explosion breccia from the volcanic neck between Iluliumanaq and Nûngutaq.

more gradually into the central portion. Microscopic examination revealed small, rounded and more basic xenoliths in the acid rock.

Dyke No. 2 cuts the composite sheet and is itself cut by dyke No. 3. It is composed of a uniform, hornblende- bearing rock resembling the basic 'craignurites' of the British Tertiary (Bailey, Thomas. and others, 1924). The central and marginal portions of this dyke are defined by an abrupt textural change.

Although there is no great difference in composition between the centre of the latest dyke (No. 3) and its sides there are two definite discontinuities and three highly ocellar bands in the central portion. At the point where it cuts the composite sheet it weathers in more rounded and less angular form, is less ocellar and tougher and fresher than elsewhere. On microscopic examination this dyke was found to contain idiomorphic phenocrysts of zoned titan-augite, a second generation of augite, basic plagioclase and ocelli of analcite. It is a lamprophyric rock which, though lacking hornblende, resembles camptonite in its well developed ocellar structure.

In the most easterly ravine a composite dyke, $1^1/_2$ metres broad, cuts, and presents a chilled margin to, a thick sheet of pyroxene-fayalite-porphyry. The margin of the dyke is a dark basic craignuritic rock; the centre a light coloured acid felsite.

Other basic dykes cutting the lavas of the southern coast are usually so decomposed as to render their original nature rather indeterminate. A fresh tholeiite dyke, striking E—W, cuts three of these altered dykes at a point about a kilometre west of the triple group of fig. 7.

Between Iluliumanaq and Nûngutaq a high cliff face, traversed by numerous, irregular acid dykes, consists mainly of a massive acid explosion breccia (fig. 8) with dark layers of acid tuff. Owing to the intense shattering of the marginal rocks the nature of the margins of this neck is difficult to establish.

On a more considerable scale is the neck at Erqua on the west coast, which is cut by monchiquite and nepheline-basalt dykes (Plate 1, fig. 1). The visible portion of the neck is obviously only a remnant of a much larger one. The part that has been left forms a steep coastal cliff about 3 kilometres in length. Lines of shattering are sometimes clearly visible. (Plate 2, fig. 2).

That this neck represents the site of a large volcanic vent is substantiated by the presence in it of large basaltic bombs (Plate 2, fig. 1). Microscopic examination of one of the bombs revealed a composition and texture closely akin to augite-lamprophyre.

In the Central Ring Complex of Arran the interconnection between explosive brecciation and igneous intrusion has been advocated by G. W. TYRRELL (1928) and has been shown by J. E. RICHEY (1940) to be a characteristic phenomenon in the British Tertiary Igneous Province as a whole.

MAJOR INTRUSIONS

Considerable difficulty was experienced in mapping the gabbro, although almost perfectly exposed, owing to its comparative inaccessibility. The best sections are sometimes in an almost vertical plane. The three drainage gullies (fig. 3) which cut through the southern cliffs are the most satisfactory means of approach and some very fine sections are exposed in two of them. Where the gabbro meets the coast it forms an almost vertical cliff face from which numerous large blocks have been detached. Although the coast can be traversed with difficulty by land the best way to investigate it is from the sea by kayak.

The gabbro is an irregular sheet about 300 m at its thickest and becoming attenuated towards the east. The westerly end has not yet been closely examined. Banding is conspicuous in parts (Plates 3 and 4) the dip of the bands conforming with the general dip of the lavas in the same area. Although the bands have not yet been studied in detail it is clear that both rhythmic layering analogous to that of the Skærgaard intrusion (Wager and Deer, 1939), but on a less spectacular scale occurs, and also banding which is more irregular and more like that ascribed to the injection of heterogeneous magma. In one section highly contorted bands were observed (cf. Tomkeieff. 1945),

Transgressive junctions of gabbro and basalt have been observed and large detached masses or 'rafts' of metamorphosed 'basaltic lava' are found completely surrounded by gabbro. In the section illustrated in Plate 3 the layering contiguous with the 'basalt raft' is neither banked up against the enclosed 'basalt' nor distorted.

An even more remarkable section is that illustrated in Plate 5, fig. 2. Here a 'basaltic raft' is, at least within the dimensions of the exposure, entirely surrounded by massive gabbro and yet is cut into ribbons by injections of acid material. For a space of two to three inches from this injected 'basalt' the gabbro is relatively rich in plagioclase, but there is no other evidence of the source of the acid injections. It is unlikely that this acid material is of earlier age than the gabbro and it must be regarded as a possibility that it originated from the gabbro itself. Some specimens (Plate 5, fig. 1) from this injected 'basalt' suggest that the 'basalt' may have been 'softened' to some extent; and a specimen from a 'basalt'-acid injection contact (Plate 5, fig. 3) reveals considerable intermixture. In the western gully intensely metamorphosed picrite-basalt occurs immediately above the gabbro.

As in the gabbros of the Skærgaard intrusion igneous lamination is sometimes developed and is usually expressed as a rude parallelism

Fig. 9. Gabbro with long bladed pyroxenes. Cross-sections exhibit igneous lamination. Dark areas are serpentinised olivine.

of tabular plagioclase crystals. A tendency to lie in one plane is occasionally exhibited by the pyroxene (fig. 9). Some specimens are obviously closely similar to the 'fluxion gabbros' of Ardnamurchan (Richey and Thomas, 1930).

