The earlier gardar igneous rocks of the Ilimaussaq area of South Greenland

James Wynne Stewart

THE EARLIER GARDAR IGNEOUS ROCKS OF THE ILÍMAUSSAQ AREA, SOUTH GREENLAND.

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ABSTRACT

During the earlier part of the Gardar Period, continental sandstones and volcanics (principally flows of olivine basalt) were laid down in the Ilímaussaq region; strata with a maximum thickness of over 3 km. are preserved. The region was characterised by block faulting with sizeable dislocations and the stratigraphic succession on each fault block is different. The geology of each of the blocks is discussed in turn and, in a final synthesis, the successions of the blocks are correlated and a preliminary analysis made of the fault system.

In addition to the basalt magma, which was erupted quietly in great quantities, a quite separate volatile-rich ultramafic magma was available in the region at intervals during the early Gardar. It was responsible for the drilling of numerous diatremes and for a phase of intense, explosive volcanic activity. There is clear evidence of the presence of a related, concealed carbonatite body, located near Qagssiarssuk, in the north of the area. The associated lamprophyric rocks in this vicinity have been subjected to calcitic carbonatisation, followed by ankeritic carbonatisation, while the country rocks have been subjected to potash feldspathisation. Necks, sills and flows of carbonatised uncompahgrite occur.

The petrography of the volcanic rocks is discussed in some detail and chemical analyses are provided. Separate studies, in which X-ray techniques were used extensively, have been made of the carbonates, the alkali feldspars and the trace elements, in rocks associated with the carbonatite.

The lamprophyre-carbonatite vulcanism has many parallels in the volcanic fields of East Africa, but the presence of olivine basalt magma in the area at the same time is an unusual feature. On occasions, the two magmas were erupted almost simultaneously, yet there is no indication of intermingling or mutual contamination.

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INTRODUCTION.

Preface.

From the beginning of 1958 until the autumn of 1960 the author was employed as a geologist by the Greenland Geological Survey and took part in geological expeditions to South Greenland in the summers of 1958, 1959 and 1960. From late 1960 until the present, material collected in Greenland has been subjected to laboratory investigation in the Department of Geology, Durham University. Leave was taken in the summer of 1962 for a further field season in Greenland.

The present study is based on field investigations carried out as part of a programme of systematic geological mapping of Southern Greenland on a scale of 1:20,000, organised by the Greenland Geological Survey.

The summer seasons of 1958 and 1960 were spent on the Narssaq Intrusive Complex. In 1959, Gardar sediments and volcanics on the Ilímaussaq Peninsula were mapped in conjunction with V. Poulsen. Poulsen was concerned mainly with the sediments, while the author investigated the igneous rocks. In 1962 a further season was spent in the region, during which the Qagssiarssuk area, with its intrusive and effusive ultramafic rocks, was mapped in some detail. The outlying areas of Igaliko, Narssarssuaq and Nunasarnaussaq were also visited and the high land of the Ilímaussaq Peninsula revisited.

Acknowledgements.

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Gratitude is expressed to the Director of the Greenland Geological Survey, K. Ellitsgaard-Rasmussen, for his constant support in providing facilities and for his consideration as an employer.

The author is grateful to Mr. J. Rasmussen of the Danish Geological Survey (Faeroes Division) for his company in the field and valuable help and advice on volcanic geology during the earlier part of the 1959 season.

Special thanks are due to the Northern Ireland Ministry of Education for financial support while the laboratory work was in progress.

Thanks are due to the geologists of the Greenland Geological Survey and to the field assistants, skippers, pilots and other personnel, whose help made the field work possible.

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Finally, the author would warmly thank Mr. C. Chaplin

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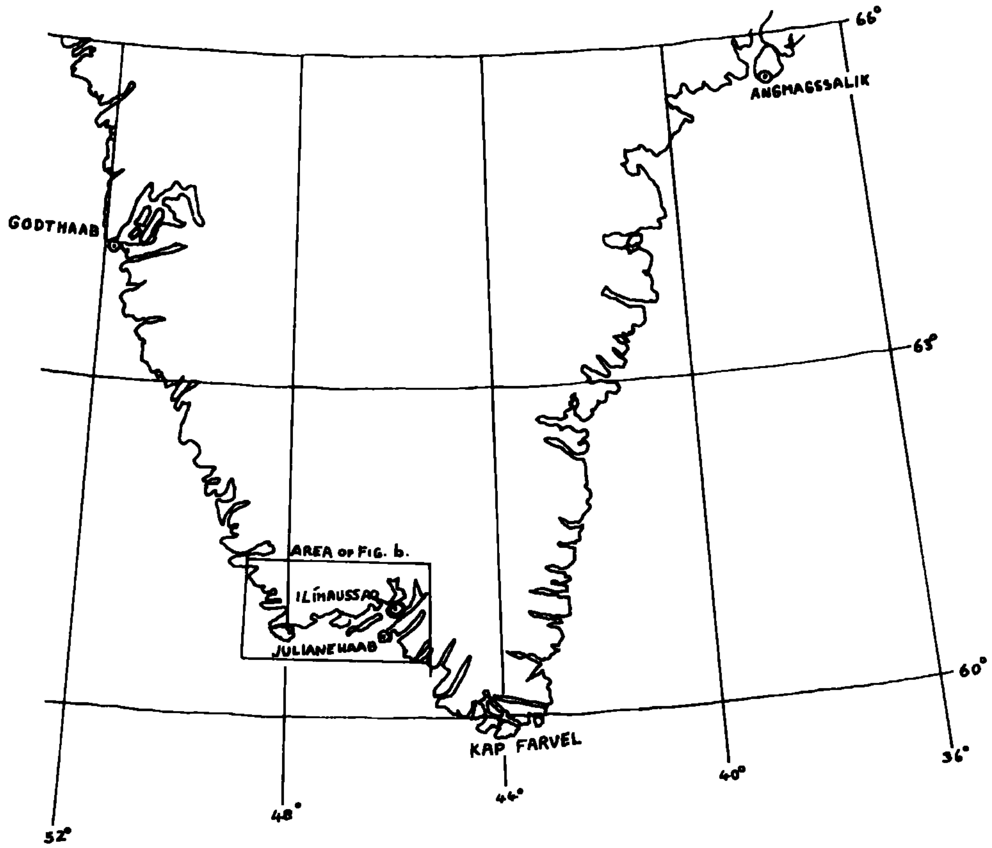


Fig. a. Southern part of Greenland to show location of Ilímaussaq region.

Location of Area and Access.

The area with which this investigation is principally concerned is located on the western side of South Greenland between 45°20′ and 46°10′ W and 60°50′ and 61°15′ N.

The deep fjords are navigable far inland and ocean-going vessels can penetrate up Tunugdliarfik (Skovfjord) to Narssarssuaq, some 80 km. from the open sea. Narssarssuaq has an airport and a regular air service to Europe is maintained.

Narssaq is the principal settlement of the area and supports a minor industry based on the processing of mutton and fish. There are smaller agricultural settlements at Igaliko and Qagssiarssuk; the population at Narssarssuaq is concerned with the harbour and airport installations.

Transport between the settlements is normally by motor-boat.

Scope of the Work.

In the Ilímaussaq region, the geology of the Gardar igneous rocks older than the well known Ilímaussaq Intrusive Complex has hitherto been largely neglected. The earliest phase of Gardar igneous activity is represented by a succession of lavas and pyroclastics which, with accompanying arenaceous sediments, make up the Gardar Continental Series.

This continental formation is only known with certainty to occur in the country between Sermilik and Igaliko Fjord in the Julianehaab District of South Greenland. The total area preserved is about 300 square kilometres. The most extensive remnant of the Gardar strata occurs on the Ilímaussaq Peninsula, adjoining the Ilímaussaq Intrusive Complex. Other remnants of lesser extent occur isolated on fault blocks in the vicinity.

The system of investigation has been as follows:

(i) The stratigraphical succession was established, first on the Ilímaussaq Peninsula where the succession is most complete, then on the outlying fault blocks.

(ii) A petrographic description of the igneous rocks was prepared.

(iii) The strata of the various fault blocks were correlated.

In the 1962 field-season, rocks of carbonatitic aspect were found near Qagssiarssuk. In view of the economic potential of carbonatite bodies as producers of niobium, rare earths, apatite, barytes, etc., material from this area was subjected to rather detailed petrographic examination to see whether the presence of carbonatite could be substantiated.

Topography and Relief.

In the part of South Greenland under consideration, the Inland Ice is as much as 100 km. from the open sea. The intervening, recently glaciated terrain has been partly inundated. The resulting network of fjords emphasises the grain of the country, which has a 50° strike.

Topographically, the area is dominated by three mountain groups;

(i) Kitdlavat, a spectacularly narrow, north-east-south-west ridge lying north of the head Kangerdluarsuk fjord and rising above 1100 m.

(ii) The Igdlerfigssalik (1750 m.) and the group of peaks at the head of Igaliko Fjord.

(iii) Ilímaussaq (1390 m.) and the adjoining High Plateau, much of which is over 1100 m.

Much of the Ilímaussaq Peninsula, as far north as Naujarssuit, rises above 700 m.. To either side, the land falls steeply to the fjords Sermilik and Tunugdliarfik; the cliff above Sermilik is particularly imposing (Fig. 1.1). There are several limited plateau areas at 600 - 700 m., possibly indicating an erosion level. North of Sitdlisit, the land is much lower, seldom rising above 300 m.. Towards the northern limit of the area, the land rises once again.

On the south side of Tunugdliarsik there is a steep coast backed by high land, except in the vicinity of Igaliko. In the latter district there is an extensive tract of low lying ground, north of which the mountains of the Igaliko

Intrusive complex rise rapidly.

Superficially, the topography reflects the recent glaciation of the country. The coasts of the fjords are the sides of U-valleys. Ice striations are found on exposed rock surfaces. There can be no question but that the movement of the ice was largely controlled by the geology. The glaciers tended to follow pre-existing 50° linears and it seems probable that the fjords are situated on important faults or crush-zones. Soundings in Sermilik show depths in excess of 300 fathoms far up the fjord while Tunugdliarfik has a depth of 100-200 fathoms as far north as Mâjût (Weidick, 1963).

The Ilímaussaq and Igaliko intrusive complexes proved resistant to erosion. In the latter part of the glaciation, at least, they probably formed nunataks for long periods.

Exposure and Conditions.

Field investigation has been hampered to some extent by acute relief, superficial deposits and vegetation. Many of the fjords and valley sides are sheer and inaccessible. Scree and glacial deposits mask many lower slopes and much of the lower ground. Low herbage and birch and willow scrub grow almost everywhere up to about 500 m. (the name Skovfjord means Wodd or Forest Fjord), and may persist tenaciously on steep slopes.

The higher fjeld areas such as the tops of Nunasarnaq and Nunasarnaussaq are devoid of vegetation and well exposed. The High Plateau of the Ilímaussaq Peninsula, is a barren, rocky wilderness. Small glaciers and snowfields persist there.

Where exposure is of particular relevance to the geological account, further details are given in the text.

During the summer season, which is roughly from the end of May to the middle of September, working conditions are usually very agreeable. Heavy rainfall is the chief disadvantage, persisting sometimes for weeks on end. Several times each summer violent föhn winds are experienced. As a rule, temperature rarely falls below freezing, nor is there any precipitation of snow below about 600 m. during the summer. The hours of sunshine probably exceed those in western Europe at the same latitude.

Most of the field mapping was recorded on 1:20,000 map sheets; the Narssaq area was mapped on a scale of 1:10.000. The topographic maps available have been prepared from aerial photographs with ground control and are of reasonable accuracy. They are contoured at intervals of 20 m. or 25 m.. Aerial photographs of various scales were used at times to supplement the maps.

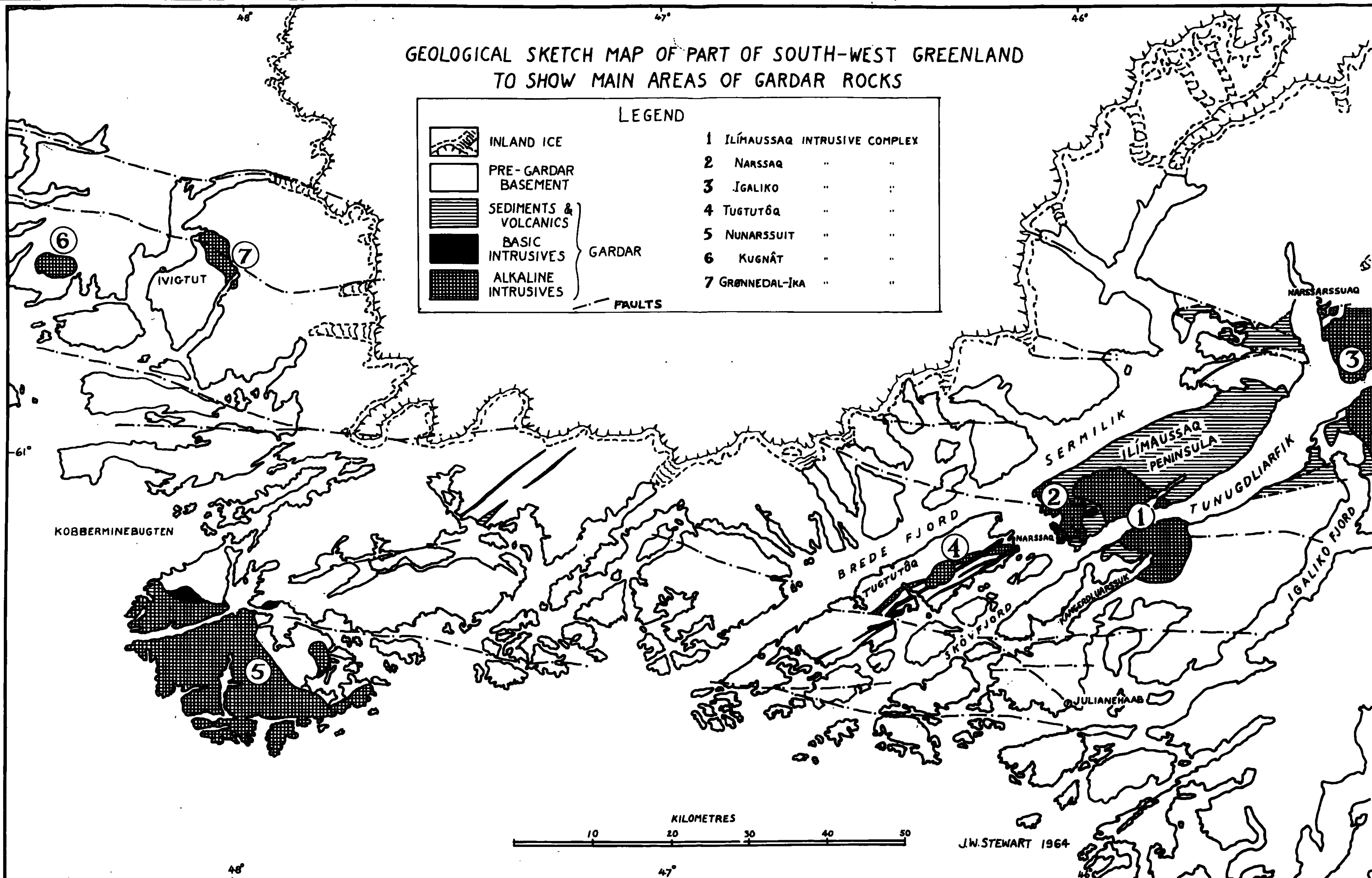
Earlier Workers.

The mineralogist K. L. Giesecke visited the area in 1806 and 1809 (Giesecke's diary, published 1910). He described the red sandstone of Igaliko, but, like most of the later workers, his interests lay mainly with the plutonic nepheline syenite rocks and their unusual suite of minerals. Later in the century C. Pingel visited Igaliko and published a description of the red sandstone and porphyry dikes in that vicinity (Pingel, 1843).

Between 1876 and 1899 K. J. V. Steenstrup made a number of expeditions to the area, resulting in a topographical and geological sketch map and a preliminary account of the main aspects of the geology. He describes the principal occurrences of Gardar continental strata and gives a rough outline of the distribution of the sediments and volcanics (Steenstrup, 1881; Steenstrup and Kornerup, 1881; Steenstrup, 1909).

The area is best known from the work of N. V. Ussing, whose account of the Ilímaussaq nepheline syenite intrusive complex is a classic of petrology (Ussing, 1912). Ussing was mainly concerned with the younger, intrusive alkaline rocks and his observations on the stratigraphy of the sediments and volcanics show little advance on those of Steenstrup. Ussing's account includes a petrographical description of a number of the principal lava types; the material was collected close to the margin of the intrusive complex, however, and is strongly altered. In particular, the analyses of volcanic rocks provided are those of contact-altered varieties; this fact is insufficiently stressed in the 1912 paper.

C. E. Wegmann paid a brief visit to the area in 1936. He distinguished the main lithological divisions of the Gardar continental sequence and related these to a regional


GEOLOGICAL SKETCH MAP OF PART OF SOUTH-WEST GREENLAND
TO SHOW MAIN AREAS OF GARDAR ROCKS
LEGEND
INLAND ICE
PRE-GARDAR BASEMENT
SEDIMENTS & VOLCANICS
BASIC INTRUSIVES
ALKALINE INTRUSIVES
GARDAR
FAULTS
1 ILÍMAUSSAQ INTRUSIVE COMPLEX
2 NARSSAQ " "
3 IGALIKO " "
4 TUGTUTÔQ " "
5 NUNARSSUIT " "
6 KUGNÂT " "
7 GRØNNEDAL-IKA " "
IVIGTUT
KOBBERMINEBUGTEN
SERMILIK
ILÍMAUSSAQ PENINSULA
TUNUGDLIARFIK
NARSSARSSUAQ
NARSSAQ
BREDE FJORD
TUGTUTÔQ
SKOVFJORD
KANGERDLUARSSUK
JULIANEHAAB
IGALIKO FJORD
KILOMETRES
10 20 30 40 50
J.W. STEWART 1964
48°
47°
46°
61°

tectonic picture. He also observed some of the diatremes of the inner reaches of Tunugdliarfik (Wegmann, 1938).

The works of Steenstrup, Ussing and Wegmann are the only significant contributions to the geology of thee Gardar Continental Series up to the present time.

Regional Setting and Age.

The oldest rocks of the region under consideration are the granites and gneisses known collectiv_ely as Julianehaab Granite (cf. Ussing, 1912, Wegmann, 1938). This syn_kinematic basement granite extends westward from the Julianehaab area to Kobberminebugten, a distance of over 100 km.. Absolute age-dating of material from the vicinity of Julianehaab gave ages of 1590 ± 70 m.y. and 1597 m.y. by the rubidium-strontium and potassium-argon methods, respectively (Moorbath, Webster and Morgan, 1960). The age of the latest mobilisation of the basement rocks, in this locality at least, is thus fixed.

In the Ilímaussaq region, the Basement is generally free from enclaves of earlier formations. Intrusive rocks older than the Gardar Continental Series appear to be absent in the areas investigated. The Basement granite is overlain by sediments and volcanics of the Gardar Continental Series. Subsequently, these strata were intruded by thick sills of olivine gabbro, succeeded by swarms of basic "Big Feldspar" dikes and aphyric and porphyritic dikes of syenitic composition. Virtually all of the dikes on the Ilímaussaq Pe_ninsula strike between 50°

and 60°.

On the Ilímaussaq Peninsula, the period of dike intrusion was followed by the emplacement of the Ilímaussaq and Narssaq intrusive alkaline complexes. Recent absolute age-dating on polylithionite from the Ilímaussaq Intrusive Complex yielded the following results:

Rb/Sr method: 1095 ± 24 m.y., 1077 ± 24 m.y., 1086 ± 20m.y.

K/A method: 1180 m.y. (Moorbath, Webster and Morgan,1960).

The Gardar rocks of the area are thus of Pre-Cambrian age and the formation of the Gardar Continental Series is fixed between 1660 m.y. and 1053 m.y. (taking the extreme values from the above results).

A long period of time must have elapsed between the latest mobilisation of the Julianehaab Granite and the earliest Gardar Sedimentation, and the surface on which the basal beds were deposited was deeply eroded. It seems probable that the earliest Gardar Sediments and volcanics are considerably younger than 1660 m.y. and their age is probably nearer to that of the Ilímaussaq Intrusive Complex.

The age of the Igaliko Intrusive Complex is not yet certainly fixed with relation to the dike swarms of the Ilímaussaq Peninsula, but it has intrusive contacts against the Gardar strata.

Other alkaline intrusive complexes in South Greenland, believed to be of Gardar age are shown in Fig. b. The Kûgnât Complex (Upton, 1960) and the Nunarssuit Complex (Harry and Emeleus, 1963) have been assigned the following ages:

Kûgnât: 1240 ± 150 m.y. (Rb/Sr method - Moorbath et al., 1960).

Nunarssuit: 1150 ± 30 m.y. (Rb/Sr method - Harry and Emeleus, 1963).

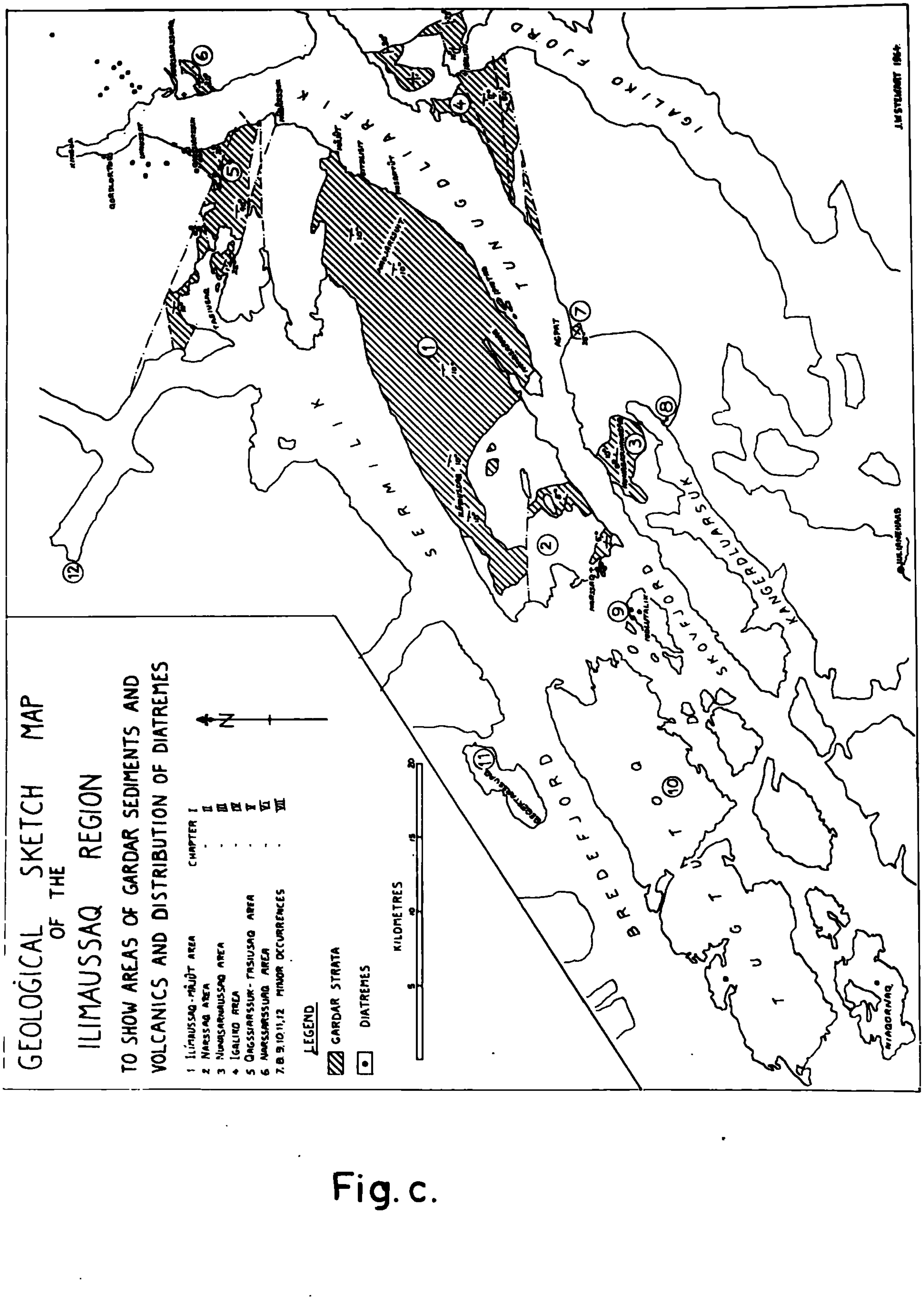

GEOLOGICAL SKETCH MAP
OF THE
ILIMAUSSAQ REGION
TO SHOW AREAS OF GARDAR SEDIMENTS AND
VOLCANICS AND DISTRIBUTION OF DIATREMES
1 ILIMAUSSAQ - MÅJÛT AREA CHAPTER I
2 NARSSAQ AREA . II
3 NUNASARNAUSSAQ AREA . III
4 IGALIKO AREA . IV
5 QAGSSIARSSUK - TASIUSAQ AREA . V
6 NARSSARSSUAQ AREA . VI
7, 8, 9, 10, 11, 12 MINOR OCCURRENCES . VII
LEGEND
GARDAR STRATA
DIATREMES
KILOMETRES
0 5 10 15 20
N
SERMILIK
TUNUGDLIARFIK
IGALIKO FJORD
BREDEFJORD
SKOVFJORD
KANGERDLUARSUK
TUTTUTOOQ

Fig. c.

Main Areas of Gardar Strata.

Ilímaussaq Peninsula	Ilímaussaq - Mâjût Area (150 sq. km.).	Chapter I
	Narssaq Area (30 sq. km.).	Chapter II
	Qagssiarssuk - Tasinsaq Area (35 sq. km.).	Chapter V
South of Tunugdliarfik	Nunasarnaussaq Area (9 sq. km.).	Chapter III
	Igaliko Area (50 sq. km.).	Chapter IV
	Narssarssuaq Area (5 sq. km.).	Chapter VI

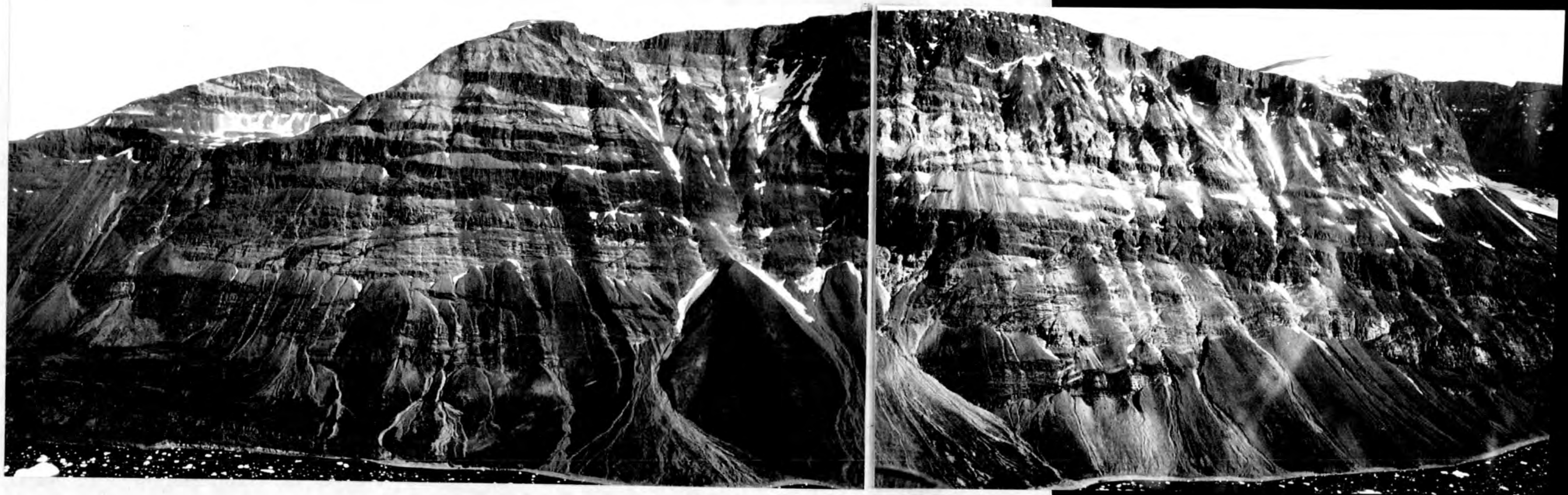


Fig. 1.1. Cliff section above Sermilik, northern side of Ilímaussaq Peninsula.