A specimen which is both banded and laminated is illustrated in Plate 6, fig. 1. In this specimen the crystallisation of quartz in the centre of the thickest feldspathic band suggests that this banding is possibly due to segregation 'in situ'.

The normal gabbros contain olivine which in some cases is fayalitic. Hypersthene also occurs. The most characteristic feature of the gabbro as a whole is the extensive development of amphiboles and micas. Commonly the rock is medium grained with a few patches, streaks and veins of coarse-grained quartz-gabbro-pegmatite, often rich in apatite. By increase in the granophyric intergrowths in this type there is a passage to 'basic granophyre' and drusy cavities may contain well-crystallised quartz (Plate 6, figs. 2 and 3).

Intermediate types uniform in appearance are found towards the top of the sheet and also as two large masses completely enclosed in granite but near the upper margin of the gabbro. Neither on field nor microscopic evidence can these types be definitely classified as hybrids. One of the enclosed masses contains pyroxene, hornblende, biotite, quartz and fayalitic olivine.

In a deep cleft north west of the main gabbro mass another exposure of gabbro was discovered (fig. 3). Whether this represents an extension of the main gabbro or a separate intrusion is uncertain.

The top and bottom of the main sheet are intricately intersected by granite veins, a feature which is analogous to the concentration of acid material at the margins of many Ardnamurchan ring dykes (Richey and Thomas, 1930). As already mentioned thin granitic dykes are sometimes found cutting the gabbro and, at their line of contact, there may be a development of large plagioclase feldspars (Plate 6, fig. 4). Composite and basic craignuritic dykes also cut this gabbro. The acid portion of the composite dykes has not been injected into the gabbro (Plate 1, fig. 2). A thin, fine-grained basaltic dyke cuts the gabbro in the western gully and both the dyke and the gabbro are traversed by anastomosing granitic veins. This occurrence is obviously important in its demonstration that at least some of the acid material postdated the intrusion and consolidation of the gabbro. This basic dyke appears to have been somewhat modified and biotite has replaced much of the original ferromagnesian minerals. A thin black dyke which cuts the north-west gabbro has not yet been classified owing to the fineness in grain and the development in it of calcite.

The intimate association of granite and gabbro has often been described and, in many respects, the relationship on Ubekendt Ejland is very similar to that obtaining in Ardnamurchan (Richey, 1930). It is significant that the granite-mass of Sarqâta qáqâ is structurally above the gabbro, and the fact that granite appears at all in the West Greenland 'Basaltic' Province in such relatively small amount, serves to emphasise its importance to the question of the origin of granite by fractionation from basaltic magma.

The name 'granite' in this paper is used only in the sense of a field term. Frost action disintegrates the rock into a rather friable mass and it was found difficult to obtain fresh specimens. A poorly exposed outcrop of granite occurs north-west of the main mass, structurally above the isolated exposure of gabbro.

In fresh specimens of the Sarqâta qáqâ granite both amphibole and pyroxene occur. A member of the stilpnomelane group is believed to

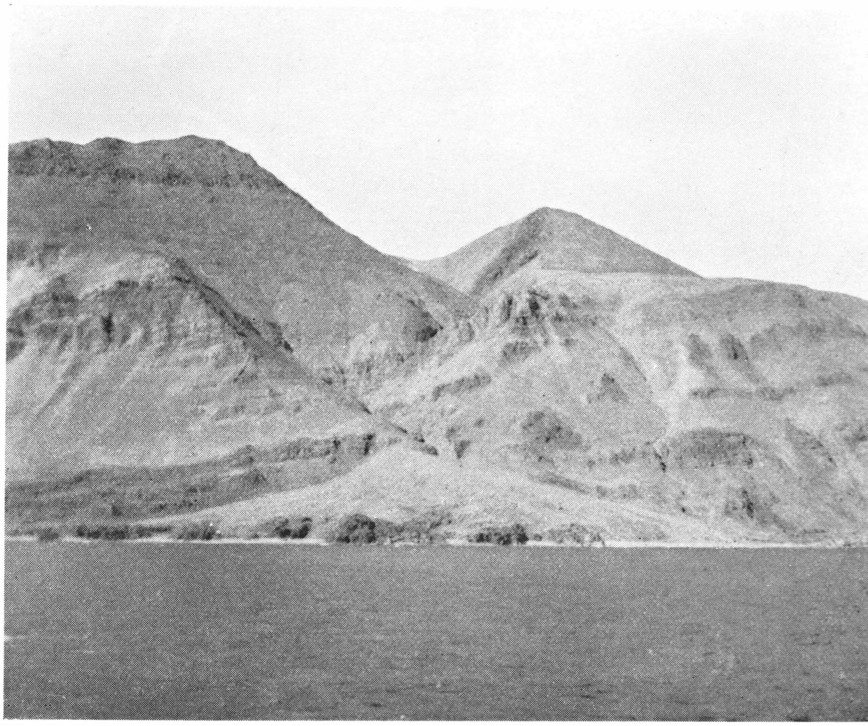

Fig. 10. Metamorphic ridge and eastern gully. Locality: Southern cliffs. Note distinctive and transgressive aspects of the rocks of the ridge.

be present and, it might be mentioned here, some very interesting iron-rich micas and chlorites have a wide distribution in gabbroic, granitic and hybrid rocks.