CHAPTER I. THE ILÍMAUSSAQ - MÂJÛT AREA.

(a) GEOLOGY

General

About 150 square kilometres of Gardar continental sediments and volcanics outcrop on the large fault block which stretches south-west from Nûgârssuk to the Ilímaussaq Nepheline Syenite Intrusion. This is the greatest single area of Gardar strata known to exist. An almost complete sequence through the Series is exposed, with a total true thickness of ca. 3 km..

The north-eastern part of the area, comprising the 600 m. plateau of Naujarssuit and the lower country to the north, was mapped by V. Poulsen in 1958 and 1959, special attention being paid to the sedimentary rocks. The volcanic intercalations were examined and the remainder of the area mapped by the author in 1959; the high plateau between Ilímaussaq and Nasanguaq was revisited in 1962.

Notes on Relief, Glaciation and Vegetation.

The relief of the area can be widely related to the stratified nature of the rocks and the regional tectonic pattern, modified by glacial action. Important glaciers exploiting fault zones have cut out deep, parallel U-shaped valleys now occupied by Sermilik and Tunugdliarfik (fjords). The U-valley of Tunuarmiut was the site of a distributary glacier.

The glaciation has been so recent that the sides of these valleys are still generally very steep or precipitous; for a distance of about 15 km. between Ilímaussaq and Kangerdluaq, the slope above Sermilik is sheer and inaccessible (Fig. 1.1). Extensive dip-slope areas with subdued relief, studded with lakes, contrast with prominent scarps. The high sandstone scarp on the north side of Naujarssuit (Fig. 1.6) is certainly due to the resistant nature of the quartzite-like rock, while the Ilímaussaq Volcanic Unit, a thick, uninterrupted sequence of extrusives, is almost everywhere bounded by a steep cliff (Fig. 1.13). On a less imposing scale, but none the less notable, there is the regular, terraced landscape of the Musartût Unit, where more resistant volcanic layers alternating with softer sediments rise in a series of steps to the base of the Naujarssuit scarp at 400 m. (Figs. 1.2 and 1.6).

Much of the lower ground is covered with thin soil of glacial derivation supporting a growth of low herbage, birch and willow scrub which manages to persist on all but the steepest slopes up to about 600m.. On the Musartût terraces and the low land to the north, and in the basin of the river complex which flows into Tunuarmiut, the vegetation is a serious hindrance to field observation and actually impedes movement. In the volcanic country on top of Nunasarnaq and stretching from above the north-west side of Tunuarmiut towards the edge of the High Plateau, there is but thin soil cover outside the river valleys and vegetation is sparse. The spurs and corries on the fringe of the High Plateau are mainly of bare rock. The Plateau itself is a barren, rocky wilderness (Fig. 1.13). The amount of snow which persists throughout the summer fluctuates widely from year to year, but certain areas of several thousands of square metres must be regarded as permanent snow-fields. Most of the country above 1200m. is covered by angular rock fragments to a depth of a metre or more. As a rule, the fragments have not been transported far from their parent rocks; thus, the course of red, alkaline dikes, well exposed on the cliffs below, can be traced across the plateau as linear zones of red fragments, occasionally deviating a little downhill where the slope steepens across the strike.

The high plateau forms a kind of glacial "interfluve" whence tributary glaciers flowed alternately north-west and south-east. On the Sermilik side, in particular, there is a wonderful succession of hanging valleys, some of which still contain small corrie glaciers.

Method of Investigation

In view of the size of the area, it was realised at an early stage in the field investigation that it would be impossible to visit all outcrops; moreover, a very sizeable area is automatically excluded due to inaccessibility. Systematic mapping, therefore, was generally limited to the recording of boundaries between the principal rock types, in particular between sedimentary, effusive and intrusive rocks. Measured sections were taken at various localities where a thick succession was reasonably well exposed on a steep but accessible slope. Variations in rock type were noted and samples taken, while the altitude was recorded from a surveying altimeter. Measured sections are best taken in the strike direction on a steep slope; the orientation ensures that the recorded thicknesses of the beds will not be affected by surface relief. In the present investigation, measured sections have of necessity been taken where conditions were less than ideal. The consequences will be apparent on comparing the Musartût Section (Table 1.2), taken almost parallel to the strike, with the relevant part of the Sitdlisit - Naujarssuit Traverse (Table 1.1), almost at right angles. Both sections are in the same stratigraphical Unit and end at the same location.

Lithology and Stratigraphy of the Gardar Continental Series.

The Gardar Continental Series, as developed on this part of the Ilímaussaq Peninsula, is readily subdivided into a number of stratigraphical units, each with special lithological characteristics and each representing a space of geological time during which particular conditions prevailed. The following units are distinguished:

TOP

6.	Ilímaussaq Volcanic Unit	Extrusive olivine basalt, followed by alkaline extrusives. 1030 m.
5.	Nunasarnaq Sandstone Unit	Sandstone with local thin flows. 350 m.

4.	Ipiutaq Volcanic Unit	Mainly extrusive olivine basalt. 150 m.
3.	Naujarssuit Sandstone Unit	Almost wholly of sandstone. 420 m.
2.	Musartût Unit	Rapidly alternating sequence of sedimentary and volcanic layers. 745 m.
1.	Mâjût Sandstone Unit	Arkosic basal beds, followed by sandstone. 390 m.

BASE

Throughout the area, the dip of the strata is generally less than 10°; accordingly, the difference between apparent thickness and true thickness is very small, (where the dip is 10°, true thickness = apparent thickness x 0.9848). The thicknesses given above are approximate, apparent thicknesses encountered in the type area for each Unit.

The type areas of the various Units follow one another down-dip along the Peninsula and, considered strictly, thicknesses only apply to the type areas where they were measured. For example, the type areas of the Mâjût Sandstone Unit and the Ilímaussaq Volcanic Unit are about 17 km. apart; it is improbable the Mâjût Unit will have the same thickness under the Summit Plateau and

Fig. 1.2. View south-west from Måjût. In the foreground, Basement granite is overlain by basal Gardar sediments. In the distance, the dark scarp of Sitdlisit is followed by the well stratified Musartût Unit. Naujarssuit sandstone forms a scarp along the skyline.

Fig. 1.4. "Igaliko" sandstone.

at Sitdlisit.

The sum of the thicknesses of the Units is 3085 m.. This figure cannot be considered as more than an indication of the total thickness of strata remaining below the Summit Plateau; however, the regular stratification of the Series, which can be seen along the steep fjord wall above Sermilik, (Fig. 1.1) suggests the Series is not subject to extreme variation in the E.N.E. - W.S.W. direction.

Several of the names applied to these Units have been used by Wegmann (1938). The localities are somewhat confused in the earlier work and the present stratigraphic subdivision and nomenclature have been established independently by the author in consultation with V. Poulsen.

1. THE MÂJÛT SANDSTONE UNIT.

At the small peninsula Mâjût, the basement granite is overlain to the south by basal conglomerate and arkose which pass up into bedded, red sandstone (Fig. 1.2). The inclination of the bedding is not very well known as recordings of dip are rather rare and sometimes conflicting. Overall, there appears to be a low dip toward the south. Most or all of the Mâjût Unit sandstone has been water-laid; cross-bedding and ripplee marks are common and sun-cracks and other structures indicating per iodic emergence are fairly common. In the upper part of the Unit, a few hundred metres north of Sitdlisit, a layer of finely banded

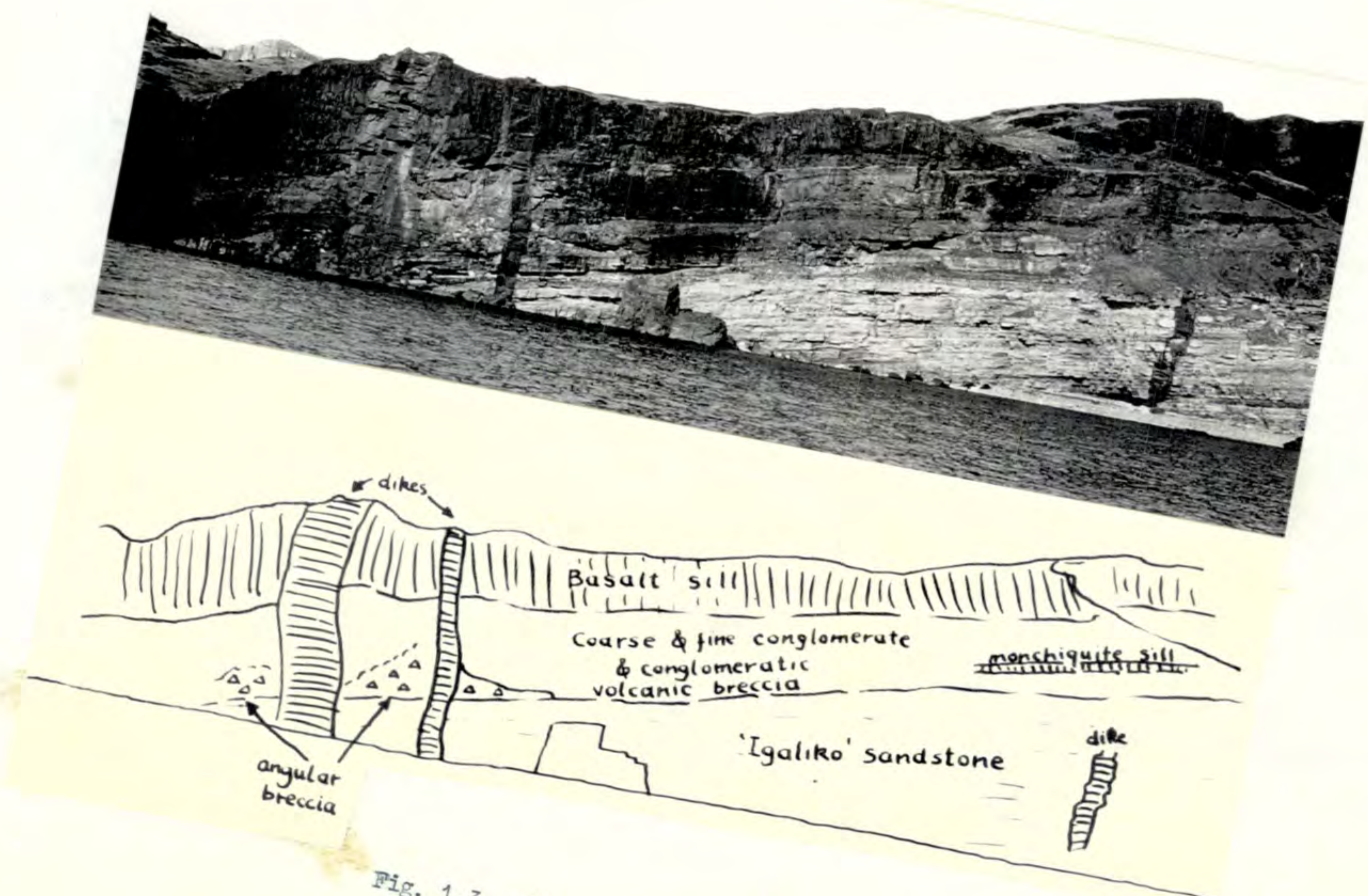


Fig. 1.3. Sitdlisit section.

green and purple siltstone, about 10 cm. thick, occurs interbedded with the normal red sandstone. This very fine grained rock appears to be indurated and is resistant to weathering.

About one and a half kilometres south-west of Mâjût, at Sitdlisit, a dark, steep topographical feature rises abruptly above the sandstone and can be seen trending westward across country (Fig. 1.2). The base of this feature (formed by a basalt sill) coincides approximately with the upper limit of the Mâjût Sandstone Unit. Exposure of the rocks of the Unit, away from the coastal sections, is exceedingly poor. The country immediately north of the Sitdlisit scarp is virtually devoid of exposure and knowledge of the lithology of the top 50 m. of the Unit is derived almost exclusively from a cliff section at Sitdlisit.

The Sitdlisit cliff section (Fig. 1.3) is perfectly exposed but exceedingly steep and locally overhanging. The lower part of the section is the classic locality for the "Igaliko Sandstone", (Fig. 1.4), a well cleaved red sandstone with white spots and streaks which has excited the interest of visitors for some two centuries (Steenstrup, 1909; Wegmann, 1938). The beds which overlie the sandstone are in accessible for sampling; observations and photographs have been taken standing on fallen blocks which lie in the water at the foot of the cliff, and from the fjord.

The uppermost two metres of the sandstone is very dark red and unspotted. Above this, there is a conglomerate bed, the basal facies of the succeeding Unit.

Poulsen (1959) estimates the average thickness of the Basal Unit as 390 m. He remarks that an angular unconformity may separate the Mâjût and Musartût Units, as the general strike directions of the two Units are rather different.

2. THE MUSARTÛT UNIT.

The lowest part of this Unit outcrops on the Sitdlisit section. The "conglomerate" which contains some thin intercalations of finer material is about 10 m. thick. (Inverted commas are used where it is suspected that the conglomerate is not of normal sedimentary deposition; see below.) The section is capped by a sheet of black, columnar basalt.

At the eastern end of the section, there is an irregular body of volcanic breccia. This is presumably the exposure referred to by Wegmann ---- "At Musartût the edge of an explosion tube is still to be seen" (Wegmann, 1938, p. 67). The breccia has a discordant, eruptive lower contact towards the uppermost sandstone layer of the Mâjût Unit. The upper contact is strongly transgressive and, although an upper limit to the body cannot clearly be distinguished, the breccia extends at least to the base of the "conglomerate". The breccia consists of flaggy blocks of sandstone up to half a metre in length, together with some well-rounded blocks of a dark, igneous rock, up to 30 cm. in diameter, set in a rather fine-grained purple matrix. The volcanic blocks are subject to spheroidal exfoliation.

The lithology of the conglomerate appears to be somewhat variable, both horizontally and vertically. Above the fallen blocks a lower, finer variety of "conglomerate" is separated

Fig. 1.5. Conglomeratic volcanic breccia. Rounded dark inclusions (e.g. to right of hammer shaft) are of lamprophyre.

Fig. 1.8. Conglomerate overlying syenite sill, south of Musartut.

from the main layer by an intercalation of fine, stratified material. The pebbles and cobbles of the upper part are quite angular here, but elsewhere they may show much better rounding. The fallen blocks below the cliff are of columnar basalt and the immediately underlying "conglomerate"; the volcanic breccia is represented in these blocks (nor is it anywhere accessible for sampling). Fig. 1.5 is a photograph of the face of such a block. It contains sandstone cobbles which are mostly well rounded but of comparatively low sphericity. There are also smaller, well-rounded igneous "pebbles" and occasional coarse, anhedral grains of iron ore. (The term "pebbles" is inserted in inverted commas to emphasise the possibility that these rounded igneous fragments do not owe their rounding to sedimentary processes). The sandstone cobbles are enveloped in a thin coating of iron oxide, and many show a concentric colour-banding. These phenomena may be related to thermal metamorphism by the overlying basaltic sill, for sandstone blocks in the volcanic breccia, occurring lower on the section, shows no such effects. The matrix of the "conglomerate" is somewhat variable from place to place; in general, it has a rugged, sometimes slaggy appearance and is dark brown to deep purple in colour. It consists of both rounded and angular grains, mostly between 1 mm. and 3 mm. in diameter. Most of the grains appear to be of igneous material, heavily impregnated with iron oxide; there are also numerous grains of quartz and, locally, concentrations of grains of anhedral iron ore 1 - 2 mm. in diameter. The mesostasis, (which is not readily visible, in view of the close packing of the grains) is of carbonate, which weathers to a buff colour. Numerous tiny veins of calcite, some white, some bright red, intersect the matrix irregularly in places. Superficially, at least, the "conglomerate" and the breccia seem to be formed of similar material; however, the fragments of the "conglomerate" show a higher degree of sphericity and rounding, and size-sorting is much better. On the grassy slope west of the cliff section, a sheet of grey monchiquite 1 - 2 m. thick is exposed, intruded into conglomerate.

The rocks which underlie the basaltic sill are not exposed for about 500 m. west of Sitdlisit, then, in a river cleft controlled by a weathered-out dike, a rather good section is seen. Because of the steep relief only the lower part of the section is accessible to relatively close inspection. Here, intrusive volcanic breccia is exposed with an eruptive, brecciated contact against sandstone. The sandstone at the contact has a glassy appearance and detached fragments of sandstone within the breccia have dark, glassy-looking margins. The breccia is penetrated by a sheet of columnar basalt 5 - 6 m. thick, which is probably an apophysis of the main sill which caps the section. Volcanic breccia is occasionally seen between the basaltic sill and the underlying sandstone for some hundreds of metres to the west; beyond, it gives way to conglomerate, apparently a normal, sedimentary variety, free from inclusions of igneous rock. This bed is 10 m. thick and its upper part is strongly metamorphosed. Continuing westward, the conglomerate can be seen below the sill in a number of exposures for nearly 2 km.. Thereafter, the sill lies directly on sandstone and the conglomerate is suppressed, though whether this is due to downward transgression of the sill or lateral impersistence of the conglomerate is not known.

The volcanic breccia at Sitdlisit has much in common with the intrusive volcanic breccia found in pipes and sheet-intrusions in the country around Qagssiarssuk (Chapter V), where well-rounded inclusions of lamprophyre and angular fragments of country rock occur together in a tuffisite matrix. At Sitdlisit, the volcanic breccia is believed to be a sheet-like intrusion. The contacts are intrusive and, since the layer persists intermittently for nearly a kilometre at the same stratigraphical horizon, it can hardly be the edge of an "explosion tube".

The "conglomerate" possesses a number of features which suggest that an original sedimentary conglomerate horizon has been invaded by the tuffisite matrix of the breccia and partly incorporated in it. (cf. Gates, 1959, p. 799). The volcanic breccia may pass up more or less gradationally to "conglomerate"; this could not be verified, due to the steepness of the section, however, the similarity of the components of both rocks is noticeable and large angular blocks occur high in the "conglomerate" (see Fig. 1.5). Many of the larger sandstone inclusions in the upper part of the "conglomerate" (Fig. 1.5) show poorer rounding and lower sphericity than is usual in the conglomerates of the Musartût Unit (cf. Fig. 1.8) and some may owe their rounding to attrition by volcanic, rather than sedimentary, processes. Primary sedimentary inclusions also occur; these include very well rounded pebbles of quartz with high sphericity. (The significance of quartz pebbles as indicators of the presence of original conglomeratic material, as distinct from "pebbles" which owe their rounding to volcanic processes, is discussed in

Chapter IV. West of Sitdlisit, the volcanic breccia appears to pass laterally into a normal conglomerate, free of volcanic inclusions.

The following observations link the "conglomerate" of Sitdlisit with the ultramafic/carbonatite vulcanism which is well evinced at Qagssiarssuk (Chapter V):

(i) The intrusion of a sheet of monchiquite into the "conglomerate".

(ii) The occurrence of volcanic (presumably lamprophyric inclusions in the "conglomerate".

(iii) The coarse grains of magnetite in the matrix and the carbonate base --- these are characteristic of the tuffisite filling of many of the diatremes near Qagssiarssuk and of certain of the pyroclastics in that area.

Reynolds (1954) discusses the industrial process known as "fluidization" and suggests that it may have been active as a geological process in the formation and emplacement of intrusive volcanic breccias and tuffisites. Of late years the principle has been advanced frequently as a possible mechanism involved in the formation of various volcaniclastic intrusions. This is particularly true of recent accounts of carbonatite complexes, e.g. Chilwa (Garson & Campbell Smith, 1958), Tundulu (Garson, 1962) and especially Rufunsu (Bailey, 1960). The prominence of the volatile fluid phase associated with carbonatites would seem to favour the development of a fluidized system.

In the present case, the fluidization process seems to offer a mechanism which would account for:

(i) The abnormal combination of sedimentary conglomerate pebbles and a matrix of volcanic microbreccia.

(ii) The thorough mixing of volcanic and sedimentary inclusions in the "conglomerate".

(iii) The absence of detrital volcanic material in the overlying part of the Musartût succession.

Table 1.1

Traverse across the Musartût Unit from Sitdlisit to Naujarssuit on a 55° bearing

TOP

Metres	
420-568	White quartzite. A weathered-out, soft, shaly red bed 1 - 2 m. thick occurs at the base.
340-420	Well bedded, red sandstone.
332-340	Basalt. A few metres of scoriae mixed with sandstone occurs at the base.
318-332	Red sandstone.

306-318	Olivine basalt containing effusive-type structures.
304-306	Very coarse conglomerate with cobbles 10 - 15 cms. in diameter, exclusively of sandstone or quartzite.
304-304	Thin bed of basalt (Note anomalous thickness due to surface relief).
296-304	Well bedded, red, sandy, tuff ("tilestone").
270-296	Strongly weathered, coarse, red syenitic rock.
265-270	White sandstone.
255-265	Basalt with effusive-type structures.
244-255	Fine conglomerate with quartz and sandstone pebbles, passing up into sandstone.
230-252-244	Basalt with effusive-type structures (note surface relief).
186-230	Red and cream sandstone.
152-186	Fine-grained dark basalt (sill 4).
106-152	Red sandstone.
90-106	Fine-grained black basalt with columnar jointing (sill 2).
86- 90	Not exposed.
74- 86	Red sandstone with several conglomerate horizons.
60- 74	Fine-grained black basalt with columnar jointing (sill 1)

52- 60	Metamorphosed conglomerate.
50- 52	Sill or flow of grey monchiquite, altered and weathered.
45- 50	Poor exposure and accessibility. Red and yellow Igaliko sandstone is overlain by thermally metamorphosed conglomerate.
10- 40	Not exposed.
0- 10	Red sandstone.

BASE

While this traverse serves to illustrate the nature of the strata comprising the Musartût Unit and gives the order of succession, it is of no use as a standard section. The line of traverse departs considerably from the strike direction and, since the ground slopes rather gently, with occasional dips and hollows, the thickness of a bed may differ widely from the difference in altitude of the top and base of the bed; e.g., the basalt layer with top and base outcropping at 304 m. is actually several metres thick. Because of rather poor exposure several beds were missed and very few contacts between layers were seen.

Discrimination between flows and sills was mainly done along the shore section, where exposure is quite good.

Considerations of relief and exposure make it impractical to take a measured section in the strike direction in the lower

Fig. 1.6. The Musartût Unit viewed from Tunugdliarfik, just south of Sitdlisit

part of the Unit. A measured section was taken on the slope above Musartût on a 110° bearing.

Table 1.2

Musartût Measured Section

TOP

Metres	
420-545	Pale, banded quartzite-like sandstone. There is a soft, red shaly bed at the base, 1 - 2 m. thick.
310-420	Very well bedded sandstone in layers 1 - 2 cm. thick.
295-310	Poorly exposed, grey, medium-grained olivine basalt.
268-295	A few outcrops of dark red "tilestone".
258-268	Unexposed, save for a single outcrop of a trachytic dike.
230-258	Very poor exposure. At the base, a few metres of basalt are exposed. A trachyte dike, strike 85°, perhaps accompanied by faulting, crosses the basalt outcrop. There is a small outcrop of basalt at 254m.
212-230	Sandstone, with a conglomerate band. Crossed by a 70° trachyte dike, perhaps accompanied by faulting.
183-212	A few exposures of olivine basalt.

165-183	Fine, dark red, well bedded "tilestone", crossed by a narrow mylonite zone, strike 55°.
135-165	Red, trachytic dike, ca. 25 m. thick, strike ca. 75°, accompanied by faulting with downthrow to the south-east.
130-135	Dark red, bedded "tilestone" containing large quartz grains.
110-130	Conglomerate of large pebbles and cobbles, well rounded, all of sedimentary material. Upper part scarcely exposed.
88-110	Red syenite sill.
82- 88	Quartzite, poorly exposed.
17- 82	Basalt, similar to that of the layer below.
5- 17	Red sandstone with fine conglomerate.
0- 5	Effusive basalt --- the top of a layer about 35m. thick.

BASE

Some of the difficulties encountered in preparing an accurate description of the Musartût Unit will be evident from the above section. Locally, exposure is so poor that most of the boundaries have to be inferred by obervation of topographic features; thus, thicknesses allocated to certain layers may be far from correct. The possibility of errors introduced by faulting also arises. There is certainly some repetition caused by a fault accompanying the 25 m. trachyte dike. The southern downthrow is between 10 and 25 m.. The effect of this fault can be seen rather well from the fjord. Other faults of unknown magnitude may further confuse the section.

A considerable amount of information about the nature of individual layers in the Unit was obtained from the coastal section for about three and a half kilometres south-west of Sitdlisit. Further to the south-west scree-fans, developed below the Naujarssuit cliff, effectively obscure most of the coastal exposure.

A thin sill, not recorded in the inland exposures, outcrops on the shore about 700 m. south-west of Sitdlisit. It is about 6 - 8 m. thick and makes a total of four basaltic sills underlying the lowest effusive horizon of the Unit. The rock type of the sills is a fine-grained, dense, dark basalt and is of rather constant appearance except that it may become slightly vesicular toward the upper contacts. The upper contacts of the first, third and fourth sills are exposed and are demonstrably intrusive. The three thicker sills are usually columnar and the columns of the second sill have a peculiar splayed appearance toward the upper surface. Since columns tend to develop normal to the bounding surface, it would seem that the upper surface in this case was far from flat, i.e. the upper surface was more likely intrusive than extrusive. Besides the lithological similarity of all the four sheets, contrasting markedly with the paler, coarser, less compact nature of the known extrusives, there is a zone of haematite staining a metre or two thick in the sandstone immediately above each of the sheets, followed by an even greater thickness of bleached sandstone (Fig. 1.6). These pale sandstone bands, which are conspicuous from the fjord, only occur adjacent to intrusive rocks, viz. sills and dikes.

The two thick flows which outcrop on the raised beach at Musartût are of purple, grey or green olivine basalt and show numerous signs of effusive origin. The layers, which are each of the order of 50 m. thick, are built up of a series of thin lava streams or flow-units, some less than a metre thick. Distinction of flows and flow-units is based on criteria listed by R. L. Nichols (1936).

The conglomerate band which separates the two thick flows contains a few pebbles of basalt. This is the lowest horizon at which detrital basaltic material has been recorded, in spite of diligent search. Some basalt pebbles have also been observed in the thin sedimentary band which succeeds the Musartût flows.

The syenite layer is a deep red or purple rock of remarkably even texture, which weathers readily. It is principally made up of euhedral tablets of orthoclase about 5 mm. long, which show no signs of preferred orientation. The upper contact is well exposed where the overlying conglomerate forms a small headland (Fig. 1.8). The uppermost few metres of the syenite have a peculiar banded appearance and from even a few metres' distance may be mistaken for sandstone. Examination of the contact reveals no evidence of intrusion and it looks as if the conglomerate has been deposited on a syenite floor. There are no signs of metamorphism or assimilation of the conglomerate and the

Ro.

shows no sign of chilling. However, Poulsen reports that further inland the syenite can be seen to transgress into the conglomerate. "Halfway across the Peninsula, the sill is 3 - 5 m. thick. As it thins, grain size decreases. Here and there coarse-grained lumps of syenite can be seen embedded in the finer matrix. On the Sermilik side of the Peninsula, it is only 2 m. thick and suddenly transgresses into the overlying conglomerate where it is very inconspicuous as it resembles the sandstone matrix in colour and texture; also, it picks up xenoliths of quartzite and sandstone". (V. Poulsen, 1959). A point worthy of note is that no pebbles of syenite, nor indeed of any volcanic rock, could be found in the conglomerate.

The matrix of the conglomerate, where exposed on Tunugdliarfik shore, alternates between coarse sandstone and a fine red sediment apparently the same as the succeeding "tilestone".

The "tilestone" is a deep red to chocolate-coloured, hard, bedded sediment. It is composed of fine tuff with a variable admixture of sand and indurated with a carbonate cement. A peculiar, cavernous weathering, probably related to the carbonate content, is developed in bands parallel to the stratification. Higher up, "tilestone" alternates with medium-grained sandstone in layers 1 - 2 cm. thick. These sediments are followed by an effusive basalt of which only a few metres' thickness is exposed.