At the junction of the granite with metamorphosed basaltic or gabbroic rock, the granite encloses a few xenoliths of 'basaltic' hornfels and at all contacts, there is no chilled margin and, frequently, a contact reaction zone with pale green clinopyroxene and sometimes fayalitic olivine. The occurrence of fayalitic olivine as a reaction mineral is of exceptional interest.

The junction of gabbro and basalt is often obscured by the intense injection of both by acid material. At places it is sometimes difficult to ascertain what is metamorphosed gabbro and what is metamorphosed basalt. A very interesting and striking rock with large pink pyroxene and large plagioclase crystals is a type whose derivation has not yet been decided. It appears to be developed at acid-basic contacts.

Large 'rafts' of metamorphosed 'basaltic lava' may be found isolated in the Sarqâta qáqâ granite. In injection zones such as occur immediately below the gabbro the basalt or gabbro is intricately veined (Plate 7, fig. 2), or angular xenoliths are detached (Plate 7, fig. 3). Another example of ribbon-injection was noted in a scree boulder (Plate 7, fig. 1). All these injected rocks are very highly metamorphosed with a widespread development in them of pale brown amphibole.

During the 1937 Expedition (Wordie, 1938) the most striking feature of the southern cliffs appeared to be a thick sheet of dark, purplish pink colour above the lavas (fig. 10). On closer examination in 1938 it was found to consist mainly of what appears to be intensely metamorphosed basaltic lava. Under the microscope pale brown amphibole is often a characteristic mineral. To what relative extent the gabbro, the granite or the sheets and dykes cutting through the "aureole" have contributed to this metamorphism is not clear. Many aspects of this interesting "aureole" require further investigation. Its apparently transgressive aspect might be interpreted as a consequence of the development of metamorphic changes along isotherms parallel to an original, transgressive intrusion.

TIME SEQUENCE AND VOLCANIC HISTORY

There are two distinct periods of eruption. The first period was one in which the conditions of eruption were so uniform that, without exception or change, flow upon flow of picrite-or olivine-rich-basalts were repeatedly extravasated. This period might be named the Period of Picritic Flood Basalt. The second period, which might be called the Period of Central Eruption, is characterised, in striking contrast to the first period, by a great diversity of eruptive products. It included an explosive phase centrally located. The basic and acid major intrusions which cut the lavas of the first period, can be allocated to this later period.

Period of Picritic Flood Basalts.

As the base of the succession of lavas is not exposed there is no evidence on Ubekendt Ejland of the opening phase of eruption. Succeeding the opening phase flood basalts were erupted, apparently along fissures, and accumulated sub-aerially to an immense thickness without interruption.

Olivine-rich basalt, and composite olivine-rich dykes cutting these lavas probably represent the position of the vertical or highly inclined channels along which the magma reached the surface, and have since been left filled with lava (or lava plus crystals) which, towards the end of this period, failed to reach the surface. This period can be compared with the opening phase of igneous activity in Mull which is characterised by the outpouring of undersaturated 'plateau basalts' on a regional scale, follwed by the more localised eruption of oversaturated 'central-basalts'.

Period af Central Eruption.

The eruption of olivine-rich lava was succeeded by flows of olivine-free basalt, intermediate types, rhyolite and trachyte followed finally by an explosive phase in which acid lavas and basic alkaline 'lamprophyric' lavas are associated with tuffs and volcanic breccias. It is uncertain to what extent the olivine-free basalts were erupted along fissures now represented by tholeiite dykes (which cut the earlier olivine-rich lavas). Also undecided, so far, is the degree, if any, of overlap of the two eruptive periods.

The latest phases of volcanic action are clearly related to eruption from central vents the origin of which can be attributed to the ascension of acid magma to a level, near the surface, of comparatively low pressure.

The general sequence of events in terms of rock-types can be summarised as follows:

(1) Olivine-rich basalt and picrite-basalt.
(2) Tholeiite.
(3) Gabbro.
(4) { Pyroxene-fayalite-porphyry and Pyroxene-fayalite-granophyre.
Granite, Microgranite and felsite.
Acid explosion-breccia. Acid lavas, tuffs and flow-breccias.
(5) Acid-basic composite dykes and 'craignuritic' types.
(6) Augite-lamprophyre, Monchiquite and Nepheline-basalt.

It will be clear from the evidence outlined earlier in this paper that, in this general sequence, there is a certain amount of overlap and one or two exceptions.

The folding and tilting of the lava-plateau appears to have been caused by the geophysical conditions obtaining after all the main phases of vulcanicity represented by the rocks of Ubekendt Ejland.

PRESENT POSITION OF RESEARCH AND FUTURE PROBLEMS

In preparation for a detailed study of the rocks of Ubekendt Ejland twelwe chemical analyses and about 500 thin sections have been made. All sections have been examined superfically and a number of modal analyses have been carried out, but a great deal remains to be done and many more chemical analyses will be required.

What is envisaged is, firstly, a detailed investigation of the lava succession, dyke-swarm and minor intrusions, to be followed later by a study of the major intrusions and problems connected with them.