Rocks of the Musartût Unit are not exposed at the coast beyond this point. The nature of the succeeding beds is not very accurately known and the evidence of the Sitdlisit-Naujarssuit Traverse (Table 1.1) and the Musartût Section (Table 1.2) is somewhat conflicting. Poulsen's mapping, based on

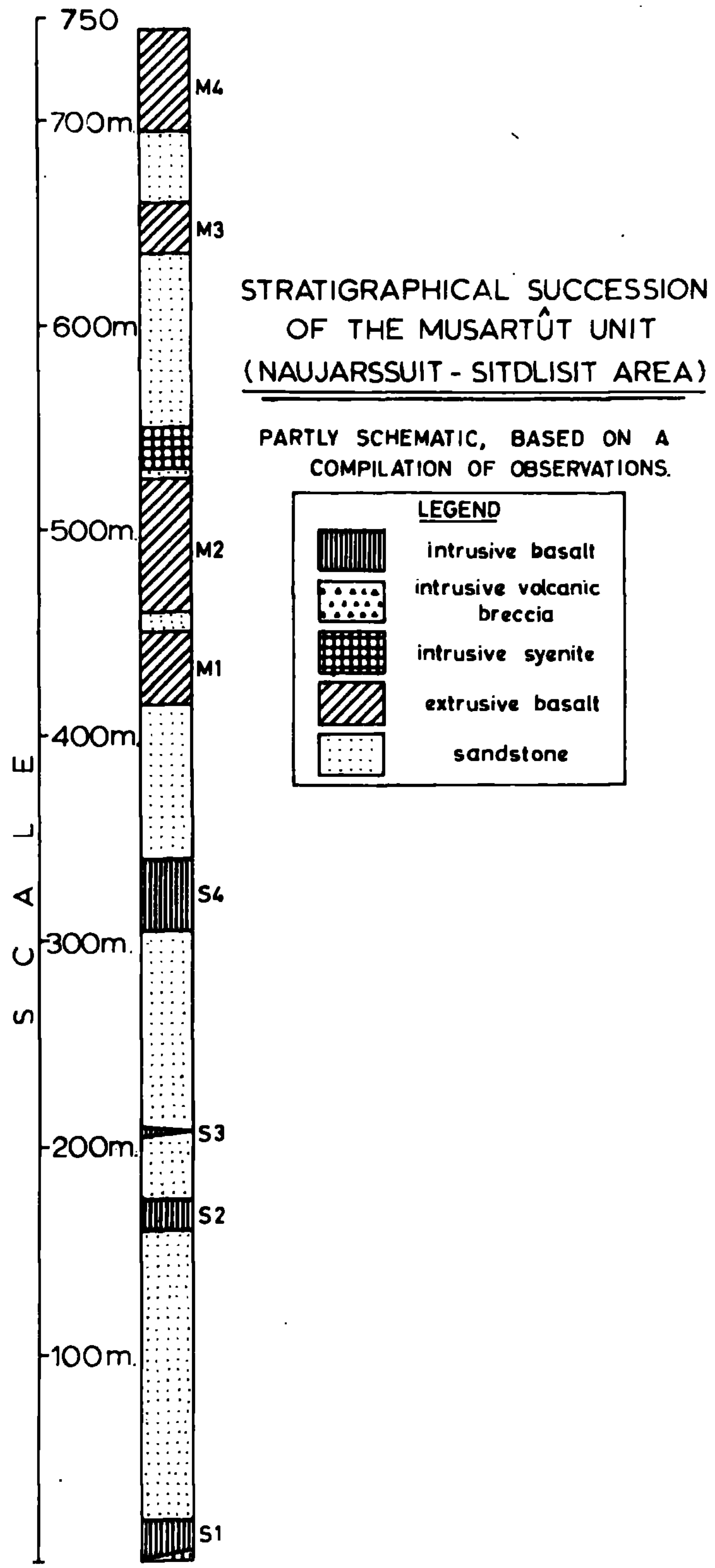

750
700m.
600m
500m.
400m.
300m.
200m.
100m.
SCALE
M4
M3
M2
M1
S4
S3
S2
S1
STRATIGRAPHICAL SUCCESSION OF THE MUSARTÛT UNIT (NAUJARSSUIT - SITDLISIT AREA)
PARTLY SCHEMATIC, BASED ON A COMPILATION OF OBSERVATIONS.
LEGEND
intrusive basalt
intrusive volcanic breccia
intrusive syenite
extrusive basalt
sandstone

Fig. 1.7.

excellent aerial photographs, shows two basalt layers, the lower 20 m. and the upper 30 m. thick, approximately. Though additional, minor volcanic layers may be developed locally, the map is believed effectively to represent the general case.

The map also shows that all the main stratigraphical layers persist right across the Peninsula without any notableechange in thickness or displacement by faulting; Poulsen (1959) remarks on a general tendency for the sedimentary strata gradually to increase in thickness westwards, and for the volcanic horizons to thin out in the same direction. The general strike of the Unit is 100^{o} with a dip of 10^{o} to the south. Thickness is calculated to be 745 m. on the southern side of the Peninsula.

3. NAUJARSSUIT SANDSTONE UNIT.

A thick sequence of almost uninterrupted sandstone forms a towering cliff above Tunugdliarfik from about 2 km. south-west of Musartût almost to Ipiutaq. The Unit is subdivided into a lower red sandstone division and an upper white sandstone division. The lower division is of a rather soft, red sandstone, while the upper is of a hard, white, quartzite-like rock. The resistance of the latter rock to erosion is responsible for the prominent Naujarssuit scarp. A thin, red, shaly bed which separates the two divisions may be a very fine tuff. It resembles certain haematite stained calcareous tuffs in the Qagssiarssuk Area. A basalt layer, ca. 15 m. thick, is exposed on the shore where scree is briefly absent, 4 km. south-west of Musartût. It is probably intercalated at the same horizon as the red, shaly bed. It is not known whether the basalt is intrusive or extrusive. Poulsen has recorded another thin basalt sheet less than 100 m. below the top of the Unit, which outcrops at the shore.

Poulsen (pers. Comm.) thinks it probable that much or all of the sandstone of this Unit has been water laid. No conglomerate horizons have been observed.

The total apparent thickness of the Unit cannot anywhere be determined by measurement of a single section. The apparent thickness of the lower division is known to be 110 m. from the Musartût Section. If the basalt intercalation is indeed at the same horizon as the red, shaly bed, strike-line construction shows the upper division to have an apparent thickness of 325 m.. The total apparent thickness of the Unit at the Tunugdliarfik side of the Peninsula is then about 435 m.. Apparent thickness of the whole Unit in the central part of the Peninsula, found by strike lines, is 420 m.. The base of the Unit strikes approximately east-west and dips south at ca. 10°.

4. IPIUTAQ VOLCANIC UNIT.

This predominantly effusive group outcrops in a kilometre-broad band stretching from the southern shore of Nunasarnaq north, via Tunuarmiut to Sermilik and thence along Sermilik coast to a point under Ilímaussaq. It also covers a sizeable area on the south-west facing dip slope south of Naujarssuit.

The dominant rock type is a grey or purple weathering olivine basalt. One variety is aphyric, the other contains stellate clusters of thin, white, laminar plagioclase phenocrysts. The name "star basalt", applied to the rock in the field, has been retained for general use. The rock is very distinctive in appearance and the stellate structures are still discernible after very heavy metamorphism.

The Unit has been built up of a succession of flows extruded in rapid succession in a sandy desert environment. Flow structures, including oxidised, corded surfaces and slaggy, scoriaceous tops are frequently seen. Cavities in the scoriaceous flow tops are often filled with windblown sand, a characteristic of many of the Permian lavas of Great Britain (e.g., Eyles, Simpson & MacGregor, 1949). Thin, sporadic intercalations of sandstone occur between flows and flow-units. Occasionally the sandstone is filled with detached scoriaceous blocks of lava which may make up as much as half of the rock. While such intimate mixtures of sand and scoriae are usually recorded directly above a visible flow, occasionally reaching a thickness of several metres, they sometimes occur isolated within a sandstone sequence. In such a case it may be assumed that lava fragments have fallen or been transported beyond the margin of some adjacent flow.

A few sandstone "dikes" have been seen, structures up to a metre in breadth, developed where fissures in the lava surface have filled with sand (Fig. 1.9). Sandstone crack-fillings are a related structure, much more frequently developed. Narrow cracks, usually less than a centimetre wide and nearly vertical, penetrate many of the flows to a depth of several metres and have likewise been filled with sand. The cracks

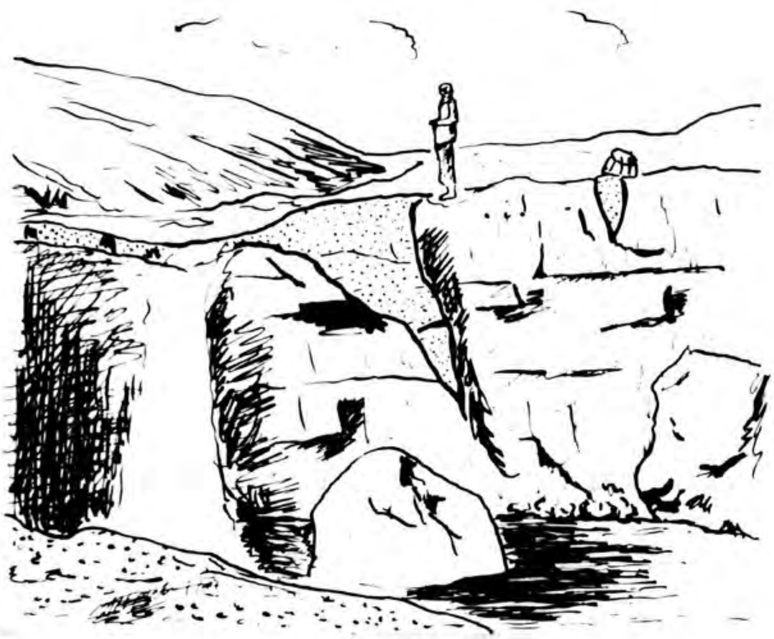


Fig.1.9.

Sandstone dikes in extrusive basalt 4 km. NNW of Ipiutaq

Fig. 1.10.

Nunasarnaq from the East. Well stratified lavas on top of the mountain are underlain by sandstone. Low sandstone islands of Qeqertat in the foreground.

may be tension cracks formed during cooling of the lava.

A measured section was taken up the side of Nunasarnaq in a due west direction, commencing from a point on the shore immediately west of the northernmost part of the Qeqertat islands. The section commences at a stratigraphical level about 50 m. above the base of the Unit. The underlying rock is star basalt, amygdaloidal, with occasional large, carbonate filled vesicles.

Table 1.3

Nunasarnaq Measured Section.

TOP

Metres	
538-680	Basalts of the Ilímaussaq Volcanic Unit, mostly "star" basalt. At a point near the base of this Unit, the line of section was abandoned and a traverse taken along the summit ridge of the mountain to the 680 m. highest point. The lithology of the basalts is quite constant. Epidote is often seen filling vesicles. A 60° fault with a throw of 20 m. to the south-east runs along the crest of Nunasarnaq. At 630 m. a 4 m. layer of pyroclastic material is exposed in a small, steep outcrop. Fine, bedded tuff of a bright, brick-red colour is overlain by a

coarser cross-bedded lapilli tuff containing bombs or blocks of basalt. Another tuff or volcanic grit is exposed at 650 m.. Neither of these clastic beds appears to persist far laterally; they may be localised intercalations preserved in hollows in the surface of the underlying lavas.

450-538	Cross-bedded sandstone with brick-red colour.
130-450	Pale sandstone, quartzite-like. This sandstone layer and the overlying sandstone layer belong to the Nunasarnaq Sandstone Unit.
120-130	Purple olivine basalt.
110-120	Not exposed.
95-110	Purple basalt.
77- 95	No exposure.
73- 77	Reddish basalt, of finer grain than the basalt below.
70- 73	Well bedded red sandstone, quartzite-like.
27- 70	Reddish "star" basalt. Contains a pod of basalt pegmatoid 25 cm. thick, ca. 1 m. long.
0- 27	Very compact dark basalt. Appearance contrasts with the more open porous nature of the underlying and overlying basalts.

BASE

It is probable that the Unit consists of four major flows. The 3 m. sandstone horizon which is exposed on the above section at 70 m. can be traced round the south side of Nunasarnaq to the coast. Other such major interbasaltic horizons have been recorded locally. Despite continual fluctuation in thickness and occasional suppression, thay have a persistence which distinguishes them from the minor sandstone intercalations between flow-units, and it is apparent that they mark significant periods during which extrusion has halted. (cf. R. L. Nichols, 1936). The lack of detrital volcanic material suggests that the interruption has not been sufficiently prolonged for the development of deep erosion.

Seen in cross-section on the Sermilik coastal cliff below Nasanguaq, the Unit appears as a thick, dark band of basalt with lensoid intercalations of pale red sandstone at two principal levels (Fig. 1). Due to very poor exposure, it has not been possible to effect correlation of the isolated outcrops of inter-basaltic sandstone horizons.

The base of the Unit strikes 105° and dips south at $7\frac{1}{2}^{\circ}$.

5. NUNASARNAQ SANDSTONE UNIT.

The dominantly effusive Ipiutaq Unit is followed by a thick sandstone sequence, interrupted in the north by a number of rather localised flows. The Unit outcrops around the lower part of Nunasarnaq and again on the north side of Tunuarmiut, continuing north to Nasanguaq and thence along the Sermilik coastal cliff to Narssaq Field, 17 km. to the south-west. A branch of the main outcrop extends up a valley south of Nasanguaq and two and a half kilometres south-west of Nasanguak a small inlier appears through the Ilímaussaq Volcanic Unit in the floor of a deeply cut corrie.

The unbroken succession of sandstone recorded in the Nunasarnaq measured section (above), is of strictly local application; on Nasanguaq, by contrast, three intercalated flows have been mapped (cf. Fig. 1.11). One of these can be traced south for ca. 6 km.. As a rule, the flows do not exceed 30 m. in thickness and they are often very much thinner; the thickness of an individual flow often fluctuates rapidly from place to place. The basalt of these flows is grey or red, usually aphyric but occasionally bearing sparse, blocky white phenocrysts of plagioclase up to ca. 2 cm. long. Mixtures of sand and scoriae above some of the basalt layers attest to their effusive origin.

Two thin basalt intercalations outcrop on the shore on the southern side of Nunasarnaq. The lower of these has a stepped lower surface which follows the cross-bedding in the underlying sandstone (Fig. 1.12 a). South-east of Nasanguak, the sandstone shows cross-bedding on an enormous scale; it is probably dune-bedding. While the regional dip is less than 10°, some of the flows show an abrupt termination to the west, with the base inclined at 30°. As in the structure recorded at the coast, the bases of the flows are parallel to the stratification of the underlying bedding sets. The trapezoid-shaped area of basalt on the southern flank of the 1070 m. hill immediately east of Nasanguak is about 200 m. long; the highest part is more

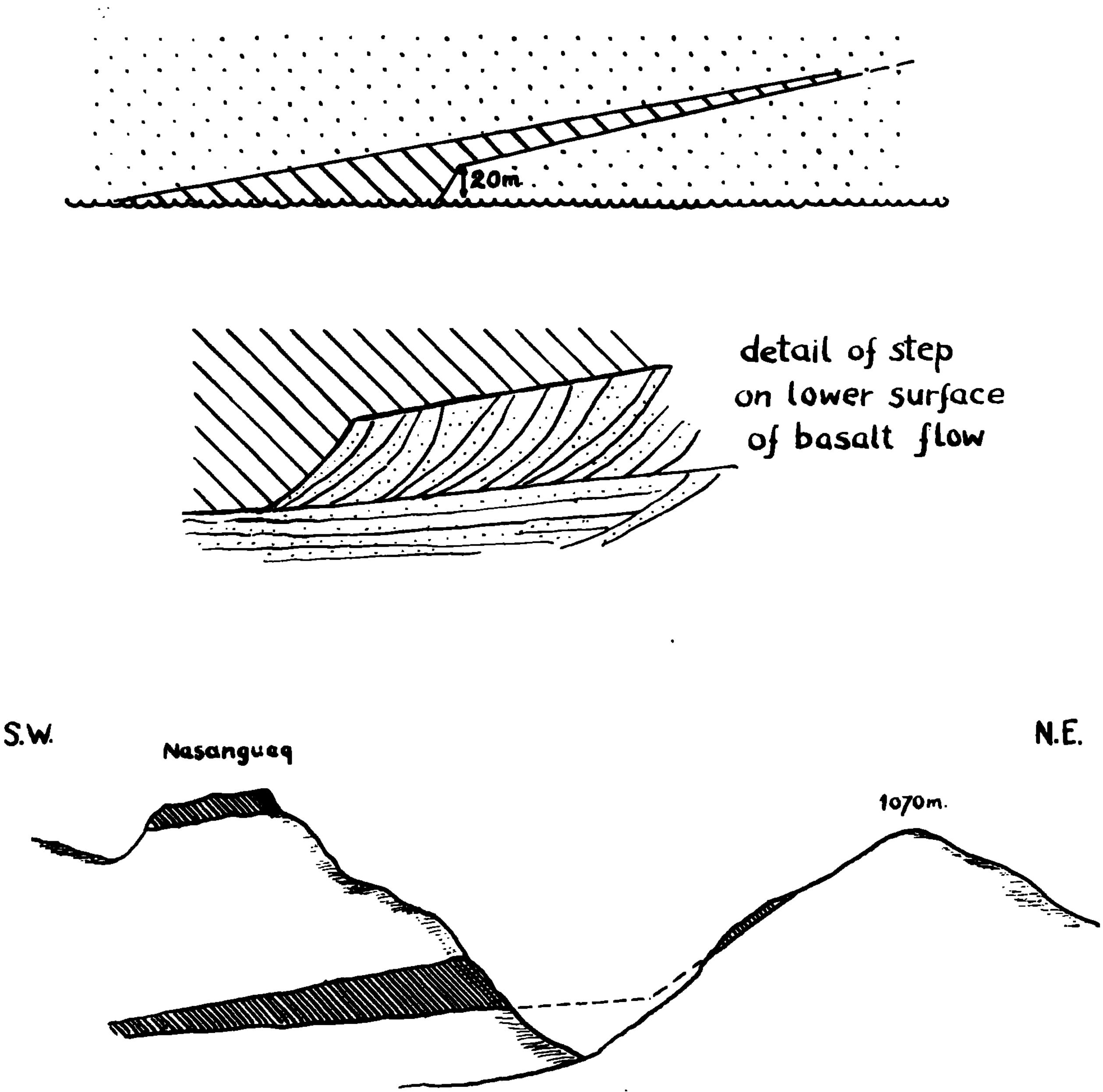


Fig.1.12. Examples of extrusive basalt banked up against dune bedding in sandstone. Above: flow on the south coast of Nunasarnaq; below: Nasanguaq from the south

than 50 m. above the lowest. The base is inclined at an angle of about 30° and is parallel to the stratification of the underlying sandstone. This outcrop is a relic of the steep termination of a flow, possibly an outlier of the basalt layer which lies ca. 200 m. to the west (Fig. 1.12 b). The effusive nature of these basalts has been definitely established and lack of displacement on adjacent geological boundaries shows that faulting is absent. The formation of these steep flow terminations must therefore date from the extrusion of the lava. It would appear that lava streams have banked up against the steep sides of sand dunes.

The only flow of monchiquite recorded in the entire region outcrops 1200 m. north of the northernmost extremity of Tunuarmiut at an altitude of 460 m.. The layer is 3 m. thick and has a well developed mixture of sand and scoriae at the upper surface. Lateral extent has been proved for 100 m.. The base of the Ilimaussaq Volcanic Unit is ca. 150 m. higher. The rock is soft and weathers readily with a mauve or greyish surface. It is seamed with veins of carbonate and irregular cavities several centimetres across are filled with coarse carbonate crystals; there are numerous small spherical vesicles, also carbonate-filled. When freshly broken the rock has a purple colour, with innumerable red flecks ca. 1 mm. in length which are pseudomorphs after olivine phenocrysts. On close examination the rock should not readily be confused with the olivine basalts.

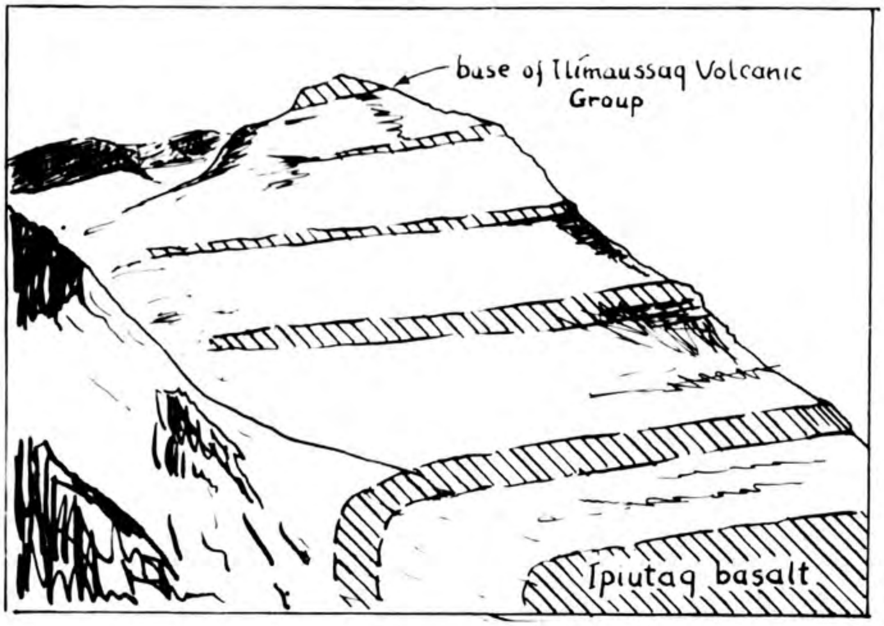


Fig.1.11. Nasanguaq from the north-east to show flows intercalated in the Nunasarnaq Sandstone Unit.

Fig.1.14. Hanging valley on the north-east side of SIlímaussaq, overlooking Sermilik. Well stratified basalts of the Ilímaussaq Volcanic Unit are underlain by the Nunasarnaq Sandstone Unit.

So far as is known, the Nunasarnaq Sandstone Unit is entirely free from conglomerate and no structure indicative of sub-aqueous sedimentation has been recorded.

The use of strike-lines in the country around Nunasarnaq is inadvisable in view of the presence of known and inferred faults, however inspection indicates that the base of the Unit strikes roughly east-west and dips south at a low angle. Strike and dip readings 110°/15°S and 105°/5°S were taken on the stratification in the lowest part of the sandstone near the shore. Just east of Nasanguaq the base of the Unit strikes 110° and dips south at 4°.

The greatest thickness of the Unit recorded is 408 m., from the Nunasarnaq measured section. Westwards, thickness decreases and on the coastal cliff below Nasanguaq the thickness is ca. 315m., including three layers of basalt with a combined thickness of 115 m.. On a measured section taken from the Steenstrup-Ilímaussaq col down to Sermilik, thickness is 290 m.. Of this, 32 m. is basalt, part of which is probably intrusive.

6. ILÍMAUSSAQ VOLCANIC UNIT.

On the extensive cliff exposures around the High Plateau and Nunasarnaq, the upper surface of the Nunasarnaq Sandstone Unit appears to be quite regular. The surface strikes between 90° and 105° and dips south at between 5° and 10°. It is overlain by a thick sequence of extrusives in which flow follows flow in orderly succession for hundreds of metres. Planes between the flows are emphasised by parallel lines of reddish scree in these sections, contrasting with the dark colour of the main lava pile and emphasising the remarkable regularity of the stratification (Fig. 1.14). It is apparent that many of the flows are of considerable lateral extent.

Ussing (1912, p. 84) and Wegmann (1938, p. 70) state that intrusive sheets occur in the Unit and imply that they are an important component of the succession; however, neither author provides any evidence in support of this conclusion. The present investigation, based on extensive field observation, has established that the succession is almost entirely of extrusives and that intrusive intercalations are virtually absent in the country east of Ilímaussaq.

Wegmann (1938, p. 70) implies that tuffs and "explosion products" should be "important guide-horizons in a more detailed study and mapping". Such, however, is not the case. Pyroclastics are of very rare occurrence in the Unit and nowhere do they form a well-defined, persistent horizon.

West of the Ilímaussaq Intrusive Complex, the Ilímaussaq Volcanic Unit has a maximum thickness of ca. 1000 m., subdivided as follows:

<u>TOP</u>

(c)	Porphyry Division	350 m.
(b)	Upper Basalt Division	290 m.
(a)	Lower Basalt Division	390 m.

<u>BASE</u>

Fig. 1.13. Ilimaussaq High Plateau; view north-east from Summit Plateau.

The lower two Divisions are formed of olivine basalt while the Porphyry Division contains porphyritic trachytes and porphyritic types with plagioclase phenocrysts, in addition to a considerable thickness of basalt.

As topographical height and height in the stratigraphical succession increase, so outcrop area and the proportion of accessible exposure decrease; also, the higher parts of the sequence are only preserved close to the nepheline-syenite intrusion and consequently are heavily metamorphosed. The field occurrence of the Porphyry Division illustrates these interrelated factors well; outcrop is mostly restricted to sheer cliff-faces and the severely limited accessible exposures mostly occur on steep, narrow ridges, while all of the rocks show the effects of thermal metamorphism.

Table 1.4

Measured Section from the South-West End of Tunuarmiut to the 1035 m. Hill.

This is the only available continuous measured section through the greater part of the Ilímaussaq Volcanic Unit. The line of section is nowhere more than 1 km. from the Ilímaussaq Intrusion; at higher levels it is within ca. 300 m. of the contact.

Examination of the succession above the Platy Basalt horizon was of a cursory nature, due to adverse weather conditions.

TOP

Metres	
850-1035	Fine grained, metamorphosed lavas. The highest rock of the succession is a vesicular, porphyritic trachyte. Clastic horizons, ca. 1 m. thick, are developed at 884 m., 904 m. and 938 m..
840- 850	Fine, blue-black rock with feldspar phenocrysts of irregular shape, up to 2.5 cm. in length.
770- 840	Aphyric basalt. Clastic layer at 816 m..
760- 770	Fine, blue-black rock with sparse tabular feldspar phenocrysts ca. 1 cm. across. Vesicular structures present.
680- 760	Aphyric basalt.
	The section is interrupted by faulting here. The top of the Platy Basalt outcrops again ca. 680 m..
598- 644	Platy Basalt; fine-grained with undirected fabric at the base, becoming coarse, with marked flow alignment of the phenocrysts toward the top.
436- 598	Fine aphyric basalt.
426- 436	Fine "star" basalt.
345- 426	Aphyric basalt.

340- 344 Clastic horizon. Small, angular fragments of basalt, seldom more than 1 cm. across, are set in a pale, quartzose, epidote-impregnated matrix. There is an intercalated layer of sandstone ca. 1 m. thick. The horizon is detrital, not pyroclastic. It appears to thin rapidly to the north-east.

210- 340 "Star" basalt.

0- 210 Sandstone of the Nunasarnaq Sandstone Unit.

BASE

(a) Lower Basalt Division. Many of the flows which make up this Division are feldsparphyric to some extent, the porphyritic character ranging from the occurrence of isolated, platy, plagioclase phenocrysts, through intermediate varieties with sporadic, irregular aggregations of a few phenocrysts, to the development of stellate aggregates. Where the agglomeration process has been most active, a high proportion of the plagioclase phenocr ysts have been drawn into clusters of regular shape, consisting of six or more platy phenocrysts ca. 0.5 cm. in length, radiating from a common focus. In the less aggregated varieties the phenocrysts may show a tendency toward flow alignment. Within some flow-units "stars" are concentrated toward the upper surface, while the base is nearly aphyric. This may have been achieved by flotation of the phenocryst clusters due to their having a specific gravity lower than that of the basaltic matrix (cf. Macdonald, 1936; p. 1076). If so, the lava must have been of very low viscosity to permit such segregation in a body only a metre or two thick.