Particular attention will have to be paid to the following:

Evidence of Fissure Eruption.
Origin of picrite-basalt.
Nature and origin of the vesicular banding in olivine-rich basalts.
Compositional trends in both rocks and minerals throughout the lava succession, and in the minor intrusions.
Banding and layering in the gabbro.
Cryptic layering in the gabbro and compositional trends (if any) in the minerals and rocks of the intermediate to granite group.
Origin, composition and distribution of amphiboles, micas, chlorites and stilpnomelane(?) in the plutonic rocks.
Injection, metasomatism and assimilation of gabbro and basalt.
Contact phenomena between basic rocks and acid magma.
Relation of gabbro to granite.
Metamorphism of basalt and picrite-basalt.
Composite acid-basic minor intrusions.

It might be emphasised that, in view of the relatively small amount of acid magma developed in this West Greenland 'Basaltic' Province, the origin of this magma may prove to be of exceptional interest.

Future problems are thus manifold, and there can be little doubt that a detailed study of this remarkable little island would be a significant contribution to igneous petrology.

APPENDIX

Note on the Survey at Sarqâ. By F. George.

Apart from some observations for latitude and longitude made at Igdlorssuit, the survey work by the expedition was confined to the mapping, on the scale of 1:50.000, of a small area of geological interest at Sarqâ in the south of the island.

The unexpected absence of a wireless-set in the settlement prevented any exact determination of longitude, but the observations indicated that the position of the island is correctly shown in the existing maps, though the topography is very inadequately represented.

For the survey at Sarqâ five stations were selected, but they would perhaps have been more useful for a more extensive survey than they were for plane-tabling among the ravines and cliffs in their immediate vicinity; for this work more stations on the sea-shore would have been useful.

A very short base was measured at one station with an improvised sub-tense bar and the length of the first side was computed from its obliquity and the angle subtended by it at a second station. This was necessitated by the terrain, but it is not to be expected that the result was very precise.

While the accuracy of the triangulation was sufficient to exclude plottable errors, it was limited by the shortness of the sides and the difficulty of centering the instrument over stone cairns and by the use, on two occasions, of satellite stations. A sun azimuth was observed at the first station and the Geodetic Institute cairn on Sarqâta Qáqâ (1150 m) was intersected, but only from two nonintervisible stations. The computed height of this point, above an assumed sea-level at the shore station, came out as 1143 metres.

The rectangular co-ordinates and the heights of the stations were computed and plotted on two plane-table sheets, but as Paterson, who had assisted in the triangulation, could not remain at Sarqâ, only one was used and an area of approximately twelve square kilometres was surveyed by the writer before the camp at Sarqâ was abandoned.

Progress was slow on the steep ground and scree which constitute most of this area, and bad weather delayed the work.

The survey was made possible by the loan from the Royal Geographical Society of a $3^1/_4$ inch Micrometer Theodolite, two plane tables, two aneroids, a thermometer and a chronometer watch.

In Plane-tabling, vertical angles were measured with an Abney Level and the differences in height were usually scaled off from a carefully prepared diagram in which the vertical interval was magnified ten times. Depression angles were occasionally used for fixing points on the coast, but it was seldom that much of the coast sould be seen from the plane-table stations.

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PLATES

Plate 1.

Fig. 1. Basic Lamprophyre dyke of the West Coast Group cutting through the acid explosion-breccia of the Erqua neck. Hammer shows scale.

Fig. 2. Composite dyke cutting massive gabbro west of the western gully on the southern coast. The acid portion of the dyke does not penetrate the gabbro. Hammer shows scale.

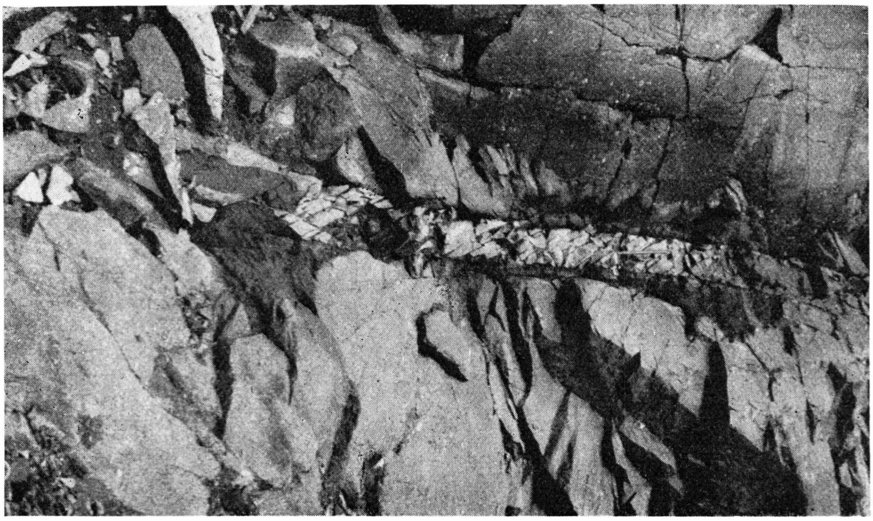


Fig. 2.