In general, the lithology of the lowest part of the Division is closely similar to that of the Ipiutaq Volcanic Unit. Extensive, low-angle sections through the Division can be observed on the top of Nunasarnaq and over about 15 sq. km. of country north of Tunuarmiut between 600 m. and 900 m.. The Division is also represented on Nasanguaq and on the plateau area immediately to the west, where, in contrast to the rest of the High Plateau, exposure is locally excellent. Here, the erosion surface intersects the stratification of the lavas at a very low angle and intra- and inter-basaltic structures are very well displayed. Most of the flows are between 2 m. and 5 m. in thickness. The weathered colour of the main part of the flows is grey. At the top of each flow, there is a purple "flow-top", ranging in thickness from a few cms. to more than a metre. This layer has a porous, slaggy appearance in cross-section. Low angle sections, parallel to the stratification, reveal corded surfaces. As many as five successive corded surfaces have been recorded within 5 cm. vertical thickness, further testimony to the extremely fluid nature of the lava. The state of preservation of these structures is remarkably good and superficially they are identical with the products of some recent lava fields (cf. Fig. 1.15). The flow-tops are usually succeeded by a layer of sandstone from a few cms. up to 1 m. thick. Greater thicknesses are exceptional. Various structures involving basalt and

Fig.1.15. Flow structures in basalt of the Ilímaussaq Volcanic Unit.

Fig.1.16.Platy Basalt.

sandstone, such as were recorded in the Ipiutaq Unit, are common. Flow-units have followed in such rapid succession that sand intercalations have been very thin, seldom exceeding 1 - 2 cm.; often one flow-unit rests directly on top of another. Wisps of metamorphose sandstone occasionally seen in the interior of flows have resulted from the implication of blown sand in actively flowing lava.

The lowest third of the Division is formed almost entirely of "star" basalt, while the upper two thirds is largely aphyric. Above Tunuarmiut at 340 m. (Table 1.4), there appears to be a distinct stratigraphical boundary between the two sub-Divisions, marked by a clastic horizon. Exposure is particularly favourable at this locality; elsewhere a boundary between the lower "star" basalt and the upper aphyric variety has not been distinguished, although the relative thicknesses of the two types are known to be essentially constant, at least on this side of the Ilímaussaq Intrusion.

(b) Upper Basalt Division. The lowest flow of this Division is of Platy Basalt, a rock type of very distinctive appearance (cf. Fig. 1.16) and widespread development which makes an admirable marker horizon. The flow (or group of flows) has a thickness of 40 - 50 m. throughout the area and is frequently underlain by a persistent bed of sandstone mixed with scoriae which at times reaches a thickness of 2 - 3 m.. Platy Basalt is particularly well displayed on a part of the High Plateau about 3.5 km. south-west of Nasanguaq, where it outcrops over an area of about half a square kilometre.

The Platy Basalt is characterised by abundant large, thin tabular plagioclase phenocrysts (hence the name "Platy Basalt"). In the lower part of the horizon, the phenocrysts are relatively small, with a breadth of 1 - 2 cm. and a thickness of 1 - 2 mm. and in general the rock resembles an unusually coarse "star" basalt. Aggregation of the phenocrysts is not very pronounced; on the other hand, flow alignment is not seen. At progressively higher levels in the Basalt, the phenocrysts become larger, more abundant and begin to show arrangement parallel to the stratification of the sequence. The upper part of the Basalt is very coarse and many of the phenocrysts are 5 cm. or more across, with a thickness of 2 - 3 mm.. They are closely packed in a coarse granular matrix, the bulk of the phenocrysts often exceeding that of the groundmass. Flow allignment is developed to a high degree.

Highly vesicular, purple flow-tops are developed at two levels at least within the Platy Basalt, indicating the presence of three or more flows or flow-units. The contrast in size and concentration of phenocrysts between the lower and upper parts of the horizon are thus not due wholly to <u>in situ</u> segregation, but rather to the extrusion in successive pulses of different fractions of a magma in which segregation was already present. (cf. Walker, 1959, pp. 191 - 195).

The remainder of this Division is made up of Aphyric or sub-porphyritic basalt flows resembling those of the upper part of the preceding Division. An exceptional variety occurs about 100 m. below the top of the Division. This type, known as "Big Feldspar Basalt", is fundamentally a rather coarse olivine

Fig.1.17. Big Feldspar Basalt.

Fig.1.18. View of Ilimaussaq from Summit Plateau. Beyond the peak, to the left, is the plateau area of Kvanefjeld (with lake) and, beyond this, Narssaq Fjeld.

basalt of normal appearance, containing scattered coarse groups of platy plagioclase phenocrysts which sometimes show stellate arrangement. In addition, there are some large blocky phenocrysts of plagioclase which reach a length of 5 cm. or exceptionally as much as 15 cm.. These phenocrysts are sparsely and often unevenly distributed (Fig. 1.17). Some outcrops are devoid of the large blocky phenocrysts, while in others there may be a moderate concentration, particularly in the lower part of the bed; it is rare that the incidence of these phenocrysts exceeds one per thousand ccs. of matrix. It is mainly the blocky phenocrysts which distinguish this horizon from the basalts above and below. The uneven development of the phenocrysts, coupled with unfavourable conditions of relief and exposure, make it difficult to define the upper limit of the layer accurately. It is at least 10 m. thick. The base is often marked by an unusually thick layer of sand and scoriae. Outcrops of Big Feldspar Basalt shown on the accompanying map (Fig. 1) are all above 1100 m.; it is probable that the bed persists along the eastern flank of the Summit Plateau. Flows of this Division are typically 10 - 15 m. thick.

With some minor exceptions, rocks of the Upper Basalt Division are only preserved within 2 km. of the margin of the Ilímaussaq Intrusive Complex. In the field, the effects of contact metamorphism may not be very obvious, particularly in the finer lava varieties. As a rule, however, the rocks are more resistent to erosion (both chemical and mechanical) than those more remote from the Intrusion and under the hammer they are harder. In freshly broken specimens, abundant specks of iron ore are discernible.

The most widespread and readily noticeable secondary effect related to the Intrusion is the development of epidote. Bright green epidote forms a coating on joints and various stratigraphic planes, impregnates all the less compact layers and almost invariably replaces amygdales. The Platy Basalt is a favoured site of epidote mineralisation. In the least affected outcrops epidote occurs in vesicular cavities, often transgressing beyond the limits of the original amygdular filling; it also speckles the rest of the rock to some extent. In more advanced cases the whole rock may be replaced by epidote, although the platy texture is still preserved. Where the Platy Basalt outcrops on the western slope of Ilímaussaq at ca. 1000 m., a plane within the bed has been heavily mineralised and a massive epidote rock is developed. The epidote, which is finely granular, has numerous irregular cavities about 5 cm. across which contain plates of specular iron ore. The Big Feldspar Basalt is also very susceptible to epidote minerlisation. Occasionally the large feldspar phenocrysts are partly or wholly replaced by the mineral.

<u>(c) The Porphyry Division.</u> On the basis of the data available at present, it is impossible to describe the Porphyry Division other than in the most general terms. In the Ilímaussaq - Summit Plateau - 1035 m. hill region, the igneous rock types distinguished are as follows:

(i) Fine grained basalt, ranging from aphyric to finely feldsparphyric, with the occasional development of "star" structures. Rocks of this group are by far the most abundant.

(ii) "Sparse Porphyry", a fine-grained, pale grey or mauve rock, occasionally vesicular, with white tabular feldspar phenocrysts 1 - 2 cm. in length. As the name implies, the phenocrysts are sparsely distributed; often they show flow alignment. Flow-tops have been recognised in outcrops of this rock. On the basis of macroscopic examination the rock is suspected of being an alkaline type, possibly convergent with the trachyte (below).

(iii) "Fox Mountain Porphyry", a fine-grained grey or blue-black matrix, occasionally vesicular, containing thick tabular phenocrysts of white feldspar (plagioclase) from 1 - 5 cm. in length. The phenocrysts are frequently rather closely packed and usually show strong flow alignment (or igneous lamination --- it is not certain that the rock is extrusive).

(iv) Fine-grained, vesicular, pale mauve trachyte with blocky phenocrysts of alkali feldspar up to 5 mm. in length. (The rock has been identified in thin section). The concentration of phenocrysts appears to be highest in the most vesicular parts; elsewhere, the phenocrysts may be quite widely distributed. These lavas are extrusive.

Clastic horizons with an average thickness of ca. 50 cms. occur quite frequently in the Porphyry Division. The familiar sand and scoria type is uncommon; most of the beds are composed of angular to rounded fragments of volcanic rocks up to ca. 5 cm. in diameter. Since these horizons are invariably highly metamorphosed, it has not been possible to determine whether they are of pyroclastic or detrital origin, nor is it known whether deposition has been sub-aerial or sub-aqueous. Some of the beds have a conglomeratic appearance, others are breccia-like. These horizons have been particularly prone to contact metamorphic and metasomatic effects caused by the adjacent Ilímaussaq Intrusion. On the 1035 m. hill some of the clastic beds are impregnated with aegirine, while on Ilímaussaq crystals of epidote garnet quartz and haematite are developed. Ussing (1912, p. 89) records rocks with the latter type of alteration and considers them to be agglomeratic. It is doubted that this identification is really justified.

Ussing (1912, p. 89) writes "According to their macroscopic appearance the rocks of the volcanic series of Ilimausak may be classified provisionally as diabase, porphyrite, porphyry and quartz porphyry". Ussing's "volcanic series of Ilimausak" is the present Ilímaussaq Volcanic Unit. His "diabase" is equivalent to the aphyric basalts found in all three Divisions and his "porphyry" to the trachyte of the Porphyry Division. The term "porphyrite", as used by Ussing, embraces various extrusive and intrusive rocks of the region in which plagioclase phenocrysts are prominent, including "star" basalt and Platy Basalt. The inclusion of quartz porphyry (dikes) in this suite is undesirable since no extrusive equivalent has been recorded.

Table 1.5

Measured Section on the North-West side of Ilîmaussaq.

TOP

Metres	
1370-1390	Fine grey basalt.
1340-1370	Highly altered reddish, finely porphyritic types, probably trachytic.
1250-1340	Scree cover. There is a 60° mylonite zone at 1340 m.
1230-1250	Sparse Porphyry.
1190-1230	Grey aphyric basalt.
1185-1190	Not exposed.
1140-1185	Aphyric basalt. At 1180 m. a 2 m. layer of sand and scoriae is succeeded by 2 m. of a rock with the appearance of conglomerate.
1130-1140	Big Feldspar Basalt. The top is not exposed.
1080-1130	Basalt with some fine "star" structures.
1040-1080	Fine aphyric basalt.

ca. 1000-1040 Platy Basalt.

BASE

- - - - - - - - -

The Summit Plateau is one of the most poorly exposed parts of the entire region. Sparse Porphyry, interrupted by a number of clastic horizons, outcrops on the ridge which leads down to the glacier from the north-west corner of the Plateau. Thickness is of the order of 50 m.. There are a few scattered outcrops of fine grey basalt, occasionally with "star" structures, on the Plateau above 1300 m. and at a few points along the western edge overlooking the Glacier.

A layer of vesicular trachyte, probably not much more than 1 m. thick, outcrops ca. 100 m. north of the 1435 m. point. It is succeeded by a fine, grey, micro-porphyritic basalt with sparsely distributed plates or laths of plagioclase 1 - 2 mm. in length which show moderate flow-alignment.

The summit is intruded by a broad zone of dikes striking between 50° and 60°. Beyond, south of the summit, there is a conglomerate bed 5 m. thick. The pebbles are poorly to moderately rounded; most are between 2 cm. and 6 cm. in diameter. They are of fine grey basalt and pink vesicular trachyte. The groundmass appears to be a coarse sand or grit of the same materials. No quartz can be distinguished with the naked eye. The conglomerate is overlain by 10 m. of quartzose sandstone with very regular bedding. The bedding planes strike 40° and

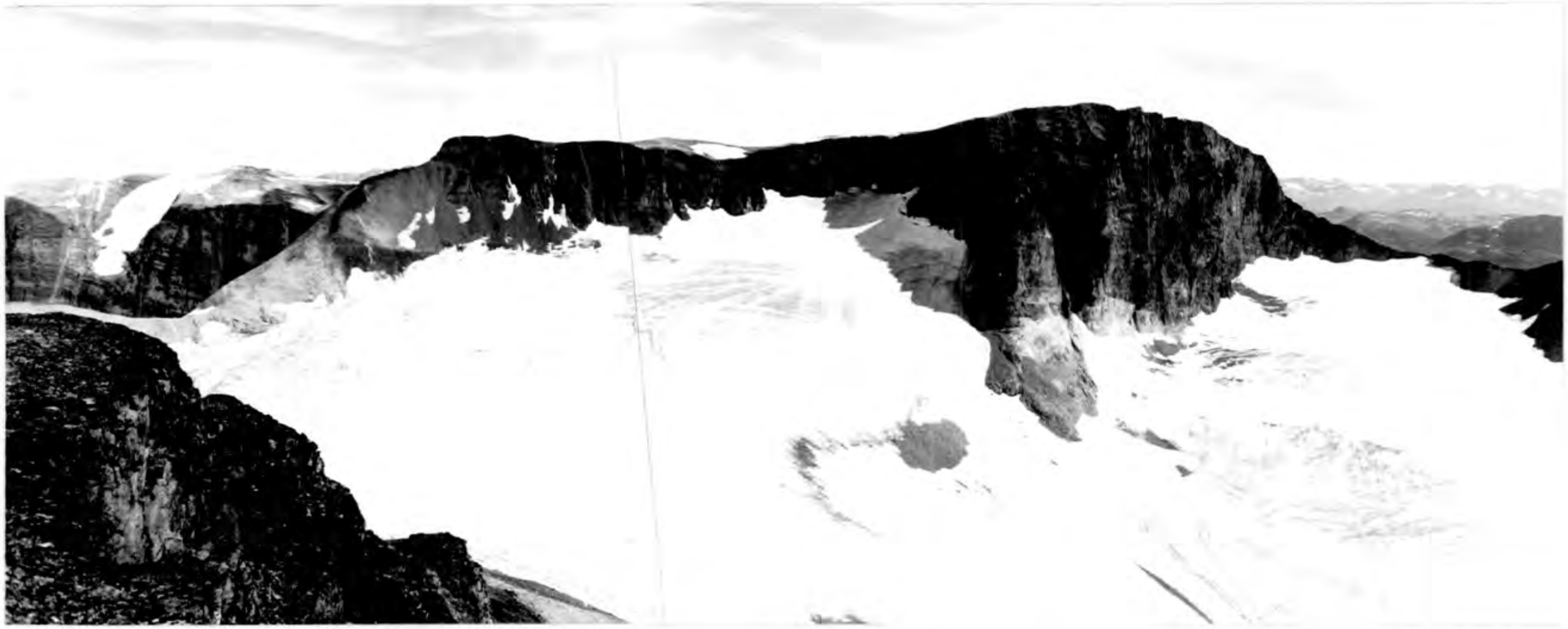


Fig. 1.19. Western face of Summit Plateau, viewed from Ilímaussaq. Naujaite of the Ilímaussaq Intrusive Complex (pale colour) intrudes the volcanics below the highest point.

dip south-east at 20°. This sediment is the highest stratigraphical horizon preserved in the Gardar Continental Series on the northern side of the Ilímaussaq Intrusion.

Several outcrops of Fox Mountain Porphyry have been recorded along the western face of the Summit Plateau, just above the glacier (Fig. 1.19). The highest of these, which occurs about half a kilometre south of the north-west corner of the Plateau, is at 1300 m.. There is another outcrop on the Summit Plateau-Nákâlâq ridge at 1250 m. and a similar rock occurs at the top of the southern face of Ilímaussaq at 1300 m.. All of these outcrops may be parts of a single horizon about 6 m. thick. At none of the above localities is there any evidence to show whether the Porphyry is intrusive or extrusive.

Because of their close proximity to the Intrusion, the rocks of the Porphyry Division are always strongly metamorphosed. The top of Ilímaussaq and the south-western part of the Summit Plateau are penetrated by veins and irregular dikes of alkali granite and in the latter locality hornfels is developed and the normal texture of the volcanic rocks is destroyed. Elsewhere, epidote is virtually omnipresent. Besides occurrences in the usual sites, e.g. vesicles and joints, there are also small irregular masses of the mineral within the volcanics, which do not appear to be replacive after any definite structure.

In vesicles, epidote is often accompanied by a younger growth of platy haematite crystals. Mineralisation of vesicles is particularly well seen on the south face of Ilímaussaq at 1150 m.. A highly vesicular lava, probably trachytic, occurs just below a clastic horizon and, like the fragmental rock, is bleached to a pale creamy colour. The vesicles are mostly lined with epidote and contain an inner layer of haematite crystals. The centre of some of the cavities is filled with carbonate in a few cases. Other secondary minerals found in this vicinity are quartz, small, honey-coloured crystals of ? garnet and a little purple fluorite.

(b) PETROGRAPHY.

1. Notes on Alteration.

None of the Gardar volcanic rocks examined is wholly fresh. Chloritisation and carbonatisation of the lavas on a moderate scale is quite widespread and in many cases may be due to deuteric alteration. There is a low-grade metamorphic aureole around the Ilímaussaq Intrusive complex and it is likely that the numerous basic and alkaline dikes (some of them more than 10 m. thick), which cut the lavas, have caused more localised alteration in other parts of the Peninsula. In many instances it is not very easy to distinguish apart the less extreme effects of weathering, deuteric or auto-alteration and hydrothermal alteration (cf. Harker, 1904, p. 41).

The great bulk of the thin-sections examined are of olivine basalt, composed principally of plagioclase, augite and olivine, with lesser amounts of iron ore. (The Porphyry Division of the Ilímaussaq Volcanic Unit has not yet been subjected to systematic petrographic investigation). Of the principal rock forming minerals, olivine has been the most susceptible to alteration and nowhere is it preserved. Where olivine is referred to in the text, it is understood that the mineral is now replaced by pseudomorphic material. Even in the freshest rocks (e.g. 39945 and 40240), where the pyroxene and feldspar are really well preserved, the olivine is completely pseudomorphed.

Alteration of the minerals has often been effected without apparent change in the outlines of the grains;

thus, the original textures of the rocks are often quite well preserved and it is then possible to make a reasonably accurate estimate of the original mineralogy. Primary iron ore is probably the most difficult mineral to distinguish with certainty, since the grains are readily confused with grains of secondary ore derived from the decomposition of the mafic silicates.

2. Systematic Petrography.

The following account is based on the examination of almost 100 thin sections. Modal, textural and mineralogical data obtained from 55 of the less altered basalts are set out in Table 1.6.

THE MUSARTÛT UNIT

The volcanic rocks which outcrop on the Musartût terraces and along the shore are often deeply weathered, and the primary minerals may be extensively replaced by secondary chlorite and calcite. Modal determinations are of moderate accuracy only, since grain boundaries are sometimes poorly defined. Pseudomorphs after olivine are less distinct than in basalts from the other Units, and it is possible that minor amounts of the mineral did occur in some of the rocks in which it is not recorded; however, it is unlikely that the proportion exceeded a few per cent. Alteration of both olivine and pyroxene resulted in the expulsion of iron ore which has sometimes been concentrated into large, subhedral grains. Generally, it is not possible to distinguish between this secondary ore and the primary type.

Monchiquite Sill. The monchiquite of the thin sill at Sitdlisit (39903) is exhaustively described in Chapter V.

Basaltic Sills. The four basic sills in the lower part of the Unit are numbered S1, S2, S3 and S4, upwards. The rock type of all the sills is quite similar in hand specimen. It is black (when freshly broken), fine grained, very compact apparently aphyric and quite distinct, as a rule, from the paler, coarser, less compact rocks of the extrusives.

Under the microscope, S1 and S2 appear almost identical (Fig. 1.20). The essential constituents are plagioclase and pyroxene; olivine is totally absent. The plagioclase forms a mesh of undirected, narrow laths, mostly of rather similar size, ranging in length from 0.2 - 0.5 mm. The pyroxene, where fresh, is pink. It is extensively altered to a pale green chlorite. Its form is subophitic. Specimen 39904, from near the base of S1, contains almost 10% iron ore by volume, as grains which are nearly idiomorphic. This specimen also contains a fraction of a percent of apatite, a mineral not recorded in the other sills. Rare, blocky phenocrysts of early plagioclase, a few millimetres in diameter, occur, containing parallel, vermiform inclusions of chlorite, presumably replacing a mafic mineral.

S2 is slightly vesicular in the upper part. The vesicles, which are mostly ca. 2 mm. in diameter, contain

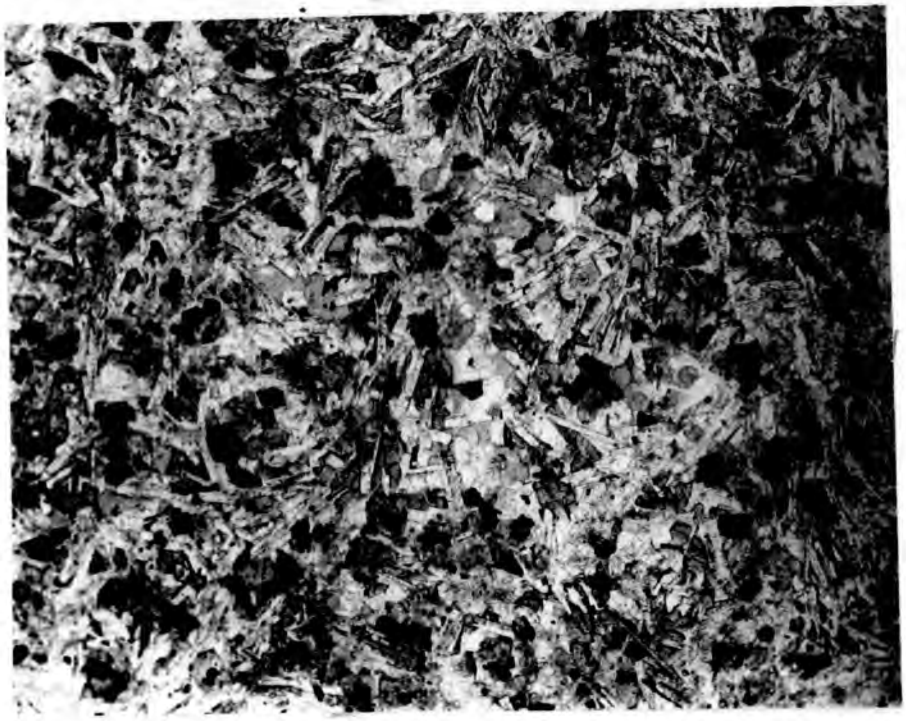
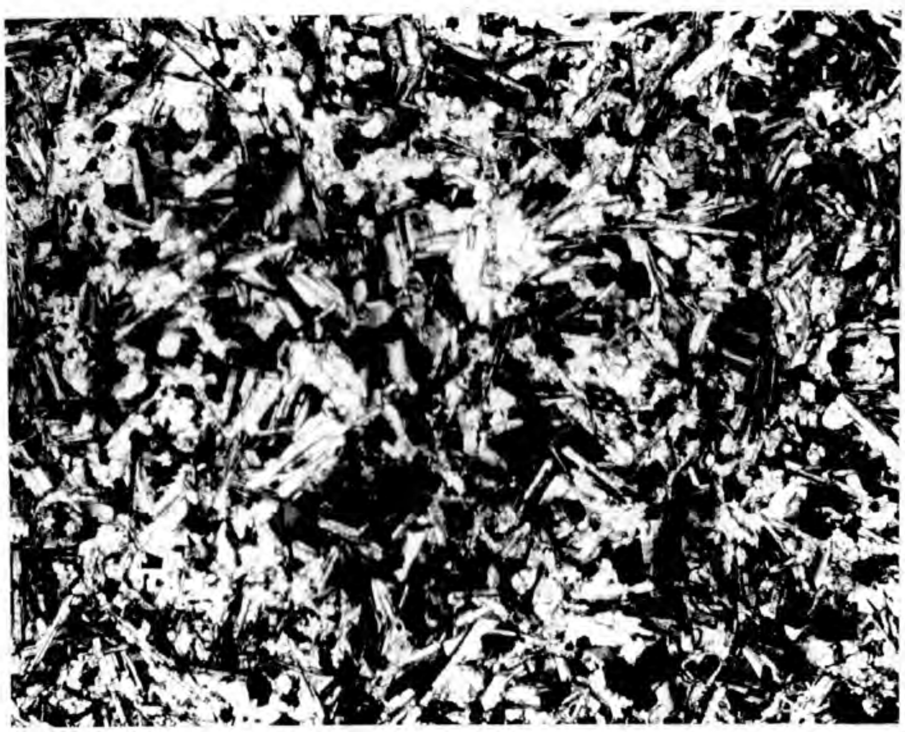


Fig. 1.20. Photomicrograph of 39904, fine grained, olivine-free, aphyric, intrusive basalt. X 40. Above: ordinary light, below: crossed polars.



concentric bands of fine chlorite and chalcedony. Occasionally the two minerals are irregularly disposed and the silica is spherulitic. The adjacent plagioclase laths show a moderate tendency to lie tangential to the vesicles.

In S3 the plagioclase grains are poorly sorted with regard to size, ranging from 0.5 mm. to 2.0 mm. in length. The rock is distinctly coarser than that of the other sills. The pyroxene, now altered, was subophitic in habit and there is no certain sign of olivine.

S4 contains small, sparse groups of lath-shaped plagioclase phenocrysts 1 - 3 mm. long, sometimes accompanied by olivine pseudomorphs up to 1 mm. in diameter. The plagioclase in the groundmass is similar in all respects to that of S1 and S2. The pyroxene, however, occurs as isolated, ophitic grains up to 4 mm. in diameter. Olivine has been present as small groundmass grains. The pseudomorphs are not readily identified, but do not constitute more than a few percent of the rock modally.

In general, the basalt of these sills is aphyric and olivine-free. Groundmass augite and plagioclase are present in almost equal amounts.

<u>Extrusive Basalt Layers</u>. The basalt horizons which overlie the sills are number M1, M2, M3 and M4.

Sections of M1 show an aphyric, olivine-free rock, consisting of undirected plagioclase laths with good size sorting 0.5 - 1.0 mm. long, and subophitic pyroxene. In hand specimen, the rock resembles the basalt of the sills.

Two varieties of basalt are represented by specimens from M2. One kind is olivine bearing, with plagioclase laths 0.5 - 1.0 mm. long and subophitic pyroxene; specimen 39908 contains 10% olivine (pseudomorphed), most of it as groundmass grains, though a few rounded grains ca. 1.0 m m. in diameter also occur. The other kind of basalt, as exemplified by specimen 39910, is petrographically distinct from other basalts in the Unit. It is fine grained and sparsely porphyritic with lath-shaped or platy phenocrysts of plagioclase up to 2 mm. long. The feldspar microlites are only ca. 0.2 mm. in length. The pyroxene grains occur as isolated, subophitic individuals 2 mm. in diameter. No sign of olivine can be distinguished.

M3 is of aphyric basalt with subophitic pyroxene and is probably olivine-free (e.g. 39921). M4, by contrast, may contain up to 20% of intergranular olivine. Texturally, this rock has closer affinity with the aphyric, olivine basalts of the Ipiutaq Volcanic Unit.

In view of the altered nature of some of the specimens and the limited material available (10 thin-sections only), comment on the petrography of the Musartût effusives as a group is limited to the following observations:

(i) The flows are all essentially aphyric.

(ii) Pyroxene seems to be generally subophitic.

(iii) Both olivine-bearing and olivine-free varieties occur.

<u>Syenite Sill</u>. This deep red rock is made up of thick, euhedral tablets of alkali feldspar with monoclinic symmetry and length : breadth : thickness approximately in the ratio 4 : 2 : 1. Average length is about 5 mm. While large parts of the grains are seemingly optically homogeneous, a fine, lamellar perthitic structure can be distinguished locally at higher magnifications, particularly in the central portions. There are also irregular turbid patches whose cause is unknown. The following 2V values were obtained from various feldspar grains: 69°, 70°, 72°, 72½° and 75°. The feldspar crystals are frequently penetrated by euhedral pseudomorphs after a prismatic, monoclinic mineral, probably pyroxene, now replaced by very fine, colourless chlorite and a narrow rim of iron ore. A few slender prisms of apatite also pierce the feldspars. The interstices between the tablets are occupied by pale green chlorite, iron ore and carbonate, singly, and in various combinations. Presumably one or more mafic silicate originally occupied these sites; the identity of the mineral(s) is unknown.