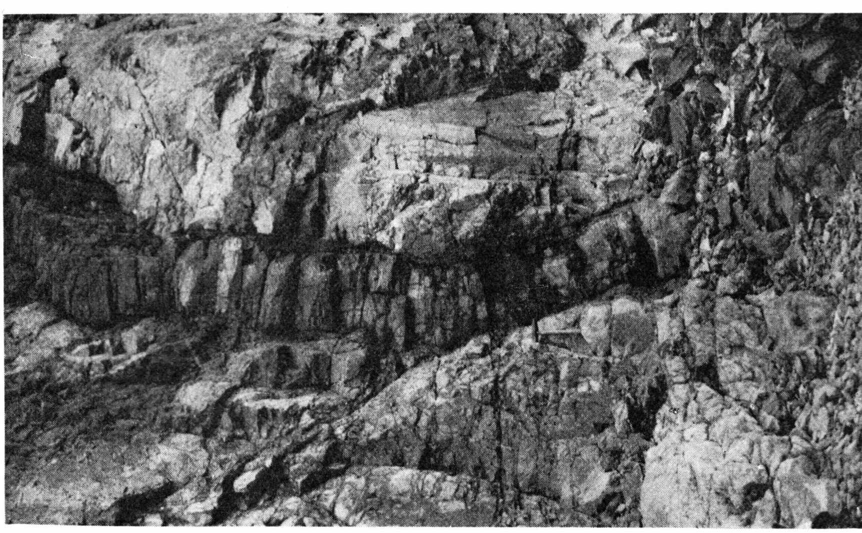
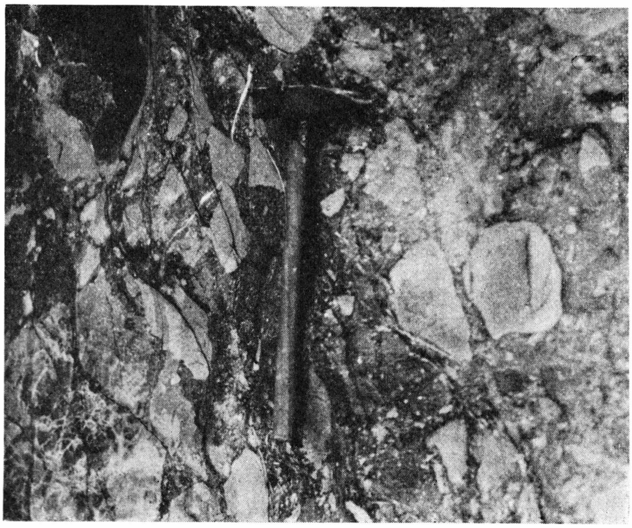


Fig. 1.

Plate 2.

Fig. 1. Large basaltic bomb in the vent at Erqua.

Fig. 2. Shatter line in the volcanic breccia of the Erqua neck.



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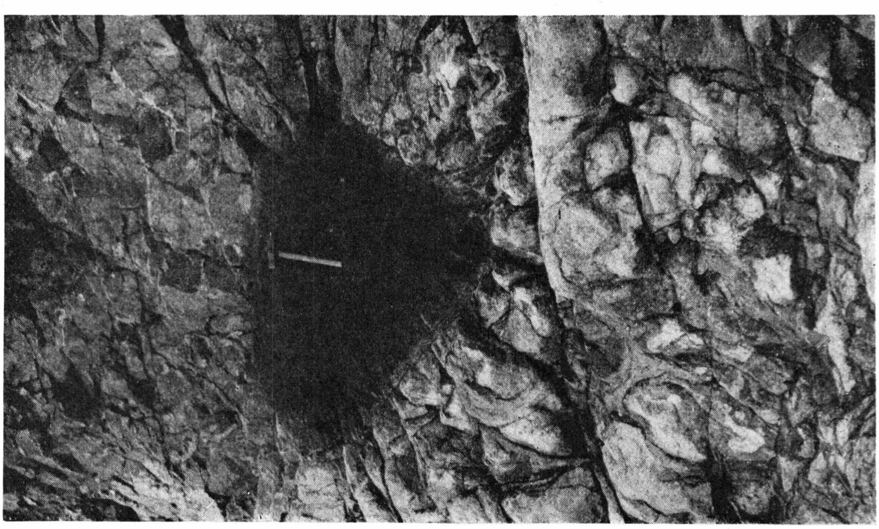


Fig. 1.

Plate 3.

Regularly banded gabbro below a large 'raft' of 'basaltic hornfels' at which the bands end abruptly and are not distorted. Loc.: Western gully, southern cliffs. Cliff section is about 350 ft. high.

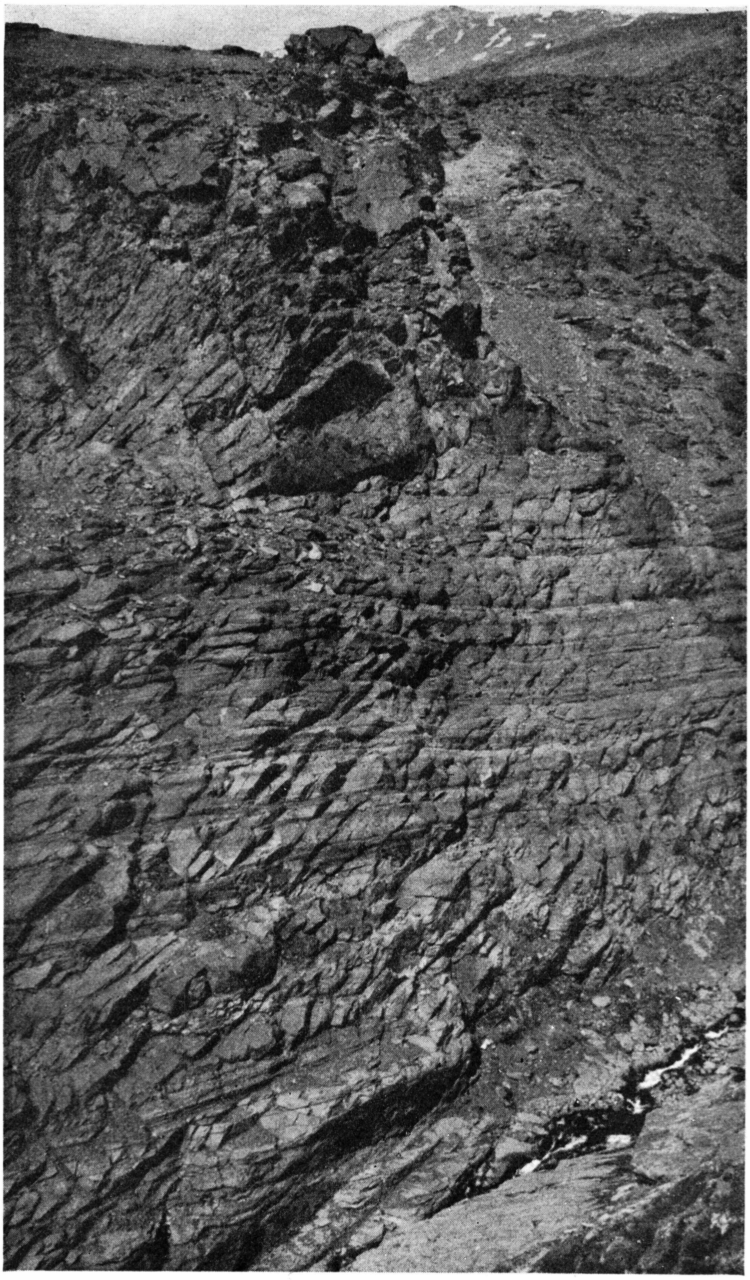
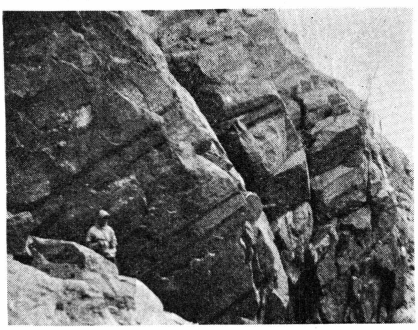


Plate 4.

The top two photopgraphs illustrate regular banding resembling the layering of the Skaergaard intrusion. East Greenland. The lower two photographs are of scree boulders showing heteregeneous banding. Loc.: Southern cliffs.



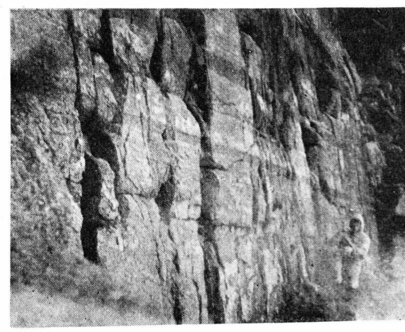
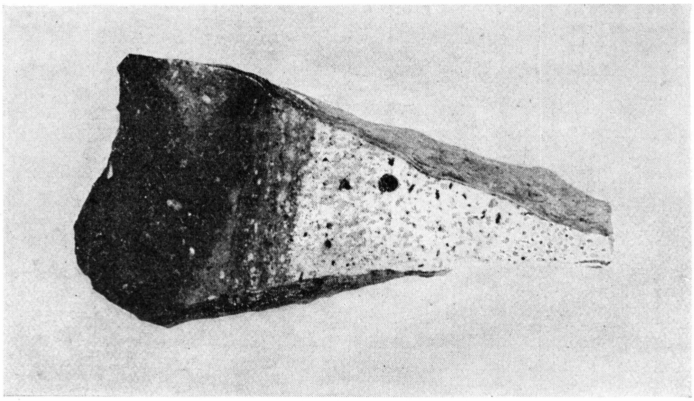


Plate 5.

Fig. 1. Ribbon injection of 'basalt' by acid material. Curved relic of 'basaltic hornfels' suggests softening. Loc.: as in fig. 2.

Fig. 2. Large 'raft' of injected 'basalt' entirely surrounded by massive gabbro. The acid injections are not visibly linked to any injections through the gabbro. Loc.: Central gully, southern cliffs.

Fig. 3. Intermixture at contact of 'basalt' and acid material. Loc.: as above.