Investigation of the feldspar of specimen 39911 by X-ray diffraction revealed the presence of a monoclinic potash phase and an albitic phase. Chemical analysis of the rock for alkalies gave the following result:

	wt.%
Na_2O	2.30
K_2O	9.40

Assuming that all the alkalies are concentrated in the feldspar, the mineral will contain 74% of the Or molecule.

The X-ray, optical and chemical characteristics of the feldspar indicate that it is an orthoclase. The rather high 2V may be due to the presence of a small amount of microcline; a slight, irregular shoulder on the low angle side of the (131) monoclinic potash feldspar peak of the diffractometer chart tends to support this hypothesis.

"Tilestone". The nature of this rock varies considerably, depending on the size and proportion of the clastic fragments, and the secondary redistribution of the carbonate in the matrix. The colour ranges from brick red to deep, chocolate brown. Angular grains, mainly of quartz, constitute up to one third of the rock. Grains which exceed 0.5 mm. are relatively rare and most are 0.2 mm. or less in diameter. By far the greater proportion of the clastic fragments are of quartz, notable angular and sharp-edged. Among the largest grains are some of quartz showing secondary overgrowth of silica and a number of grains of micfocline. Rounded grains of carbonate are not uncommon and may be either clastic or secondary.

The matrix is of very fine grained carbonate, often so full of tiny ore granules as to be semi-opaque; the colour of the rock is ascribed to these. An exceedingly fine fraction of clastic quartz is distributed in this base and there are occasional minute grains of a colourless flaky mineral of moderate birefringence. Within the fine-grained groundmass the clastic grains are assembled in wispy concentrations of irregular development. The ore pigmentation is also developed irregularly and quite extensive patches of groundmass are of clear, crystalline carbonate. Minor veinlets of carbonate are developed in parts of the rock. The "tilestone" is believed to be a calcareous tuff. The excellent stratification of the rock and its occurrence interbedded with conglomerate point to its having been deposited under water.

NAUJARSSUIT SANDSTONE UNIT.

Volcanic horizons within this Unit are represented by two specimens. 39935 is from the basalt layer which coincides with the important lithological change which occurs about one quarter way up the Unit. Despite very heavy alteration, it is unmistakably an aphyric variety, even grained, with plagioclase laths ca. 1 mm. in length. The rock shows no sign of olivine, the pyroxene was probably subophitic.

44431, collected by V. Poulsen from near the top of the Unit, is also heavily altered. Pseudomorphs after olivine are very numerous and the mineral must have made up 15 - 20% of the rock. The size and arrangement of the plagioclase grains recall 39935. The habit of the pyroxene cannot be determined.

IPIUTAQ VOLCANIC UNIT.

The flows of this Unit are basically of rather constant petrography. The chief variant is the incidence of plagioclase phenocrysts and there is a range of varieties from aphyric basalt to "star" basalt. 39940 (Fig. 1.21) is an unusually well preserved example of the aphyric type. More than half of the pyroxene remains unaltered. It is pink, and shows a subophitic relationship toward the feldspar laths. Alteration is to a fine-grained aggregate of pale green chlorite. Pseudomorphs after olivine, which make up approximately 15% of the rock, are particularly clear. Each grain is replaced by a single crystal of chlorite which has the following properties: pleochroic from colourless to pale green, birefringence very low, slightly anomalous, R.I.= 1.58, 2V very small. The curved cracks of the former olivine are marked by lines of iron ore. The plagioclase has a moderate overall sprinkling of sericite and other fine alteration products. The laths average ca. 1 mm. in length. A number of subhedral to anhedral grains of iron ore are judged to be of primary crystallisation.

In other specimens of the Ipiutaq lavas, platy phenocrysts of plagioclase, seldom exceeding 5 mm. in length, occur as irregular clusters (e.g. 39915), as tiny, well-shaped stars made up of phenocrysts only about twice the average size of the groundmass laths (e.g. 39942) or as large, coarse stars in a vesicular variety with a very open texture (40234). Many of the lavas are vesicular; the

Fig. 1. 21. Photomicrograph of 39940. Aphyric olivine basalt. X 40. Above: ordinary light, below: crossed polars.

vesicles contain carbonate, sometimes enclosed in a peripheral zone of chlorite. In all the specimens examined, pseudomorphed olivine is abundant as groundmass grains. Where the habit of the augite could be determined, it was invariably interstitial. Plagioclase is much more abundant than augite; in 39940 the ratio plagioclase : augite is approximately 3 : 1. Specimen 40235, which contains more than 20% of olivine, is taken from the basal part of the lowest flow in the Unit. The enrichment in olivine may be due to gravitational control.

NUNASARNAQ SANDSTONE UNIT.

Up to three successive intercalations of basalt may be found in the Unit at any one place; however, the very localised nature of the flows discourages lateral correlation. A distinction of lower, middle and upper flows has been made; while this division may not be valid stratigraphically, the flows included in the upper or lower divisions are more likely to be younger or older respectively. Thus, the classification helps to illustrate the overall change in the petrographic characters of the lava with time.

The basalt of the lower group of flows does not differ appreciably from the aphyric varieties of the Ipiutaq Unit. Olivine is present in all and the pyroxene is subophitic.

The upper flows are of a different textural type. The plagioclase laths are much smaller (0.2 - 0.4 mm., as against 1.0 mm.), while augite, where preserved, is ophitic, forming grains up to 4 mm. in diameter. Abundant, rounded pseudomorphs after olivine are scattered through the rock, forming 10 - 15% of the basalt modally. Platy feldspar phenocrysts, such as are found in the Ipiutaq and Ilímaussaq basalts, are wholly absent. Instead, phenocrysts of plagioclase with a thick, tabular habit, 1 - 2 cm. long, are sparsely scattered throughout some of the higher flows. These phenocrysts, in contrast to the groundmass laths, which are often quite fresh and clear, have been sericitised to such an extent that practically no clear feldspar material remains and structures such as twinning and zoning are obliterated. A line of tiny, elongate inclusions, probably of altered mafic minerals, is arranged parallel to, and a little way in from, the margin. These grains contrast markedly with the platy phenocrysts found in other lavas of the region and appear to be foreign to their present environment.

Flows on the south side of Nunasarnaq are within two kilometres of the nepheline syenite intrusions and are strongly altered (e.g. 39966, 39958). The plagioclase has been altered to sericite, albite, etc., while much of the pyroxene has been replaced by a colourless amphibole. The pseudomorphs after olivine are now of ore and epidote.

The rock of the monchiquite flow (e.g. 39959) is very similar to the Sitdlisit monchiquite (39903) both as regards the identifiable primary minerals and the degree of alteration. Rather more pyroxene is preserved, however, some as prismatic phenocrysts up to 2 mm. in length. In the groundmass, there are corroded needles and tiny prisms of similar pyroxene; the majority of the grains have a length in the range 0.1 - 0.25 mm., however, all sizes from this range up to that of the nominal phenocrysts are represented. Where fresh, the mineral has a pale yellow colour. In parts of the rock pyroxene may occupy nearly 50% of the groundmass. The vesicles are filled with fine grained carbonate and there is much carbonate in the groundmass. It is suspected that most of the carbonate in this rock may be primary.

ILÍMAUSSAQ VOLCANIC UNIT.

(a) Lower Basalt Division. Most of the specimens listed in Table 1 are from the north-eastern end of Nunasarnaq and the basalt plateau 1 km. north-west of the inner end of Tunuarmiut. This material is relatively unmetamorphosed and forms a useful standard with which the more altered rocks can be compared.

(i) "Star" Basalt Group.

There is a great contrast in grain size between the groundmass and phenocrysts in these "star" basalts. Typically, the plagioclase microlites are only 0.1 - 0.25 mm in length, show good size-sorting and form an undirected mesh in which are set small rounded granules of olivine, fully ophitic grains of pink pyroxene with a maximum dimension of ca. 1 mm. and perhaps a little primary ore. Specimens 39945 (Fig. 1.22), 39960 and 39963 are well preserved examples. 39947 is an unusual variant in which the pyroxene is intergranular and the plagioclase microlites

Fig. 1.22. Photomicrograph of 39945, "star" basalt. x 40. Above: ordinary light, below: crossed polars.

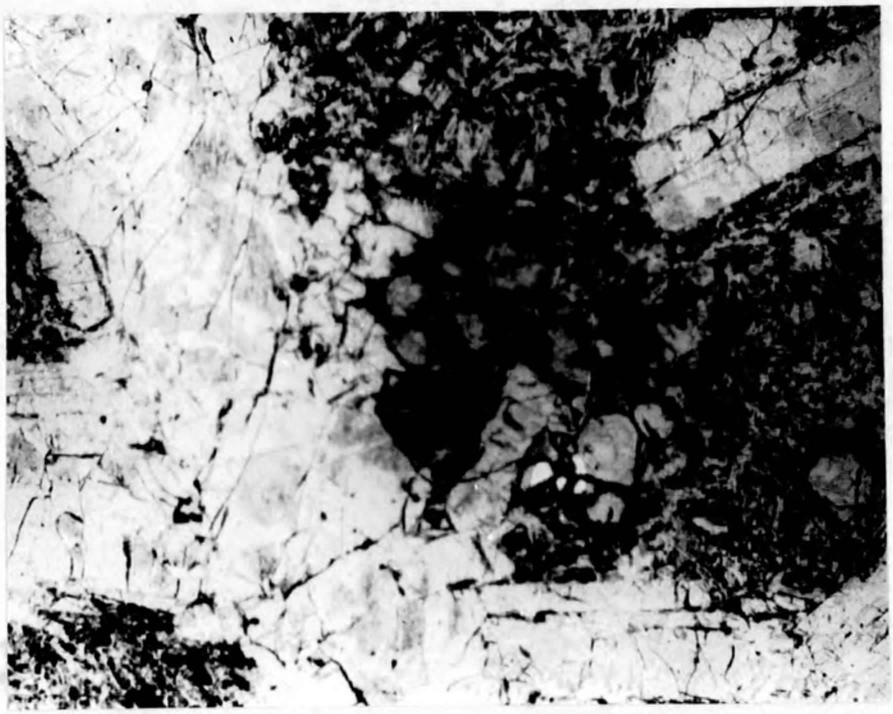


Fig.1.23. Photomicrograph of 40258, "star"basalt, x 40, in ordinary light, to show group of large olivine grains at focus of stellate cluster of plagioclase phenocrysts.

have a moderate fluxional arrangement.

The plagioclase phenocrysts are broad laths or narrow plates, mostly under 1 cm. in length, twinned on the albite, Carlsbad and occasionally the pericline laws. These phenocrysts tend to be arranged into star-shaped clusters (cf. the Ipiutaq lavas, above). Rounded grains of olivine up to 2 mm. in diameter are scattered through the groundmass. While in most specimens groundmass grains and phenocrysts of olivine contrast markedly in size (e.g. 39945), in some cases (e.g. 39963) there is a whole range of sizes and it is not possible to make a demarcation between groundmass grains and phenocrysts. Large olivine grains are occasionally concentrated at the foci of plagioclase phenocryst groups in botryoidal clusters of considerable extent (e.g. 40258, Fig. 1.23).

(ii) Aphyric Basalt Group.

Rocks of this group are very similar to aphyric lavas of the Ipiutaq Volcanic Unit (see above). The plagioclase laths are undirected, the pyroxene is subophitic and there is granular groundmass olivine. A series of specimens was taken through the group on the "Tunuarmiut - 1035 m. Hill" measured section (Table 1.4) (39971, 39972, 39974, 39975 and 39976). Despite alteration, it is apparent that the whole group of lavas has been of essentially constant composition. The chief variable is grain size; the average length of plagioclase laths ranges from 0.4 - 0.8 mm. in various specimens. The percentage of modal olivine in specimens 39952, 39953 and 39974 (Table 1.6) is probably ca. 5% above the average value.

(b) Upper Basalt Division.

The Platy Basalt may be considered an unusually coarse variant of "star" basalt. At the base of the layer, the rock appears to be essentially identical with "star" basalt (39978). In the coarser, higher facies, the large, platy phenocrysts of plagioclase tend to mask the identity of the rock, but the matrix, though coarser, with plagioclase laths 1 mm. in length, appears to be of similar composition (39979). Some ophitic or subophitic pyroxene remains in 61673, a variety of intermediate grain size. So far as is known, phenocrysts of olivine do not exceed ca. 2 mm. in diameter nor does the mineral show any tendency toward aggregation (ctr. the botryoidal clusters in the "star" basalt, above). In particular, there is no indication of a coarse, phenocrystalline development of the mineral when accompanying the large plagioclase plates.

Specimens collected from higher parts of the Division on the "Tunuarmiut - 1035 m. Hill" section (Table 1.4) are nearly all of aphyric olivine basalts similar to those of the Lower Basalt Division, but on the whole rather coarser; this is supported by field observation. 39980 from just above the Platy Basalt horizon is an exception. This rock is unusually well preserved, perhaps on account of its unusually fine-grained and compact nature. The plagioclase laths are 0.1 - 0.2 mm. in length, show remarkably good size sorting and a rather strong fluxional arrangement. Sub-ophitic grains of pink pyroxene ca. 0.5 mm. in diameter are preserved and there are tiny pseudomorphed olivine granules in the feldspar mesh, ca. 0.01 mm. in diameter. There are a few scattered lath-shaped phenocrysts of plagioclase up to ca. 1 mm. in length, containing broad patches of sericitisation (the microlites are quite clear and unaltered). Three such phenocrysts have been observed grouped together with some large grains of olivine (diameter 0.3 mm.) in close association. This rock type is undoubtedly a variety of "star" basalt.

The succeeding basalts, typified by 39981 and 39984 are much coarser. The plagioclase laths, which show poor size sorting and no tendency toward a directed arrangement, are frequently 1 mm. in length. Pyroxene has been sub-ophitic, olivine has been coarse and abundant.

Big Feldspar Basalt is represented by specimens from the northern edge of the Glacier, 40275 and 40276. In thin section the initial impression is that the plagioclase laths show very poor size sorting; however, although the altered nature of the rocks does not permit certainty, there is a suggestion of two distinct size groups of laths. In one group, average length is ca. 0.2 mm. and size sorting is good; in the other group laths are of all sizes from ca. 0.25 mm. to 2 mm. and occasionally larger. The latter group probably grades into the coarse, platy phenocrysts observed in the field at some localities. The large, blocky feldspar crystals of basic plagioclase may be considered as belonging to yet another category of plagioclase grains. Augite appears to have been ophitic and olivine has been an abundant constituent in grains up to ca. 1 mm. in diameter. This rock would appear to have close affinities with "star" basalt.

The petrography of the Porphyry Division has not yet been investigated.

Table 1.6. Modal, Textural and Mineralogical Data of Gardar Basalts.

Horizon	Specimen number	Porphyritic character	Modal Data						Augite ratio	Augite texture	Plagioclase composition (% An).		Augite optics	
			Phenocrysts		Groundmass									
			Plag.	Ol.	Plag.	Augite	Ol.	Ore			Phenocrysts	Microlites	2V (deg.)	β R.I.
S1	39904	Aphyr.	-	-	47.3	42.1	-	9.8	47.1	SO				
S1	39929	Aphyr.	-	-	+	+	-			SO				
S2	39905	Aphyr.	-	-	51.1	48.9	-		48.9	SO	62-50	62-50		
S2	39936	Aphyr.	-	-	+	+	?			0		54	50	1.710
S2	39937	Aphyr.	-	-	51.4	48.6	-		48.6	SO				
S3	39932	Aphyr.	-	-	+	+	-			?		56		
S3	39933	Aphyr.	-	-	+	+	-			?		59-49		
S4	39906	SP	+	+	+	+	+			0	70-66	60-50		
S4	39938	SP	+	+	49.3	48.3	+	2.4	49.5	0	65	65		1.710
M1	39907	Aphyr.	-	-	+	+	-			SO		57		
M1	39916	Aphyr.	-	-	58.3	40.2	-		40.8	SO			51	
M2	39908	SP	-	+	+	+	20			SO				
M2	39909	Aphyr.	-	-	+	+	-			SO		54	53½	
M2	39910	SP	-	-	+	+	-			0	68	55	51	1.705
M2	39917	Aphyr.	-	-	+	+	+			SO			50½	1.710
M3	39913	Aphyr.	-	-	+	+	-			?		57		
M3	39921	Aphyr.	-	-	+	+	-			SO			50½	1.710
M3 or M4	39924	Aphyr.	-	-	53.1	26.9	20		33.6	SO				
M4	39914	Aphyr.	-	-	+	+	+			?				
Nj	39935	Aphyr.	-	-	+	+	-			SO		58		
Nj	44431	Aphyr.	-	-	+	+	+			SO				
Ip	40235	Aphyr.	-	+	64.5	9.0	24.4	3.8	13.8	SO				
Ip	39915	Star	+	-	60.8	23.7	15.4		28.1	SO		56		
Ip	40234	Star	+	-	+	+	+			SO				
Ip	40233	Aphyr.	-	-	+	+	+			SO				
Ip	39940	Aphyr.	-	-	59.8	21.1	14.7	4.5	26.1	SO			52½	
Ip	x39941	Aphyr.	-	-	72.6	10.1	14.2	0.3	12.2	SO			52	
Ip	40239	Star	+	-	+	+	+			SO				
Ip	40240	Aphyr.	-	-	63.8	13.3	17.7		17.3	SO				
Ip	39942	SP	+	-	59.3	18.3	20.0		23.6	SO			54	
Ip	39954	Aphyr.	-	-	58.7	28.5	13.1		30.6	SO				
N	39966	Aphyr.	-	-	+	+	+			SO				
N	39967	Aphyr.	-	-	+	+	+			SO				
N	39334	Aphyr.	-	-	+	+	+			SO				
N	39958	SB	+	-	+	+	+			?				
N	39319	Aphyr.	-	-	+	+	+			SO				1.710
N	x39340	SB	+	-	+	+	+			0				
N	39376	SB	+	-	+	+	+			?				
N	39341	Aphyr.	-	-	+	+	+			0			52	
N	39332	Aphyr.	-	-	+	+	+			0				
LB	39943	Star	+	+	+	+	+			0	61			
LB	x39944	Star	23.7	+	39.5	21.3	15.7		35.0	0	72	60	52	1.710+
LB	39945	Star	14.2	+	46.7	22.6	16.4		32.6	0	70	60	52	1.710
LB	39946	Star	+	+	+	+	+			0				
LB	39947	Star	16.1	8.5	47.6	19.6	+		27.17	IG			52	
LB	39960	Star	17.4	+	38.2	19.7	+		34.0	0	71	57-47		1.710
LB	39961	Star	+	+	+	+	+			SO	70	61		
LB	39962	Star	+	+	+	+	+			0				
LB	39964	Star	+	+	+	+	+			0		62		
LB	39952	Aphyr.	-	-	58.8	19.0	22.1		24.4	SO		60	51	ca.1.71
LB	39953	Aphyr.	-	-	55.2	24.7	20.1		30.9	SO				
LB	39972	Aphyr.	-	-	56.6	24.6	18.6		30.3	SO		59-48		
LB	39974	SP	+	-	+	+	+			SO				
UB	39980	Aphyr.	-	-	64.2	20.5	15.4		24.2	SO				
UB	39981	Aphyr.	-	-	62.7	23.0	14.2		26.8	SO				

Explanation of Table 1.6

Horizons:

S1-S4 = sills of the Musartut Unit

M1-M4 = flows of the Musartut Unit

Nj = basalt horizons of the Naujarssuit Sandstone Unit.

Ip = flows of the Ipiutaq Volcanic Unit

N = flows of the Nunasarnaq Sandstone Unit

LB = Lower Basalt Division, Ilímaussaq Volcanic Unit

UB = Upper Basalt Division, Ilímaussaq Volcanic Unit

Porphyritic character (with respect to plagioclase phenocrysts):

Aphyr. = aphyric

SP = sparsely porphyritic, with platy phenocrysts.

SB = sparsely porphyritic, with blocky phenocrysts.

Star = porphyritic, with stellate clusters of platy phenocrysts.

Texture of augite:

Θ = fully ophitic.

SO = subophitic.

IG = intergranular.

Where the modal amount of a constituent is not given, a plus sign implies that the mineral is present; a minus implies that it is absent.

The three analysed specimens are marked thus *

3. Notes on Mineralogy.

The anorthite-content of plagioclase crystals has been determined on the universal stage in many instances, using the method of extinction angles, measured on the trace of (010) twin planes of albite twins or, less frequently, from Carlsbad-albite twins. The refractive index and 2V of pyroxene grains have been measured wherever possible. The results of these optical determinations are tabulated together with modal and textural data in Table 1.6.

Olivine No olivine remains, nor has serpentine been identified. The pseudomorphs are mainly composed of iron ore and a mineral or minerals referred to the chlorite group. The thickness of the ore rim is usually out of all proportion to the amount of iron held in solid solution by the original olivine (cf. C.I.P.W. norms, Table 1.9). In some cases the chlorite is confined to a tiny central grain enclosed by ore and not infrequently the pseudomorphs are of solid ore. There can be little doubt that the ore of these pseudomorphs has been considerably augmented by the migration of iron from elsewhere in the rock.

Pyroxene When fresh, the pyroxene is a clear pink colour. Cleavage is not well developed and difficulty was experienced finding fragments suitable for R.I. determination. The R.I. was 1.710 ± .005 in almost every pyroxene examined. The 2V was obtained by the extinction method -- areas large enough for the conoscopic method are extremely rare. In general 2V ranged from 50° to 54°. In the Musartût flows and sills most grains have a 2V between 50° and 51°; in higher Units, 52° is the most usual value. A slight gradational zoning effect can be detected in occasional grains. The range of 2V readings obtained from different grains within the same thin section is illustrated by the following values from 39940: 51, 53, 53½, 51, 51, 53½, 52½, 54, 53½, 47½, 53, 57. The 2Vs in Table 1.6 are the average values in the various specimens.

Plotted on the determinative diagram of Muir (1951, p. 713), the optical properties of the pyroxenes correspond to compositions toward the magnesian side of the ferro-augite field. (Deer, Howie and Zussmann, 1963, Vol.2 p. 132, remark that pyroxene compositions obtained in this manner may differ by as much as 5% of the Ca, Mg or Fe content from their true values).

The textures of the pyroxenes are described variously as ophitic, subophitic or intergranular (cf. Williams, Turner and Gilbert, 1954 p.22). The terms are defined as follows:-

(i) <u>Ophitic</u>. Laths of plagioclase are completely enclosed in pyroxene (the enclosed laths are usually a great deal smaller than those elsewhere in the groundmass).

(ii) <u>Subophitic</u>. This term covers a range of textures from the stage where a number of adjacent areas of pyroxene enclosed by feldspar laths are in optical continuity, to a stage where pyroxene is moulded around the ends of the laths.

(iii) Intergranular. Each small isolated area of pyroxene within the feldspar mesh is an individual crystal.

Plagioclase. Practically all the plagioclase lies within the compositional range of labradorite, viz., between An_{50} and An_{70}. Most of the microlites have a composition between An_{54} and An_{62}. Some show normal gradational zoning near the margins, corresponding to a change of ca. 10% An, and some grains zone out to basic andesine, e.g. 48% An.

The plagioclase phenocrysts are generally more basic than the microlites, containing ca. 10% more of the anorthite molecule. Several grains showed optical properties corresponding to ca. 70% An.

4. Modal Data and Augite Ratios.

The modes of a considerable number of basalts were determined (Table 1.6). It must be emphasised that the values obtained are not of very high accuracy due to (i) the inaccuracies inherent to the modal determination of such fine grained rocks (cf. Larsen and Miller, 1935, p. 262) and (ii) the altered nature of many of the rocks. The modal estimation of olivine is an example of the latter factor. Where the pseudomorphs have thick rims of iron ore, it is necessary to make a subjective decision as to the limits of the original olivine grain. The modes are based on counts of 2,000 to 5,000 points.

Above the Naujarssuit Sandstone Unit, all the basalt flows are olivine bearing. The average olivine content of 14 samples is 17.2%; this value may be somewhat weighted by the inclusion of a number of specimens from flow bases where olivine may tend to concentrate and 15% is thought to be a more typical value (cf. the C.I.P.W. norms, Table 1.9).

To compare the relative amounts of augite and plagioclase in the groundmass of the modally analysed rocks, the "augite ratio" has been calculated.

$$\text{Augite ratio} = \frac{\%\ \text{augite}}{\%\ \text{augite} + \%\ \text{plagioclase}} \times 100$$

The percentages are volumetric; Tomkeieff (1945) makes use of a different "augite ratio" in which the weight percentage of the minerals are employed.

In view of the small amount of data treated and the questionable accuracy of the modes, only limited conclusions can be made as to the manner in which the augite ratio varies from one group of lavas to another. The high augite ratio of the Musartût sills (average 48.5) is quite distinctive and the four values obtained are similar (see Table 1.6). In almost all the other basalts which have been modally analysed, the augite ratio is a clear 15 units lower. There appears to be extreme variation of the ratio within the Ipiutaq lavas (12.2 - 30.6), and there also appears to be a concentration of unusually low values; the analysed specimen 39941 has an augite ratio of 12.2. The four augite ratio values for "star" basalts of the Ilímaussaq Volcanic Unit are moderately high and quite close to one another.

The data available is insufficient to establish whether or not there is a relationship between the augite ratio and the textural form of the augite (cf. Tomkeieff, 1945, p. 74).

5. Plagioclase Phenocrysts.

No phenocrystalline pyroxene has been recorded in the basalts. The phenocryst minerals are plagioclase and olivine, the plagioclase being by far the more conspicuous. Two types of plagioclase are distinguished:-

(i) Plates or broad laths with tabular development to (010).

(ii) Blocky grains with squat, prismatic form.

In the stratigraphical sequence platy phenocrysts first appear, very sparsely, in the upper flows of the Musartût Unit. They reappear in greater concentrations at various horizons in the succeeding Units, particularly in the "star" basalts of the Ipiutaq Unit, in the well defined

100 m. thick group of "star" basalts at the bottom of the Ilímaussaq Volcanic Unit and in the spectacular Platy Basalt. These plagioclase phenocrysts are normally accompanied by olivine phenocrysts and sometimes the two minerals are clustered together in glomeroporphyritic groups. There can be no doubt that these minerals are early crystalling phases of the enclosing magma. Platy feldspar crystals are very common in the basic (and alkaline) intrusives of Gardar age in South Greenland, (cf. Upton, 1961, pp. 10 - 11; Ferguson and Pulvertaft, 1963).

Small blocky phenocrysts are sparsely distributed in the sills of the Musartût Unit and in the upper flows of the Nunasarnaq Sandstone Unit. The most striking occurrence however, is in the Big Feldspar Basalt where large blocky phenocrysts occur in association with platy phenocrysts. Some of the blocky phenocrysts contain small, heavily altered inclusions of mafic minerals, which may be arranged in a zone parallel to the grain margin. While the blocky phenocrysts of the Musartût sills are moderately fresh and may have a glassy appearance in hand specimen, those occurring at the higher stratigraphical horizons are heavily altered, seemingly more so than the feldspar of the adjacent matrix. A phenocryst from S2 showed gradational zoning from An_{62} - An_{50}.

It seems reasonable to assume that the blocky phenocrysts and the platy phenocrysts formed in quite different environments. The blocky phenocrysts may have a xenocrystalline relationship to the host basalt. Their appearance recalls the blocky "phenocrysts" of the Gardar Big Feldspar Dikes, some of which may be fragments derived from anorthite (cf. Upton, 1962, pp. 32-35).

6. Principal Varieties of Basalt.

Table 1.7

	Basalt Type	Nature of plagioclase phenocrysts	Textural form of augite
1.	"Star" basalt of the Ipiutaq Volcanic Series.	Platy, forming stellate clusters.	Subophitic.
2.	Fine grained, dense, sparsely porphyritic flows of the upper part of the Nunasarnaq Sandstone Unit.	Sparse, blocky.	Fully Ophitic.
3.	"Star" basalt of the lowest 100 m. of the Ilímaussaq Volcanic Unit.	Platy, forming clusters.	Fully Ophitic.
4.	Platy Basalt.	Platy, flow aligned.	Subophitic.
5.	Big Feldspar Basalt.	Blocky and Platy	Subophitic.

The "star" basalts, 1 and 3 above, cannot be distinguished apart in the field.