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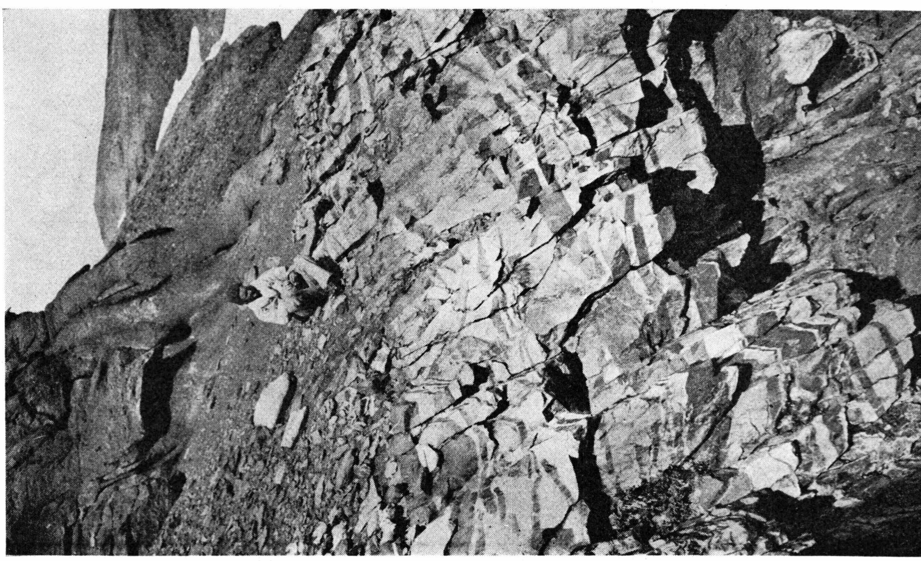

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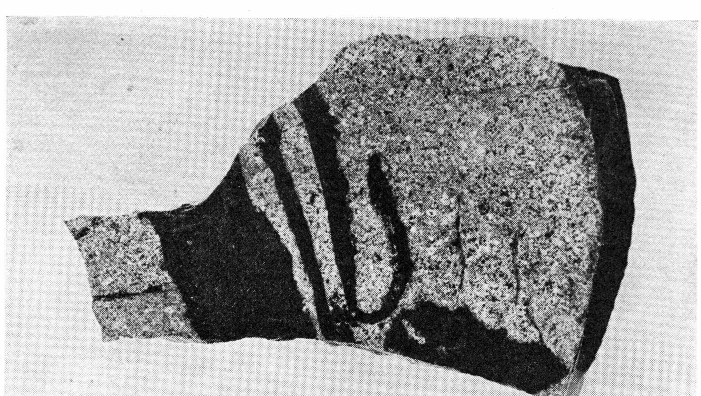


Fig. 1.

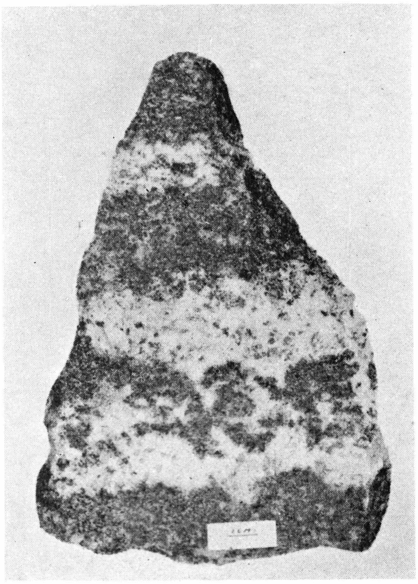
Plate 6.

Fig. 1. Irregular banding in gabbro. Quartz is concentrated in the centre of the thickest plagioclase-rich band. The plagioclase tends to be orientated roughly parallel to the banding.

Fig. 2. Drusy cavity with well-formed quartz crystals in gabbro-pegmatite.

Fig. 3. Basic granophyre-pegmatite with biotite.

Fig. 4. Large plagioclase crystals developed at the contact of a granophyre dyke intrusive into gabbro.



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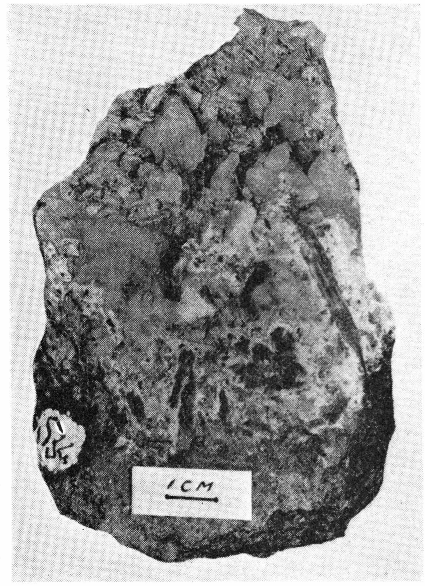

Fig. 2.

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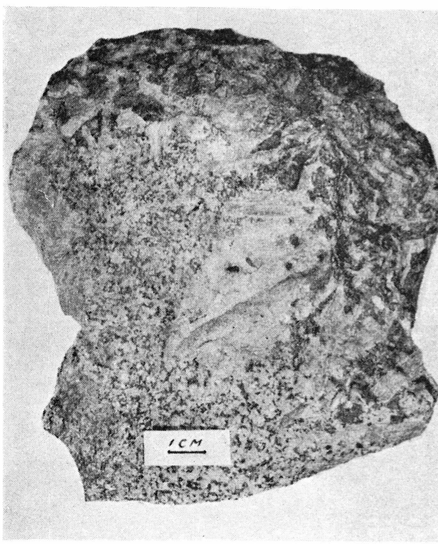

Fig. 4.