The basalt of the Musartût sills is distinctly different from almost all of the lavas. It is fine grained, compact, very dark and nearly aphyric. Olivine is typically absent and augite (subophitic) is very abundant. The sills are characterised by the development of columnar structure, which has not been recorded in the flows. These sills represent an injection of a magma type quite different from that of the extrusives.

7. Analyses of Basalts.

Table 1.8

	1	2	3
SiO_2	46.46	47.41	46.44
TiO_2	2.15	1.96	1.86
Al_2O_3	18.14	16.50	17.01
Fe_2O_3	10.91	7.42	9.78
FeO	2.37	4.82	4.12
MnO	0.13	0.22	0.18
MgO	4.80	5.85	4.82
CaO	8.65	6.77	8.14
Na_2O	3.58	3.77	3.30
K_2O	0.41	1.52	1.26
P_2O_5	0.37	0.22	0.26
CO_2	0.00	0.00	0.00
H_2O+	1.58	2.64	2.07
H_2O-	0.27	0.51	0.34
S	0.05	0.02	0.04
ZrO_2	0.00	0.00	0.00
BaO	0.02	0.02	0.04
Total	99.89	99.65	99.66

1. 39941. Aphyric olivine basalt from the Ipiutaq Volcanic Unit. Locality: shore immediately west of northernmost extremity of Qeqertat islands, Ilímaussaq Peninsula,

South Greenland.

Analyst: B. I. Borgen.

2. 39340. Sparsely porphyritic ophitic olivine basalt from a thin flow intercalated in the Nunasarnaq Sandstone Unit. Locality: 550 m. altitude, 3.5 km. from Nasanguaq on a 138° bearing, Ilímaussaq Peninsula, South Greenland.

Analyst: B. I. Borgen.

3. 39944. "Star" basalt from 550 m. on the ENE ridge of Nunasarnaq, Ilímaussaq Peninsula, South Greenland.

Analyst: B. I. Borgen.

The three Gardar basalts chosen for analysis are not obviously weathered nor metamorphosed and represent some of the freshest rocks available. Specimen 39941 is the freshest of the three. The feldspar is only slightly dusty and all of the pyroxene seems to be preserved. The pseudomorphs after olivine are composed of ore, chlorite and quartz, the proportion of ore being unusually low. A small amount of fine chlorite occurs in interstices of the fabric and is probably deuteric.

Specimens 39944 and 39340 are rather more altered. The plagioclase phenocrysts are quite heavily sericitised and the groundmass feldspar more lightly altered. About 50% of the pyroxene remains, but there is a considerable development of chlorite throughout the rock, which may or may not be of deuteric origin. Comparing the analyses of these rocks against that of the fresher 39941, the higher potash and lower Fe_2O_3 : FeO ratio are the most striking differences. The original potash content has probably been added to, and is related to the development of sericite; the increase in potash may be due to mild weathering (cf. Dennen and Anderson, 1962, p. 382), or to dilute hydrothermal aolutions (cf. Schwartz, 1939).

The contrasting Fe_2O_3 : FeO ratios are difficult to explain. During hydrothermal alteration, basic igneous rocks might be expected to show a loss of Fe^{++} and a slight gain of Fe^{+++} (cf. Schwartz op.cit. p. 213), while oxidation of iron is a common feature of weathering (cf. Macgregor, 1928, p. 355). In the present instance, however, the freshest basalt also has the highest Fe_2O_3 : FeO ratio. Macgregor (op.cit. p. 355) notes a similar anomaly. Pallister (1952) pp. 346-347) discusses analyses of Jedburgh and Markle type basalts in which the oxidation state of the iron is even higher than that of the Gardar basalts. He remarks that the high relative percentage of ferric iron, together with the high water content, well reflect the altered nature of the lavas, and agrees with Tomkeieff (1945 p. 72) that the alteration is deuteric rather than due to weathering.

It is concluded that the predominance of ferric iron over ferrous iron in the Gardar basalts is due to deuteric alteration and the K_2O percentages of 39945 and 39340 may be exaggerated by up to ca. 1%. Otherwise the analyses probably reflect quite accurately the original chemical composition of the rocks. The ferric iron is evidently located in the iron ores and examination in reflected light shows haematite to be abundant.

Norms of the analysed specimens are shown in Table 1.9. The normative mineralogy contrasts strongly with the modal composition of the rocks (cf. Table 1.6). The oxidised state of the iron is chiefly responsible for this disparity. If the total iron of the analyses is redistributed in a ratio more typical of normal basalts, viz. with $FeO : Fe_2O_3$ = 3 : 1, and the norms recalculated (Table 1.10), the normative mineralogy agrees much better with the actual mineralogy.

Table 1.9

C.I.P.W. Norms of Gardar Basalts.

Normative Minerals.		39941		39340		39944	
q		1.3		-		0.6	
or		2.2		9.5		7.8	
ab		30.9		32.0		27.8	
an		32.3		23.4		27.8	
ne		-		-		-	
wo	di	3.3	6.1	3.5	13.7	4.8	4.8
en		2.8		10.2		-	
fs		-		-		-	
en	hy	9.2	9.2	-	-	12.1	12.1
fs		-		-		-	
fo	ol	-	-	3.1	3.1	-	-
fa		-		-		-	
il		4.1		3.8		3.5	
mt		1.9		10.7		8.6	
he		9.6		-		3.8	
ap		1.0		0.7		0.7	
pr		0.1		-		-	

Table 1.10

C.I.P.W. Norms of Gardar Basalts

(recalculated with total iron redistributed in ratio

$FeO : Fe_2O_3 = 3 : 1$)

Normative Minerals.		39941		39340		39944	
q		-		-		-	
or		2.2		9.5		7.8	
ab		30.4		30.9		27.8	
an		32.3		23.4		27.8	
ne		-		0.6		-	
wo	di	3.3	6.4	3.5	6.8	4.8	9.5
en	di	1.6		1.9		2.2	
fs	di	1.6		1.5		2.5	
en	hy	2.6	5.1	-	-	-	-
fs	hy	2.5		-		-	
fo	ol	5.5	11.6	9.0	16.7	7.0	15.4
fa	ol	6.1		7.8		8.4	
il		4.1		3.8		3.5	
mt		4.9		4.4		5.1	
he		-		-		-	
ap		1.0		0.7		0.7	
pr		0.1		-		-	

8. Metamorphism

Metamorphic effects attributable to the Ilímaussaq Intrusive Complex extend for about 2 km. from the contact on the average. The immediate contact zone has not been specifically investigated, but so far as is known, high grade recrystallised hornfelses with pyroxene, biotite, etc., are of very limited development. The indications are that the contact temperatures have been relatively low.

Olivine basalt of the Ilímaussaq Volcanic Unit constitutes the country rock along most of the eastern side of the intrusion. The transition from the normal country basalt into the altered varieties of the aureole is gradational; in the field, the appearance of epidote in vesicles is usually the first indication. Nearer the contact, the usual reddish or purple colour of the basalt changes to a dull grey and the rock becomes more compact and resistant to erosion. Even in the field it is noticeable that epidote persists farthest from the contact in coarse, open textured lavas such as the Platy Basalt and the Big Feldspar Basalt and in porous flow tops and clastic horizons. Thin section study confirms that alteration advances preferentially in the less compact horizons.

In the series of specimens from the Tunuarmiut - 1035 m. measured section (Table 1.4), samples equidistant from the intrusion may show a very different degree of alteration. As an example, specimens 39980 and 39981 will be compared. These specimens are from the Upper Basalt Division and have already been referred to earlier in the petrographic section.

39980 is one of the freshest basalts of the region. The plagioclase occurs as well-formed rectangular laths and is quite clear, apart from some patches of sericite in a few larger laths. The pyroxene is almost completely preserved. This rock is unusually fine grained and compact and the plagioclase laths are only ca. 0.1 mm. in length.

Specimen 39981 is in complete contrast. It too is an olivine basalt, but a coarse grained variety with plagioclase laths averaging nearly 1 mm. in length. The plagioclase is so heavily dusted by fine chlorite and clay minerals that the lamellar twinning is no longer discernible on rotation between crossed nicols. The margins of the laths are ragged and uneven. Pyroxene has been completely destroyed. A few portions of grains are pseudomorphed by pale green, fibrous amphibole, but most have been altered to a fine grained felt of chlorite with coarse rods of iron ore. Pseudomorphs after olivine, consisting of a single grain of chlorite within an ore rim, are quite well preserved; in some cases the chlorite is replaced by epidote. Epidote, pleochroic from pale yellow to colourless, also occupies vesicular cavities.

In the majority of the metamorphosed basalts examined, the pattern of alteration is similar to that in 39981. At a slightly higher grade of metamorphism albite begins to appear, at first as irregular marginal patches around the altered plagioclase grains (e.g. 39984). Pyroxene is sometimes extensively pseudomorphed by a fibrous amphibole which is pleochroic from colourless to very pale green (cf. actinolite) and often sprinkled with fine ore. In a few instances some pyroxene remains in association with such pseudomorphs (e.g. 39984). Often, the pyroxene is completely broken down to aggregates of fine grained alteration products, including ore and material of high relief, some of which is epidote and some possibly sphene (e.g. 39969).

In specimen 40276, a Big Feldspar Basalt from the eastern side of Ilímaussaq, just above the glacier, the alteration products in the feldspar phenocrysts are concentrated into coarse grained aggregates of epidote and chlorite. The plagioclase is relatively clear, with distinct lamellar twinning, and albitic in composition. Some coarse granules of sphene are present in the rock.

The highest grade of metamorphism encountered in the rocks examined corresponds to the albite-epidote-hornfels facies as defined by Fyfe, Turner and Verhoogen (1958, pp. 203-204).

The extent of the metamorphic aureole has been largely controlled by the texture of the country rocks. In the case of unusually porous horizons, the effects may extend more than two kilometres from the contact. The heavy epidote mineralisation (sometimes with associated haematite) found in the Platy Basalt horizon points to the easy passage of a fluid, probably a hydrothermal liquid, through the rock.

(c) GEOLOGICAL HISTORY

The arkosic basal facies represents the in situ weathering products of the basement granite. With the initiation of Gardar sedimentation great quantities of quartz sand became available in the area and the basal arkose passes up to a pure sandstone. The sandstones deposited throughout the Gardar Continental Series have a very limited petrographic range although some have been deposited under water and others have been formed by aeolian deposition. In the absence of some definitive structure such as sun-cracks, conglomerate or extrusive lava (all of the lavas seem to have been erupted under terrestrial conditions), it is usually impossible to be certain in which environment a particular sandstone has been laid down.

The depositional environment during Gardar times was probably comparable to that of the Old Red Sandstone or the continental facies of the Permian and Trias (cf. Ussing, 1912, pp. 18-24 and 284), consisting of a sandy desert landscape with impersistent shallow lakes.

The Mâjût Sandstone Unit represents a period of sandstone accumulation unbroken by tectonic movement or volcanic activity in this area. This was followed by a period of tectonic unrest throughout Musartût times, indicated by the existence of a small angular unconformity at the base and the repeated occurrence of conglomerate beds. The earliest manifestation of vulcanicity appears rather more than half way up the Unit with the extrusion of the thick flows of olivine basalt which outcrop at Musartût.

The Naujarssuit Sandstone Unit was deposited during an extended period almost free of tectonic disturbance and volcanic activity. The lavas of the Ipiutaq Volcanic Unit, which follows, were erupted rapidly and extrusion of lava outstripped the deposition of sandstone. During Naujarssuit Sandstone times volcanic activity waned. Local, minor flows were extruded from time to time in a sandy desert environment. One of these was of lamprophyric composition.

The base of the Ilímaussaq Volcanic Unit marks the commencement of a period of intense volcanic activity. The area must have been a volcanic field for a very long time. Occasional thin intercalations of wind-blown sand indicate that psammitic sediment remained continuously available elsewhere in the region, during this period. The conglomerate, followed by sandstone, which outcrops near the 1435 m. point of the Summit Plateau, indicates a return to subaqueous sedimentation after the extrusion of a lava pile 1000 m. thick.

All of the lavas were extruded terrestrially, so far as is known. The "tilestone", believed to be a pyroclastic product connected with carbonatite - ultramafic vulcanism, was deposited, in part at least, during a period of local submergence. The olivine basalt vulcanism was only rarely explosive and the thin, discontinuous bed of basaltic pyroclastics developed developed locally ca. 100 m. above the base of the Ilímaussaq Volcanic Unit is the only well documented example.

The conglomeratic intrusive breccia, the basaltic sills and the syenitic sill are all cut by the regional swarms of basic and alkaline dikes. The basaltic sills are shown to be younger than the intrusive breccia. These considerations aside, the latest period at which the intrusives could have been emplaced can not be fixed more accurately.

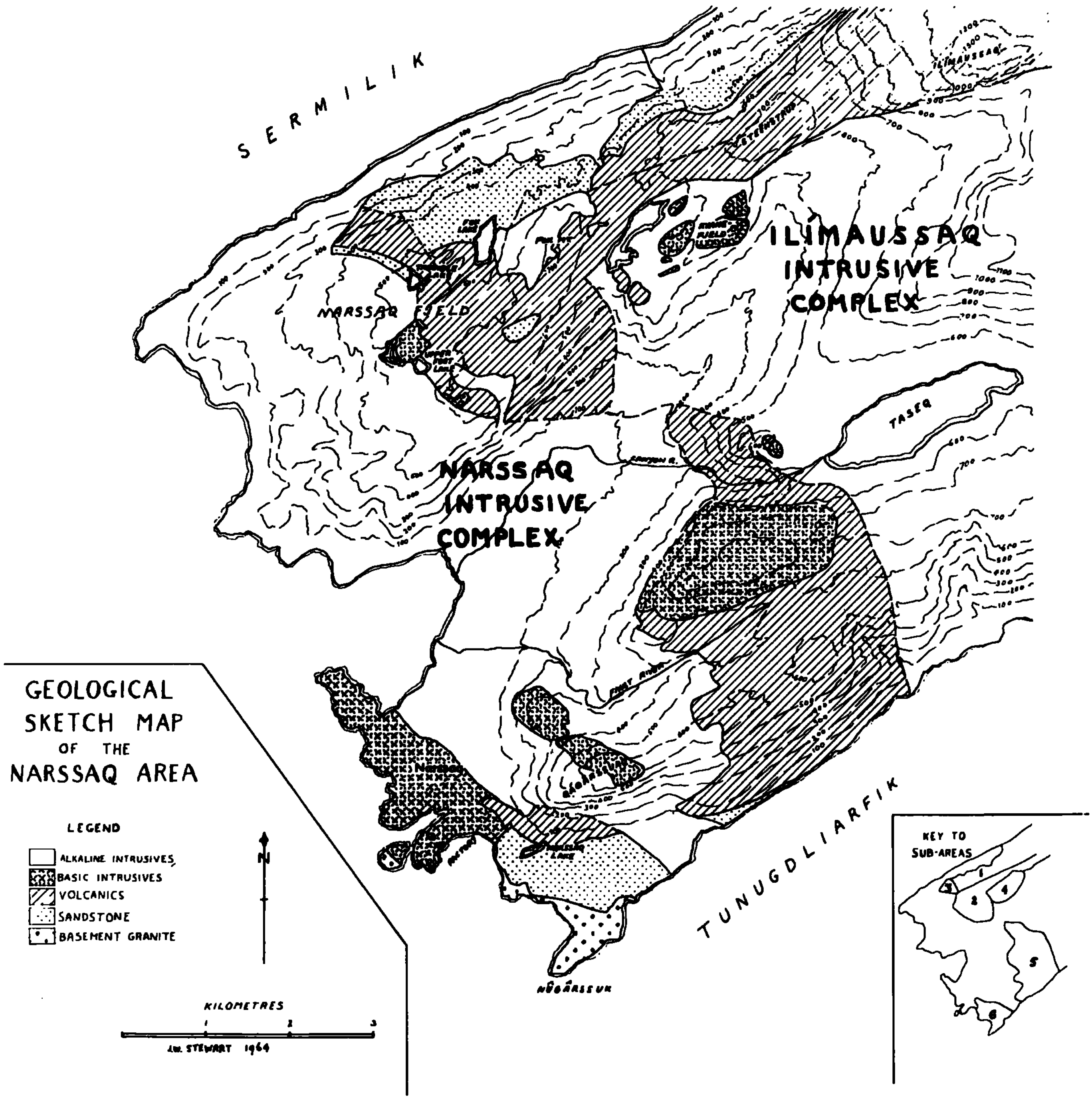

GEOLOGICAL SKETCH MAP OF THE NARSSAQ AREA
LEGEND
ALKALINE INTRUSIVES
BASIC INTRUSIVES
VOLCANICS
SANDSTONE
BASEMENT GRANITE
N
KILOMETRES
1
2
3
J.W. STEWART 1964
SERMILIK
TUNUGDLIARFIK
ILIMAUSSAQ INTRUSIVE COMPLEX
NARSSAQ INTRUSIVE COMPLEX
NARSSAQ FJELD
TASEQ
KEY TO SUB-AREAS
1
2
3
4
5
6

Fig. 2.1.

CHAPTER II

Geology of the Area West of the Ilímaussaq Intrusive Complex. (with notes on the areas of Gardar strata in the roof zone of the Complex.)

West of the Ilímaussaq Intrusive Complex, strata of the Gardar Continental Series are dissected into a mosaic of minor sub-areas inclining in various directions and depressed or elevated with relation to one another. A great part of this country must be underlain by younger alkaline rocks of the Ilímaussaq and Narssaq intrusive complexes. The Gardar Strata which roof these plutons are faulted, tilted and in many instances penetrated by the intrusives. The earlier gabbroic intrusions are mainly concordant with the strata while the later alkaline intrusions tend to be discordant.

The six main sub-areas are shown in Figure 2.1.

Sub-area (1).

The strata of this narrow sub-area are in continuity with those of the main part of the Peninsula (Chapter I) but their disposition is virtually horizontal. The top of the Nunasarnaq Sandstone Unit coincides approximately with the 550 m. contour and is overlain by "star" basalt of the Ilímaussaq Volcanic Unit.

This sub-area is separated from sub-area (2) by a 70° hinge fault. Upthrow on the northern side has led to the horizontal disposition of the strata in sub-area (1). The maximum throw is of the order of 500 m. and occurs in the south-west. To the north-east the throw decreases and the fault dies out somewhere on the northern flank of Steenstrup.

Sub-area (2).

Strata of this sub-area are in continuity with strata of the main part of the Peninsula and maintain a similar low dip towards the south. The stratigraphical succession found around the Summit Plateau is repeated here, with successively higher horizons being exposed in the down-dip direction and at lower altitude i.e. towards the south and west. On the western side of Steenstrup the Platy Basalt horizon is developed, somewhat displaced by 50^{o} faults. Further west, the volcanics are increasingly metamorphosed and veins and small irregular intrusions of alkaline plutonic rocks appear. On the eastern side of Fox Mountain four horizons of Fox Mountain porphyry with thicknesses ranging from 3 m. - 20 m. are intercalated in fine grained meta-volcanics. Further intercalations of this rock type are found immediately south of Fox Lake and on the north-east side of Triangle Lake.

About 800 m. south-south-east of Fox Lake there is an area of ca. 1000 square metres of sediment. A conglomerate bed ca. 5 m. thick, containing pebbles of basalt and finely porphyritic red trachyte is followed by bedded sandstone. The total thickness of sediments is 25 m. - 30 m.. Strikes and dips of 93^{o}/15^{o}S and 70^{o}/12^{o}S were recorded. This sedimentary horizon is correlated with that on top of the Summit Plateau (Chapter I).

It is not certain which rock succeeds the sediments. To the south and west obscure, reddish, fine grained types and fine porphyries outcrop. Some of these are intrusive towards the sediments. These rocks extend over a considerable area to the west. Not all are intrusive, however, and sandy intervolcanic horizons have been recorded at several places. Westwards, a distinctive rhomb-porphyry is developed; (a similar rock in sub-area (5) is extrusive). In the extreme west, corresponding to the highest stratigraphic level, basaltic types outcrop. These are open textured, greyish rocks and their appearance contrasts with the red or purple colour and compact fabric usual in the types described above.

Allowing a 10^{o} dip, it is estimated that the thickness of volcanics which overlies the conglomerate horizon is approximately 175 m.

Sub-area (3).

The strata in this small sub-area atrike 110^{o}-115^{o} and dip south-west at 40^{o}. The lowest distinctive horizon seen is Platy Basalt, which outcrops on the hillside above Sermilik. This is followed by thin flows of olivine basalt and the succession is terminated by a band of fine conglomerate which extends westwards from Triangle Lake. No alkaline volcanics occur and this sedimentary bed is probably intercalated near the top of the Upper Basalt Division of the Ilímaussaq Volcanic Unit.

Sub-area (4).

A number of small areas of volcanic and sedimentary rocks occur isolated in the nepheline syenite of Kvanefjeld and are probably roof-pendants. The country rock has been intensely altered. The rock types still recognisable are conglomerate, unusually coarse "star" basalt and rhomb-porphyry. The "star" basalt finds no exact parallel in the known Gardar Continental succession and may represent some intrusive type.

Sub-area (5).

Well stratified rocks of the Gardar Continental Series outcrop on the steep hillside above Tunugdliarfik between the Ilímaussaq Intrusive Complex and the intrusives of the Narssaq region. There is a dip of about 5° to the north-east.

At the south-west boundary, 60 m. - 80 m. of sandstone is exposed above the fjord. This is overlain by "star" basalt of the Ilímaussaq Volcanic Unit. The plane between the two rock types dips into the fjord nearly 4 km. north-east of Nûgârssuk (the headland east of Narssaq). At this point a traverse was taken directly uphill. Exposure is very poor because of scree and vegetation; very limited observations were possible and the following section is far from satisfactory.

Table 2.1

Measured Section on Hillside above Tunugdliarfik, ca. 4 km. North-East of Nûgârssuk.

TOP

metres	
Above 620	Rhomb-porphyry
450-620	Various finely porphyritic volcanics, mostly of alkaline types.
255-450	The conglomerate is succeeded by a vesicular trachyte. Above come fine volcanics with occasional thin intervolcanic horizons. At 340 m. there is a layer, a few metres thick, of cf. Fox Mt. Porphyry.
250-255	Conglomerate, with pebbles and cobbles up to 15 cm. in diameter. Those at the base are poorly rounded, but rounding improves upwards. Most of the pebbles are of basalt, a few are of cf. jasper; no sandstone pebbles were observed. Other rock types, provisionally identified in the pebbles, are syenite, trachyte and rhyolite.
150-250	Fine, grey, aphyric basalt.
10-150	"Star" basalt, without any visible break. At 150 m. there is a tenuous horizon of sand or

	sandy tuff which coincides with a marked break in the slope.
0- 10	Quartzite.

BASE

Platy Basalt was not recorded in this section, but the horizon might well have coincided with one of the numerous interruptions in exposure.

Fine grained, porphyritic rocks, mostly alkaline in type, occur on the 600 m. ridge overlooking Tunugdliarfik, in the Fault River valley and in the Canyon River gorge. The rocks are strongly metamorphosed and their relationships are frequently obscure. In particular, it is sometimes impossible to be certain whether the rocks are intrusive or extrusive. The most abundant variety is a very fine grained, deep red rock with tiny pink phenocrysts which resembles the porfido rosso antico of the ancient world.

Occasional thin, sandy intervolcanic horizons testify that the rock was at least locally extrusive. Rhomb-porphyry is another important variety of the alkaline extrusives. It, too, contains some inter-stratified sandy material. A few small outcrops of Fox Mt. Porphyry occur, and hybrid varieties between this type and rhomb-porphyry have been recorded in which rectangular plagioclase pheno-

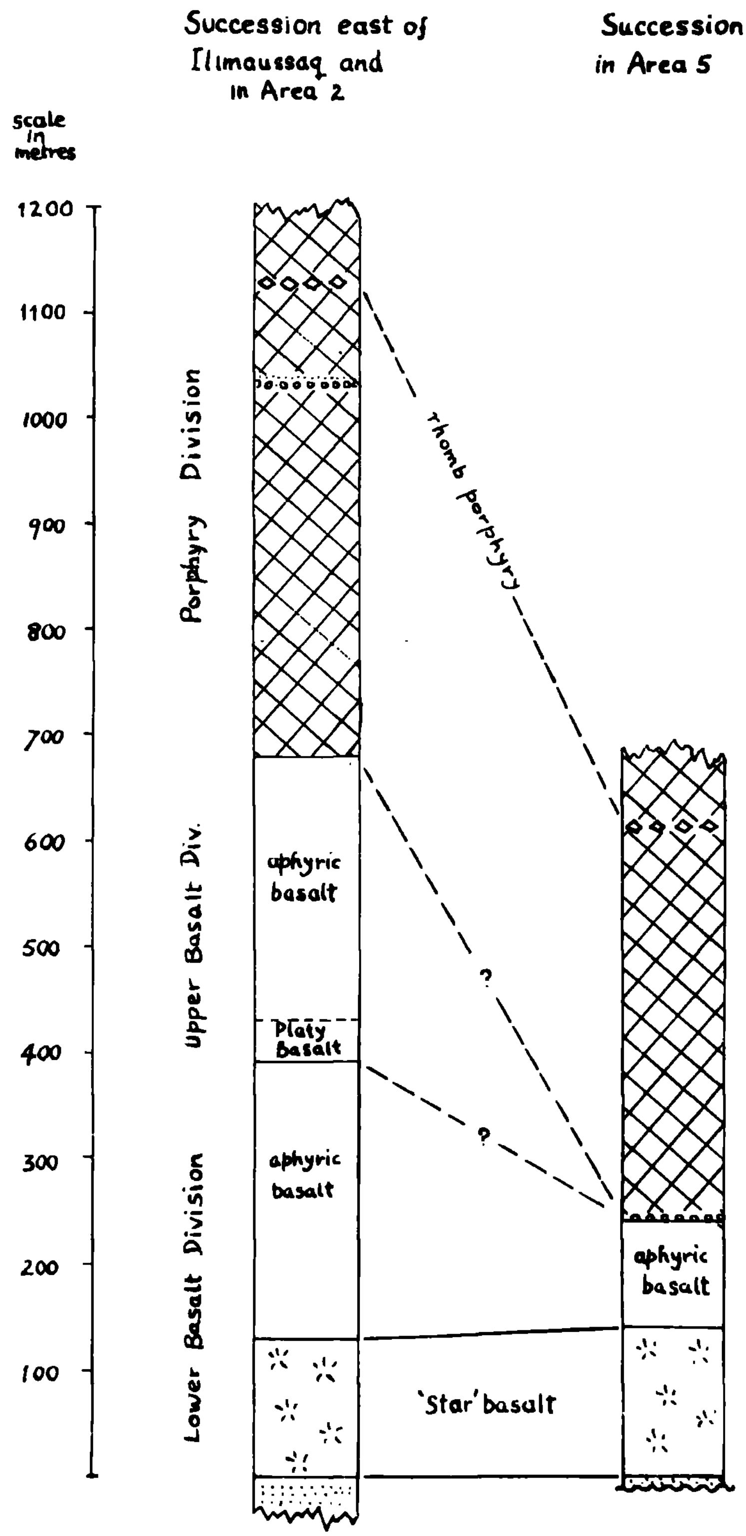

Succession east of Ilimaussaq and in Area 2
Succession in Area 5
scale in metres
1200
1100
1000
900
800
700
600
500
400
300
200
100
Porphyry Division
Upper Basalt Div.
Lower Basalt Division
aphyric basalt
Platy Basalt
aphyric basalt
rhomb porphyry
?
?
aphyric basalt
'Star' basalt

Fig 2.2

crysts and rhomb-shaped phenocrysts of alkali feldspar co-exist in various proportions.

The stratigraphy of sub-areas (1) and (2) corresponds well with that of the country east of Ilímaussaq (cf. Chapter I). That of sub-area (5), however, shows some outstanding differences. The total thickness of strata of the Ilímaussaq Volcanic Unit preserved in sub-area (5) is approximately 700 m.. Rhomb-porphyry occurs ca. 600 m. above the base of the Unit. Elsewhere, this rock type occurs above the stratigraphic level of the Summit Plateau sedimentary horizon; in sub-area (2), it is judged to occupy a horizon ca. 100 m. above the sedimentary bed. The "star" basalt of sub-area (5) is undoubtedly the equivalent of the lower part of the Lower Basalt Division, while the alkaline volcanics which occur above 255 m. (Table 2.1) invite correlation with the Porphyry Division. In sub-area (5) there appears to be a major reduction in thickness of the group of basalts which, east of Ilímaussaq, comprise the aphyric upper part of the Lower Basalt Division.