Plate 7.

Fig. 1. Scree boulder showing ribbon injection of 'basalt' by acid material. Loc.: Southern cliffs.

Fig. 2. Net-veining of 'basaltic hornfels' by acid material. Loc.: Scree boulder, southern cliffs. Scale: $\times\ ^1/_3$.

Fig. 3. Intrusion-breccia formed by the explosive injection of 'basalt' by acid material. Loc.: 100 ft. below lower contact of gabbro, central gully. Scale: $\times\ ^1/_3$.

Fig. 1.

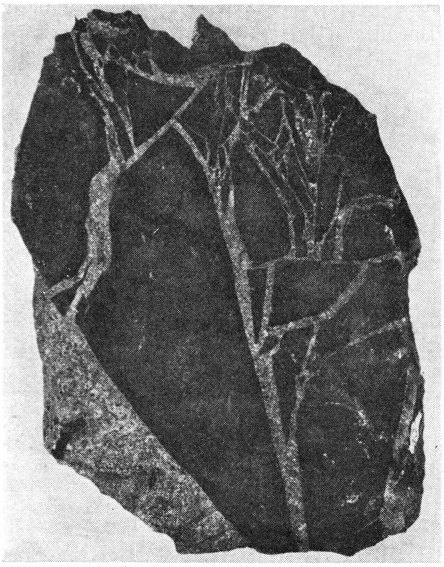

Fig. 2.

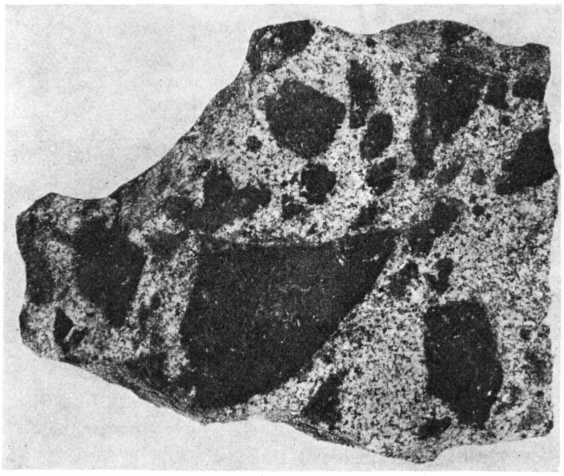

Fig. 3.

Plate 8.

Fig. 1. Quartz vein traversing a vein of dolomite on crystals of which the quartz is moulded. Both veins are intrusive into an acid dyke. Loc.: 1 1/2 miles north east of Sarqâta qáqâ.

Fig. 2. Quartz crystals on dolomite. Loc.: as above.

Fig. 3. 'Chopped' or 'hacked' quartz. Lamellar cavities in quartz revealed after the removal by weathering of the dolomite. Loc.: as above.

Fig. 4. Lamellar cavities uncovered after the dolomite (upper right part of photograph) has been partly removed. Loc.: as above.

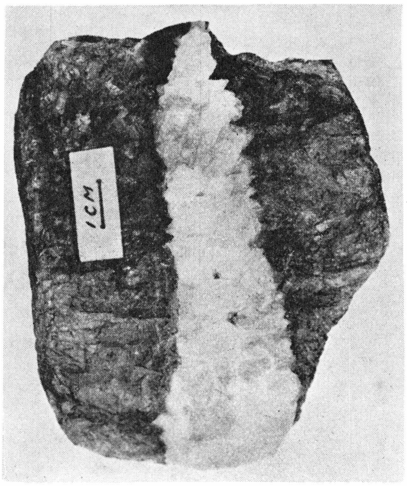

Fig. 1.

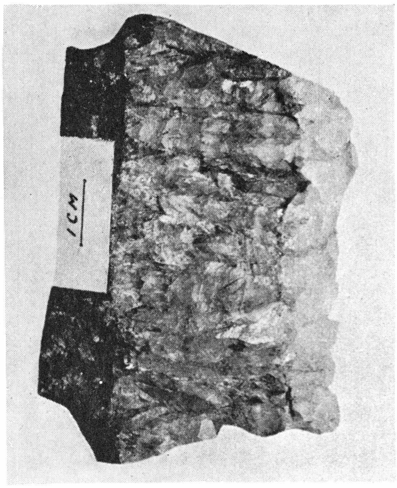

Fig. 2.

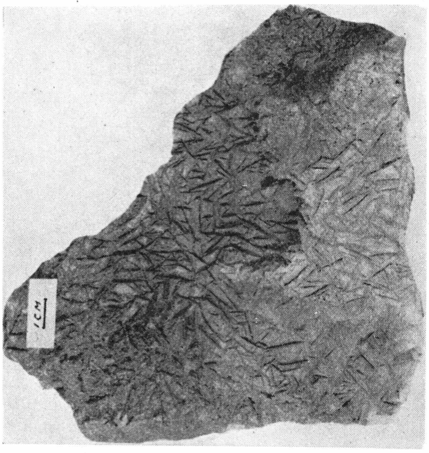

Fig. 3.

Fig. 4.