The situation cannot be resolved further, pending recognition of marker horizons in the succession on the hillside overlooking Tunugdliarfik in sub-area (5).

Sub-area (6).

The southern face of the mountain Qáqârssuaq is very steep, with many stretches of sheer cliff. At the base, between 100 m. and 200 m., there is a great scree, which is "live". To the south, there is a triangular piece of land with very subdued topography, some 2 square kilometres in area. The southern apex of the triangle is the headland Nûgârssuk (not to be confused with a headland of the same name near Qagssiarssuk). Here, Basement granite is exposed.

The granite is overlain by arenaceous sediments of the Gardar Continental Series, which dip at ca. 5° toward the north. The basal facies, which has a maximum thickness of ca. 10 m., is an arkosic grite. The lower part of the grit is indistinguishable from the granite and has evidently formed by the _in situ_ disintegration of the crystalline rock.

Local hollows in the pre-Gardar surface are indicated. These have been filled up by arkose prior to the main deposition of transported sediment. The grit is succeeded by a red, cross bedded sandstone with a maximum thickness of 5 m.; the transition is quite sharp. The red sandstone is followed by 80 - 100 m. of white sandstone. Locally, the rock is coloured purple or green and in one instance it was seen to be recrystallised to a coarse quartzite. These effects may be related to younger plutonic and hypabyssal intrusions of the area. A few thin, dark bands may represent accumulations of fine volcanic ash.

About 100 m. above the base of the Gardar Series, there is a bed of volcanic breccia. The matrix is a black, fine grained dense material, often highly magnetic. The blocks are sharply angular fragments of quartzite or sandstone up to 0.5 m. across. The igneous matrix is intensely altered, probably by an underlying body of gabbro. Comparison with similar, though less altered rocks at Nunasarnaussaq (Chapter III) indicates that it was probably of lamprophyric composition.

This bed can be followed from west of Narssaq Lake almost to Tunugdliarfik. The maximum width of outcrop is less than 100 m.. Thickness is uncertain, since the top is usually eroded away; it probably does not greatly exceed 5 m.. It is unknown whether the breccia is of intrusive or effusive origin.

Above this horizon, observations have been severely restricted by alluvial deposits on the low ground and scree at the foot of the mountain. The breccia is probably succeeded by ultramafic pyroclastics. A deeply weathered, metamorphosed volcanic breccia is exposed for several hundred metres north of the Factory adjacent to the gabbro, which intrudes it. The groundmass, which appears to be tuffaceous, contains relatively few blocks of quartzite. Most of the inclusions are of dark, basic igneous rock, quite well rounded.

This breccia is succeeded by fine, banded tuffs. The bands are alternately pale green and black and seldom more than a few centimetres thick. A rock of identical appearance from Nunasarnaussaq has lamprophyric affinities. Similar banded tuff also outcrops on the hillside above Narssaq Lake.

Uphill from the Factory in a north-east direction, just east of the younger alkaline intrusives, tuff is developed sporadically to 215 m.. Between 100 m. and 200 m. the strata are extensively veined and disrupted by alkali granite. Blocks of quartzite and metavolcanic rock occur in the granite. It is probable that the succession contained layers of sandstone. Above 215 m. there is fine grained quartzite with minor dark bands, possibly of tuff. The section is again interrupted by intrusive granite at 260 m.. Above, quartzite xenoliths are common in the intrusive. At ca. 300 m. there are some large xenolithic bodies of hornfelsed, basic volcanics in the granite.

Some distance to the east, a bedded volcanic breccia outcrops at 140 m.. Sharp fragments of dark basic rock lie in a pale, fine grained matrix. Above, quartzite outcrops at ca. 200., overlain by a fine grained, basic volcanic type; both rocks are strongly intruded and brecciated by granite. A basalt which approaches "star" basalt in appearance has been recorded at 230 m..

The southern face of Qáqârssuaq is a great breccia zone in which a succession consisting of sandstone, tuffs and basaltic lavas has been broken up and penetrated by alkali granite. No great stratigraphical significance can be attached to included blocks, for these may have been carried above or below their original horizon by the eruptive magma.

A highly schematic stratigraphic succession is illustrated in Fig. 2. 3.

STRATIGRAPHICAL SUCCESSION IN SUB-AREA 6, NARSSAQ

(highly schematic)

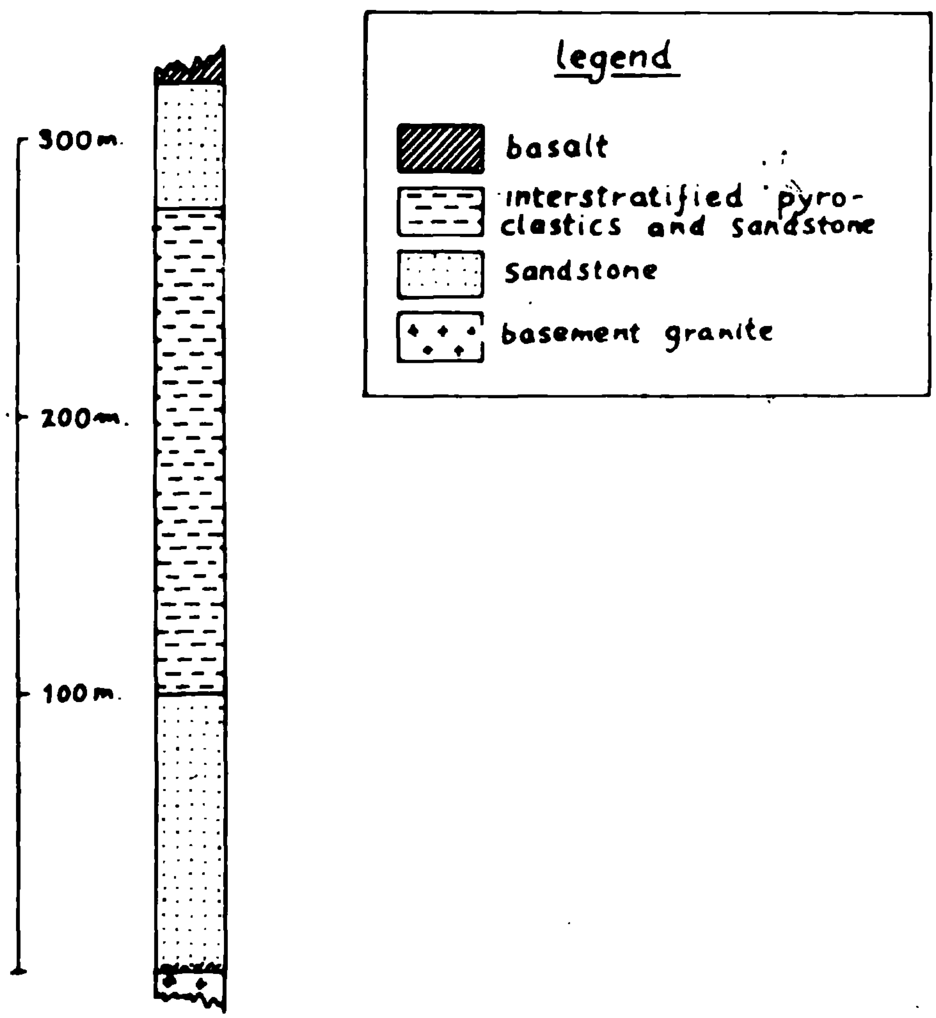


Fig 2.3.

The base of the Gardar Continental Series, exposed on the lowlands below Qáqârssuaq, is at the same topographic level as the upper part of the Nunasarnaq Sandstone Unit of subarea (5), which outcrops nearby on the coast of Tunugdliarfik. The great difference in stratigraphic level between these adjacent areas is explained by an east-west fault along the south face of Qáqârssuaq; the site of this fault is now occupied by intrusive alkaline rocks. Based on the stratigraphic succession east of Ilímaussaq (see Chapter I) there is a southerly upthrow of ca. 2 km. on this fault. Comparison of the Gardar succession of sub-area (6) against that of the Mâjût and Musartût areas (cf. Chapter I) indicates that the lower Gardar succession in the Narssaq area may be considerably condensed, compared with the other areas; accordingly, the upthrow may be much less than 2 km..

Fig.2.4. Well stratified volcanics of sub-area 5, Narssaq area, viewed from Tunuğdliarfik. The contact of the Ilimaussaq Intrusive Complex is to the right of the picture.

Fig.2.5. View of Hatten from Summit Plateau. The top of the mountain is of volcanics, the underlying rocks are alkaline intrusives.

Gardar Volcanic Strata in the Roof-Zone of the Ilímaussaq Intrusive Complex.

Isolated areas of metamorphosed volcanic rocks on the mountains Hatten and Nákâlâq are interpreted as parts of the roof of the Ilímaussaq Intrusive Complex which have escaped erosion. The volcanics comprise rhomb-porphyry and other alkaline varieties resembling those developed in sub-area (5), (above), north-east of Qáqârssuaq. There can be little doubt that these rocks represent parts of the Porphyry Division of the Ilímaussaq Volcanic Unit stratigraphically higher than the succession on the eastern margin of the Complex. It is probable that these outliers have subsided some 300 m.-400m. relative to the strata of the country north and east of the Intrusive Complex.

CHAPTER III - THE NUNASARNAUSSAQ AREA

(a) GEOLOGY

Lavas and sandstones of the Gardar Continental Series with a total area of ca. 9 square kilometres are preserved on the south-west flank of the Ilímaussaq Intrusive Complex between Tunugdliarfik and Kangerdluarssuk (fjords). The flat topped mountain Nunasarnaussaq (755 m.) is capped by basalt, which has an area of ca. 2 square kilometres. Only the mountain and its immediate surroundings have been visited by the author during brief visits in 1959 and 1962. The boundary of the Continental Series against the Basement was previously established by other members of the Survey (H. K. Schmidt, P. Ahrensen and others). The strata have an overall east-west strike and dip northwards at 10^{o}-15^{o}.

The Gardar basal unconformity has been examined at 380 m. where it outcrops on a spur on the south side of the mountain. The actual basal plane cannot be defined within several decimetres since the lowest metre of sediment is an arkosic grit, formed of weathered products of the underlying granite, from which it is scarcely distinguishable. Pebbles of quartzite included in a rock which to all appearances is granite emphasise this phenomenon.

The main features of the stratigraphy of Nunasarnaussaq are

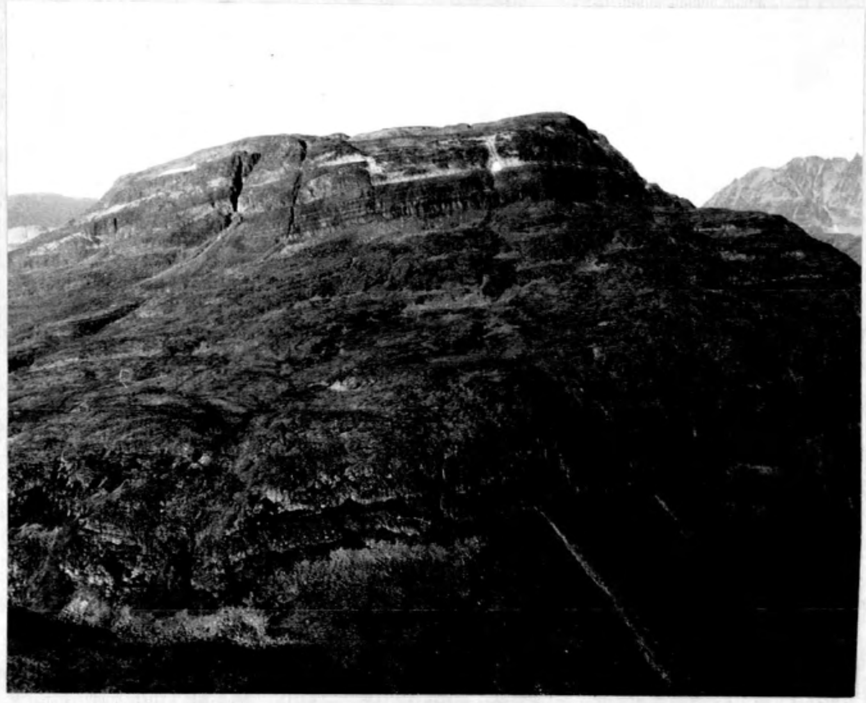


Fig.3.1. Nunasarnaussaq from the south.

described by Ussing and a measured section on the north-western slope is recorded (Ussing, 1912, pp. 56, 57, 60 and 61). Four measured sections taken by the author are represented in Fig 3.2 together with that of Ussing. The sections are all taken on steep or very steep ground and the stratification is inclined at a small angle to the horizontal --- accordingly, the thickness recorded departs only slightly from true thickness values.

About 200 m. of sandstone with localised, coarse conglomerate horizons is succeeded by ca. 100 m. of tuff and sandstone in rapidly alternating layers. The stratification of this group of beds is very regular, emphasised by the colour contrast between the dark tuff and the pale sandstone, and can be seen distinctly on the hillside from a considerable distance (Fig 3.1).

The nature of the pyroclastic beds is best illustrated by excerpts from measured sections. The following data are from sections (2) and (4) (Fig 3.2).

Table 3.1

Part of Measured Section (2) on the west side of Nunasarnaussaq

TOP

Metres.	
500-502	Tuffaceous sandstone.
490-500	Not exposed.

476-490	Sandstone, with an admixture of ash which increases upwards until sand and ash are in equal proportions.
452-476	Very fine basic lava or tuff (31302).
425-452	Not exposed.
400-425	Alternating 0.5 m. layers of very fine, dark tuff (31302) and fine sandstone.
397-400	Dark, very fine grained tuff (40300); upwards, fine sand intercalations appear (31301), followed by a 10 cm. layer of coarse sandstone containing fragments of quartzite and sandstone. This is succeeded by a fine, purple tuff with sandstone blocks ca. 10 cm. in diameter.
360-397	Rather coarse sandstone.
340-360	Conglomerate, passing up to poorly exposed coarse sediments. The conglomerate has a sharp uneven contact against the underlying quartzite-like sediment. It consists of very well rounded pebbles, cobbles and boulders of quartzite 5 - 20 cms. in diameter (most are ca. 10 cm. in diameter) together with markedly angular fragments of fine grained, dark purple or black tuff up to 10 cm. across. The matrix is a mixture of tiny tuff fragments and quartz grains, the latter often large and notably glassy in appearance.

BASE

Table 3.2

Part of Measured Section (4) on the south-west side of Nunasarnaussaq.

TOP

Metres.	
620-640	Sandstone with occasional thin partings of fine grained tuff.
617-620	Greenish black compact tuff. The uppermost 0.5 m. is fragmental.
613-617	Sandstone.
610-613	Fine, red sandy tuff.
600-610	Ca. 5 m. of fine grained, greenish black tuff or basic lava with fine, irregular pale veins is overlain by 5 m. of similar material in which the veining is parallel to the stratification.
565-600	Sandstone.
550-565	Alternating layers of (i) pale, creamy-coloured tuff or sediment containing large quartz grains and (ii) deep red to purple, fine grained tuff also containing quartz grains. The thickness of the layers ranges from less than 10 cm. to ca. 1 m..

BASE

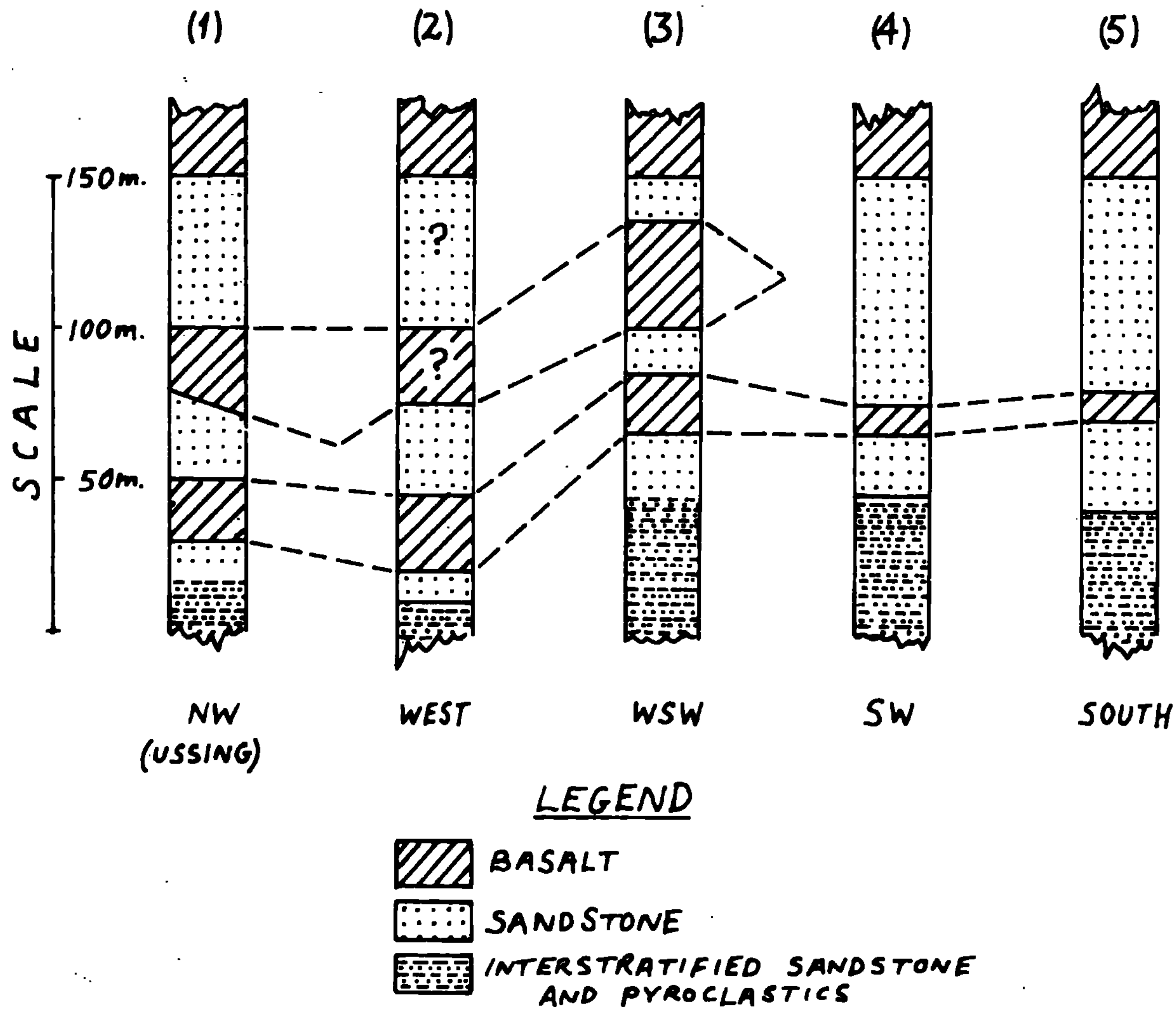


Fig. 3.2. Measured sections on Nunasarnaussaq. Numbers correspond to those on Fig. 3.3.

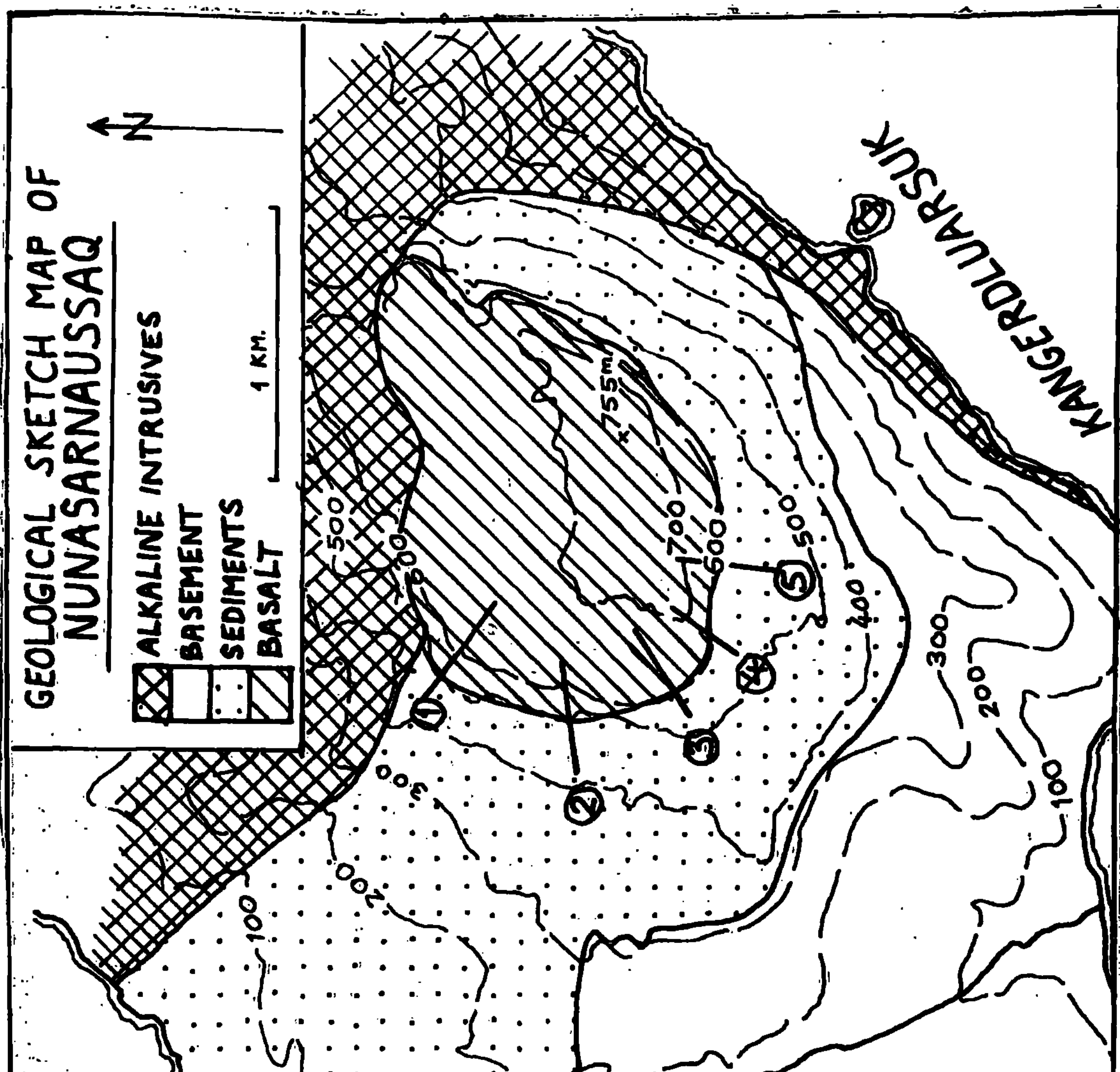

GEOLOGICAL SKETCH MAP OF
NUNASARNAUSSAQ
ALKALINE INTRUSIVES
BASEMENT
SEDIMENTS
BASALT
1 KM.
N
KANGERDLUARSUK
TUNUGDLIARFIK
755m
700
600
500
400
300
200
100
1
2
3
4
5

Fig. 3.3.

The highest pyroclastic layer is followed by 10 - 30 m. of tuff free sandstone or quartzite. This is succeeded by the lowest sill or flow which Ussing (op. cit. p. 61) describes as "a dark reddish grey, dense rock, almost felsitic in outer appearance and probably an altered tephritic type". According to Ussing it occurs as an intrusive sheet almost 20 m. thick and of great regularity. In section (2), Fig 3.2 a very fine grained dark igneous rock with sparse, blocky white phenocrysts of feldspar 0.5 - 1 cm. long, was observed at the corresponding horizon (specimen 31305). The rock, although strongly metamorphosed, is identified as an alkaline variety c.f. trachyte (see petrographical section, below). Most of the volcanic layer is poorly exposed; the uppermost 2 m. contains partings at 5 - 10 cm. intervals, parallel to the general stratification. The total thickness of the layer is 25 m.. It is possible that more than one igneous horizon is present.

In section (3), an aphyric igneous rock of basaltic aspect was recorded. The upper part contains low-angle, parallel cleavage planes. In sections (4), the corresponding layer is of aphyric basalt. No partings were observed. In section (5) the rock is a compact aphyric basalt with numerous vein-like partings. The upper contact, which is exposed, is intrusive.

Summing up, it appears that in its principal development at least, the layer is an intrusive sheet of compact, aphyric basalt which tends to develop a cleavage toward the upper contact. The porphyritic alkaline rock of section (2) is very similar to a dike rock encountered elsewhere in the region, which is younger than the Gardar strata preserved here. A sill of the alkaline type may underlie a sill of the compact basalt at this locality and continue north and east to section (1) (Ussing's measured section).

The next igneous layer is of olivine basalt. It persists around the western side of the mountain with thicknesses ranging from 20 m. - 60 m. (op. cit. p. 61) and wedges out at the south-west corner of Nunasarnaussaq. The upper contact has not been seen and it is not certain whether the layer is a sill or a flow. (Ussing refers to the sheet as a sill, but his distinctions between intrusive and extrusive layers are generally unreliable).

Ussing states that the basalt which forms the top of the mountain is about 150 m. thick. This value is considered unduly high and it is unlikely that the thickness exceeds 80 - 100 m.. The basal contact is irregular with local dips and hollows. At the base, the basalt is chilled to a dense, fine grained facies nearly 2 m. thick. Proceeding eastwards from (4) towards the highest point (755 m.) the rock above the basal facies is at first aphyric, a rather coarse, open textured variety which weathers to a pale grey colour and is purplish-green when freshly fractured. Some 20 m. - 30 m. higher in the succession, the rock develops a porphyritic character with the appearance of small platy phenocrysts of plagioclase. These become progressively more abundant and show a tendency toward aggregation, forming stellate aggregates. The basalt of the upper 20 m. is a "star" basalt, resembling the "star" basalts of the Ilímaussaq Peninsula. There is a rough stratification in the basalts of the summit plateau, producing layers ca. 3 m. thick which probably represents individual flows; however, no definitive extrusive structures have been seen. Ussing (op. cit., p. 210) reports that a flow-structure can be seen in some places near the summit.

(b) PETROGRAPHIC NOTES.

In view of the proximity to the Ilímaussaq Intrusive Complex, all of the rocks described are altered to a greater or less extent. Alteration is least in the vicinity of section (4). where some of the tuffs are red in colour (cf. the "tilestones" of the Ilímaussaq Peninsula); elsewhere they are deep purple or greenish black. Towards the contact the sandstones are recrystallised and eventually a tough, vitreous quartzite is produced. The distinction between sandstone and quartzite in the text above is based on field appearance only.

The limited number of thin sections available are from measured section (1) (see Table 3.1), with the exception of specimens 31307 and 31308, which are lavas from near the summit.

<u>40300</u> This specimen is of a dark basic rock which has been altered to a mass of iron ore and fine clay minerals. There are numerous pseudomorphs after olivine crystals, mostly anhedral, though a few are subhedral with a suggestion of pointed terminations. These grains make up about half of the rock;

few are more than 0.5 mm. long. In addition, there are faint traces of narrow, lath shaped grains up to ca. 0.5 mm. long.

There is a suggestion of direction in the fabric; this could be evidence of fluxion structure in a flow or sill, or of bedding in a tuff. In composition, the rock may have been a kimberlite or a picrite basalt. Alteration is so far advanced that neither of these points can be decided. Specimen 31303 is similar.

31301 In thin section, highly corroded grains of quartz and small fragments of quartzite are seen to be set in a matrix of fine clay minerals and silica. Part of the matrix is heavily dusted with fine ore and shows an irregular, swirling, sometimes cross-cutting stratification which may indicate post-depositional slumping.

31302 This greenish black, fine grained rock has a banded appearance produced by pale green, vein-like structures ca. 2 mm. thick, set at intervals of ca. 0.5 cm.. It is believed to be a metamorphosed lamprophyric tuff. The rock is now largely composed of tiny, pale green grains of cf. diopside with some perthitic feldspar, particularly in the "veins". The original minerals are now practically obliterated, save for some ore grains and pseudomorphs after olivine. The latter are preserved in outline by tiny granules of garnet and sometimes enclose "diopside" or occasionally alkali feldspar. The pseudomorphs are near euhedral with pointed terminations and are mostly less than 0.5 mm. in length.

31305 The bulk of this rock is formed by extremely narrow laths of low relief feldspar which has rather uneven extinction but occasionally shows suggestions of perthitic structure. The laths, which have very ragged margins, occur in a range of sizes up to 2 mm. long. There is no sign of directed fabric; instead, the laths tend to be arranged in radiating groups. The mafic minerals which occupied the small narrow interstices have been altered to fine grained indeterminable material of high relief. There is also a sprinkling of fine ore. Harker (1954, p. 158 Fig 55 A.) figures a trachytoid phonolite with similar texture.

31306 This rock, originally a medium grained olivine basalt from the uppermost of the two basaltic intercalations, has been altered to a mass of fine grained clay minerals and iron ore. Even the outline of the plagioclase laths is virtually obscured. Groundmass grains of olivine are outlined by ore. About 15% of original olivine is indicated. The grains are anhedral and grouped in irregular clusters; their habit is quite distinct from that of the olivines in lamprophyric rocks of the region.

31307 This rock is an aphyric olivine basalt. The plagioclase laths show poor size sorting and are up to 1 mm. in length. There are large, interstitial to sub-ophitic pyroxene grains partly preserved and partly altered to pale green amphibole. Olivine grains pseudomorphed by ore and chlorite are very abundant; they are large, often occur in extensive glomero-porphyritic groups and must constitute at least 15% of the rock modally.

31308 Although much more altered than rock number 31307, this rock has been essentially similar. The plagioclase laths show an even greater range of sizes; the majority are from 2 mm. - 0.2 mm. in length and in addition there are some larg er grains up to 1 - 2 cm. across. These phenocrysts are not very sharply demarcated from the groundmass grains with regard to size. In field appearance this rock is classed as a "star" basalt. In thin section it is apparent that its affinities lie with the "star" basalt of the Ipiutaq Volcanic Unit (characterised by interstitial to sub-ophitic pyroxene and rather coarse groundmass feldspar with poor size sorting) rather than the "star" basalt of the Ilímaussaq Volcanic Unit in which the groundmass feldspar laths are very tiny and the pyroxene grains notably ophitic.

Ussing (op. cit. pp. 210 - 213) describes basalts from the top of Nunasarnaussaq which resemble specimens 31307 and 31308, and provides an analysis of a typical example. On the basis of the chemical composition, he then classifies the rock as a trachydolerite. In view of the known metamorphic history of the rock, this nomenclature is misleading and the rock is better referred to as a metamorphosed olivine basalt.

(c) GEOLOGICAL HISTORY

When Gardar sedimentation in the area commenced, the old Basement land surface was deeply weathered and mantled in decayed granitic material.

Approximately the lowest 200 m. of the series is of sandstone, free from volcanic material. The conglomerate horizons point to occasional tectonic activity and indicate subaqueous deposition.

The stratified sandstone and pyroclastic sequence is evidence of persistent explosive volcanic activity. Some of the pyroclastics have been nearly pure volcanic ash, probably lamprophyric; others, of the "tilestone" type, contain a considerable amount of fine, clastic sedimentary material also probably of pyroclastic origin. A conglomeratic agglomerate is recorded in which well rounded pebbles and cobbles of sedimentary rock are set in angular fragments of tuff. The thinness and regularity of the alternating sand and tuff horizons in parts of the sequence indicates a cyclic pattern of eruption.

It is probable that most of the tuff was laid under water and pyroclastic and sandy material are frequently combined in a manner which points to contemporaneous deposition rather than mixture by reworking.

The period of persistent explosive volcanic activity was succeeded by a period of volcanic quiescence in the area. Both of the igneous intercalations in the succeeding sandstone are probably intrusive.

Presently, volcanic activity was renewed, this time characterised by the extrusion of olivine basalt. No pillow lavas have been recorded, so it is assumed that the extrusion took place under continental conditions.

Intercalations of continental sandstone between flows have not been recorded; this may imply that the flows followed one another in rapid succession.

CHAPTER IV. THE IGALIKO AREA.

(a) GEOLOGY

Initial mapping of the area was carried out by V. Poulsen in 1961. The author spent two and a half days there in the following year, paying particular attention to the three lowest volcanic horizons on the slope south-west of Igaliko village; in addition, a brief excursion was made to the volcanic layers in the west of the area.

The accompanying map (Fig. 4.2) is essentially that prepared by Poulsen, with omission of the dikes and slight amendments to the boundaries of the lower volcanic horizons.

Basement granite occurs in the low ground around the head of Igaliko Fjord. The basal facies of the Gardar Series is infrequently exposed. In most respects the earliest Gardar sediments at Igaliko (i.e., those which underlie the lowest volcanic horizon) resemble those of the Mâjût Sandstone Unit on the Ilímaussaq Peninsula (cf. Chapter I). Due to faulting, the full thickness is not exposed in this area; a thickness of some 100 m. is exposed above Igaliko village. Here, the upper part closely resembles the development at Sitdlisit (cf. Chapter I). There are horizons with ripple-marks and conglomeratic beds with small pebbles of sedimentary rock types. Varieties similar to the "Igaliko Sandstone" also occur. Above the lowest effusive horizon, the sandstone becomes coarser and

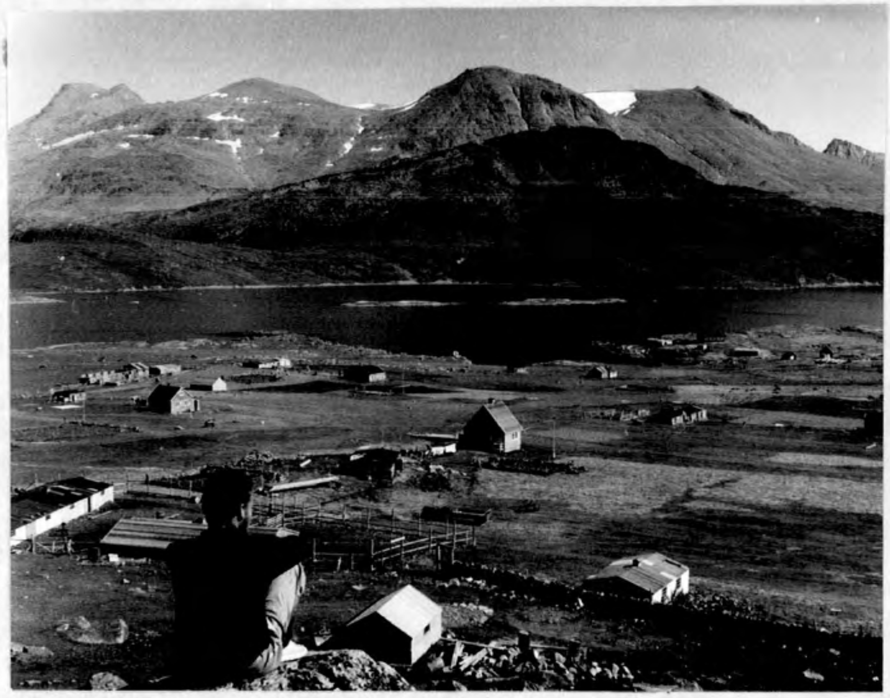
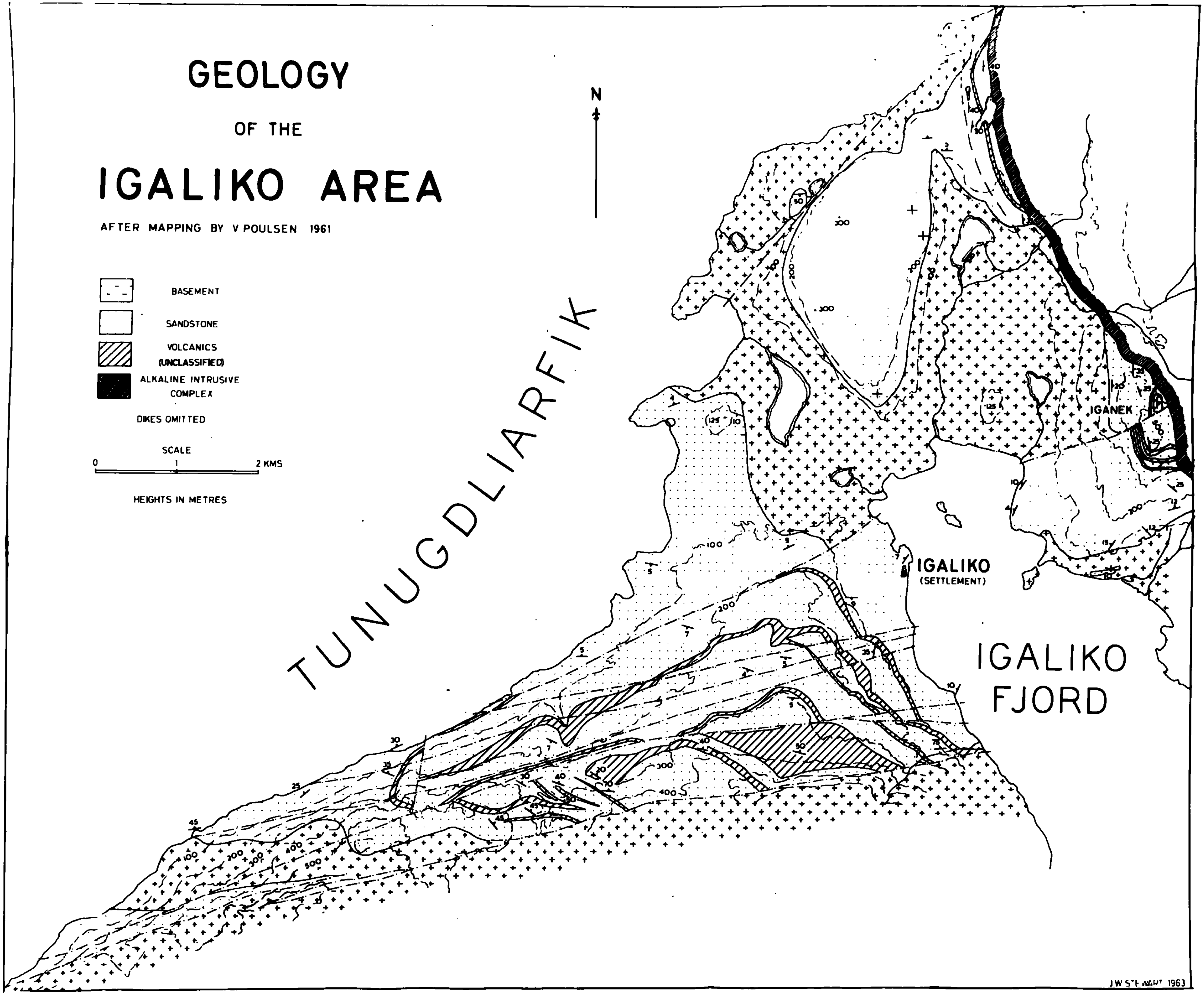


Fig.4.1. Igaliko settlement from the south-west. The hill Iganek lies across the fjord and the syenite hills of the Igaliko Intrusive Complex are in the distance.

Fig.4.4. Streams "N" and "S" on the hill-side south of Igaliko.


GEOLOGY
OF THE
IGALIKO AREA
AFTER MAPPING BY V POULSEN 1961
BASEMENT
SANDSTONE
VOLCANICS
(UNCLASSIFIED)
ALKALINE INTRUSIVE
COMPLEX
DIKES OMITTED
SCALE
0
1
2 KMS
HEIGHTS IN METRES
N
TUNUGDLIARFIK
IGALIKO
(SETTLEMENT)
IGALIKO
FJORD
IGANEK

occasionally conglomeratic. No coarse conglomerates similar to those of the Musartût Unit are seen (cf. Chapter I). The above paragraph summarises observations by V. Poulsen (1961).

The hillside south of Igaliko village has a distinct terraced appearance as the result of the different rates of weathering of the alternating sedimentary and volcanic horizons. The compact, intrusive basalt is the most resistant rock, as a rule, and produces the most pronounced features.

The lowest three volcanic layers above the village are of rather more complex structure than local inspection would indicate. All appear to be composite and while the overall thickness may be rather constant, the thickness of the individual components is subject to considerable variation.

In the field, a preliminary subdivision of the layers into components is readily effected, viz.:

(i) dark, greenish, compact basalt, aphyric and fine grained, often columnar, usually quite fresh in appearance.

(ii) reddish brown, deeply weathered rocks, sometimes showing spheroidal exfoliation. While the nature of the rock type is generally obscure in outcrop, there is often a superficial resemblance to tuff. Certain layers are distinctly fragmental and locally the fragments may be of a size suggesting a comparison with agglomerate. Compact and vesicular layers also occur; it was suspected in the field that certain of these might prove to be lavas and subsequent thin-section examination has shown them to be meta-olivine basalt.

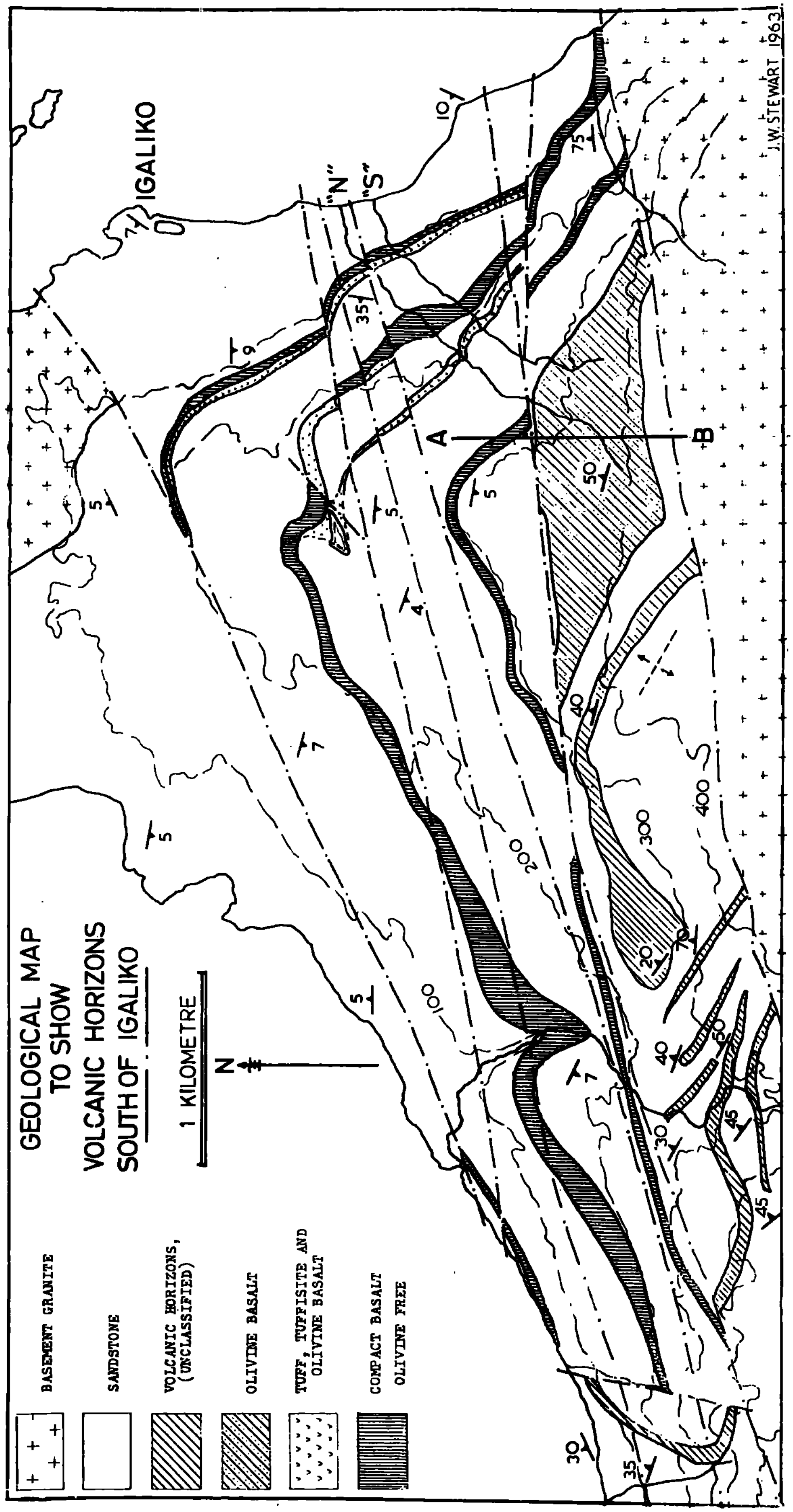

GEOLOGICAL MAP
TO SHOW
VOLCANIC HORIZONS
SOUTH OF IGALIKO
1 KILOMETRE
N
IGALIKO
"N"
"S"
A
B
100
200
300
400
J.W. STEWART 1963
BASEMENT GRANITE
SANDSTONE
VOLCANIC HORIZONS, (UNCLASSIFIED)
OLIVINE BASALT
TUFF, TUFFISITE AND OLIVINE BASALT
COMPACT BASALT OLIVINE FREE

Fig. 4.3.

Table 4.1

The (N) and (S) Stream Sections

About 1 km. south of Igaliko village, two parallel streams about 200 m. apart flow north east down the hillside. Both are quite deeply incised and exposure is reasonably good. A composite stream profile was taken, changing from one stream to the other as exposure directed. For convenience, the streams are named "(N)" and "(S)", being the more northerly and more southerly streams respectively (see Figs. 4.3 and 4.4).

TOP

Metres	
205-250	Sandstone. Above the third volcanic horizon, exposure is very limited. The important 85° fault which crosses the streams at 250 m. may be taken as the upper limit of this succession.
195-205	Volcanic Horizon (3). A 10 m. thick layer of tuff-like rock. The lower part resembles Volcanic Horizon (1), shows vesicular development and seems to consist of a series of layers ca. 2 m. thick (probably a succession of flows of olivine basalt); spheroidal weathering is common. The top 2 m. of the horizon is of quite a different nature, being distinctly fragmental and resembling agglomerate. The fragments, which are dark purple or nearly black, range in size

from ca. 10 cm. down to tiny pellets 1 mm. in diameter. The fragments are sub-angular to well rounded. Shape is usually elongate and the long axes tend to be orientated parallel to the stratification. The fragments are very closely packed, without any obvious systematic size-sorting, in a fine-grained pink matrix. Small, anhedral bodies of green(chlorite) and pink (alkali feldspar) material, a few mm. in diameter, fleck the rock. The mode of formation of this rock-type is uncertain (see petrographic section below).

160-195 Sandstone,,with occasional pebbles. At 190 m. there is a 1 m. layer of "puddingstone", a fine conglomerate with numerous well-rounded pebbles of white quartz and red chert-like material. No volcanic pebbles have been seen.

135-160 (S) <u>Volcanic Horizon (2)</u>. Dense, compact, fine-grained basalt with well-developed columnar structure. The columns are ca. 30 cm. in diameter.

80-135 The "tuff" is succeeded by a coarse, arkosic sandstone with frequent impersistent layers of well-rounded sedimentary pebbles seldom exceeding 3 cm. in diameter.

60- 80 <u>Volcanic Horizon (1)</u>. A compact, dark, fresh-looking basalt layer 6 m. thick is overlain by a red tuff-like rock 10 m. thick. The "tuff" has a ½m. thick vesicular layer near the top (meta-olivine basalt). The uppermost part of the tuff is much veined by proportions of lava and clastic rock are unknown.

Volcanic Horizon (2). In the stream section, a layer of compact, columnar basalt is the sole representative of this horizon. To the north west, however, the horizon becomes composite. About 250 m. north west of stream (N), between the most southerly of the three parallel 80° faults and the next fault to the north, 7 - 8 m. of compact basalt is overlain by 3 m. of a tuff-like rock. Beyond, as far as the northerly 80° fault, compact basalt occurs and is about 30 m. thick. Beyond this fault, the horizon becomes more complex; poor exposure and two intersecting dikes tend to confuse the picture.

A small body of monchiquite lies immediately north of the northerly fault. This heavily altered rock is closely similar in appearance to that found at Sitdlisit and Qagssiarssuk. The rock has been subjected to intense cross jointing which tends to split it up into small blocks (Fig. 4.5). The outcrop is only a few square metres in extent; to the north, a red tuff-like rock has a sharp, apparently intrusive contact against it. About 2 m. thickness of this rock is exposed (the base is drift covered). It is a compact rock, containing sparse, angular fragments of sandstone.

This is followed by a 5 m. layer of a conglomerate-like rock which has many features in common with the volcanic breccia and "conglomerate" at Sitdlisit (Chapter I). Well-rounded pebbles and cobbles of quartzite and sandstone, large angular blocks of sandstone and rounded blocks of monchiquite are closely packed in a matrix of dark grey, calcareous tuffisite (Fig. 4.6).

Fig. 4.5. Outcrop of closely jointed alnöite.

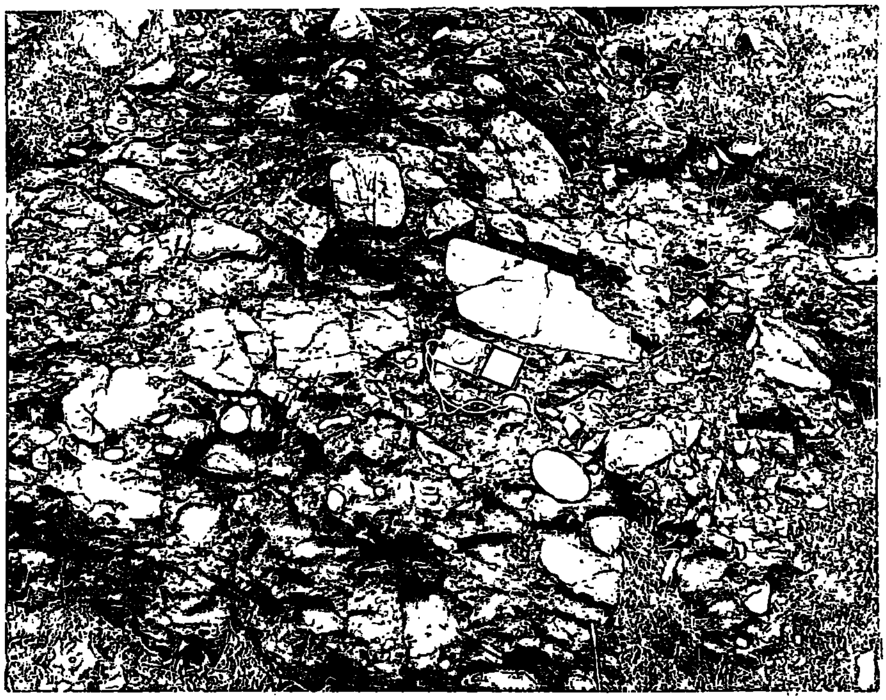


Fig.4.6. Volcanic breccia, containing large blocks of sandstone, rounded pebbles of sandstone and quartzite and exfoliated, rounded blocks of alnöite.

The monchiquite inclusions are of material identical in appearance to the adjacent monchiquite outcrop; this latter may be the source rock of the igneous inclusions. While the relationships of the "conglomerate" are not sufficiently clear to permit a definite conclusion as to the mode of origin, the similarities to the Sitdlisit occurrence are so striking as to suggest strongly that the Igaliko rock was formed in a similar manner.

While the "conglomerate" at Sitdlisit is developed within a prominent sedimentary conglomerate horizon, there is no evidence of such a conglomerate layer at Igaliko. It is possible that there was a conglomerate body of very limited extent (e.g., in a fossil river bed), or that the conglomeratic material was introduced intrusively from elsewhere. Well-rounded pebbles of quartz, a prominent constituent of sedimentary conglomerates throughout the region, are also common in this "conglomerate". So far as is known, there is no primary source of large quartz fragments (e.g. thick quartz veins) in the underlying sediments and the absence of accompanying granitic Basement material precludes a deeper source. Accordingly, the quartz pebbles and no doubt many of the sandstone pebbles as well, must have been derived from conglomerates already extant.

The "conglomerate" is overlain by a dark red, very compact, well bedded "tilestone", closely similar to "tilestones" found at Musartût and Qagssiarssuk. The "conglomerate" does not persist very far to the north west and the volcanic horizon appears to revert to undifferentiated red "tuff". This rock

Fig.4.7. Columnar jointing in sill of fine, aphyric basalt.

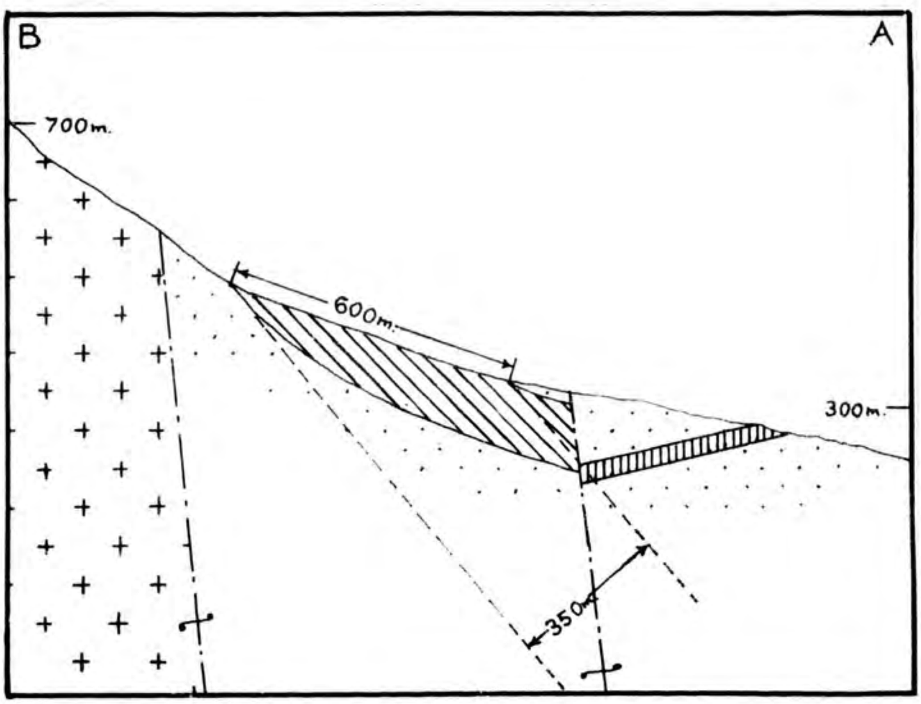


Fig.4.8. Cross-section A - B (refer Fig.4.3.)
Not to scale.

stops abruptly at a 60° fault on the eastern side of the small lake. Beyond, there is a layer of compact, columnar basalt, 5m. or more in thickness (Fig. 4.7). The base of this layer must be at approximately the same level as the top of the "tuff" layer south of the fault. A short distance to the west, on the lake shore, the basalt is seen to be overlain by a 2 - 3 m. layer of red, heavily altered (olivine?) basalt. This layer is probably in continuity with Volcanić Horizon (3).

Further west, the red volcanic layer appears to be absent and the horizon consists of a single component - - the sill of compact basalt.

<u>Volcanic Horizon</u> (3). This horizon appears to consist of red, metamorphosed olivine basalt overlain by a layer of fragmental rock. The lava is often amygdaloidal, tending to become more so in the upper part of the layer. Locally, chalcedony-filled vugs up to 2 cm. in diameter are developed. So far as is known there is no intrusive, compact basalt at this horizon. Probably more than 10 m. thick in the south part of the area, the horizon gradually thins northwards. 700 m. north west of stream (N) it is 5 m. thick.

<u>Volcanic Horizon</u> (4). A narrow outcrop of basalt occurs on the hillside south west of Igaliko just below the 300 m. contour. Its stratigraphical position is ca. 100 m. above Volcanic Horizon (3). The nature of the layer is known only from a specimen collected by Poulsen (44447). The specimen is of a compact, olivine-free basalt and analogy with other

such rocks from lower horizons suggests that the sheet is probably intrusive.

This horizon is overlain by sandstone of which a thickness of approximately 50m. remains. This is the highest stratigraphical level reached in the main Igaliko fault block.

A contact with implications of considerable importance is exposed ca. 1km. south west of Igaliko.

The outcrop, which is about 100m. across, is located on a rather flat terrace, probably that between Volcanic Horizons (1) and (2). A reddish brown tuff or tuffisite breccia, containing angular fragments of sandstone seldom exceeding 10cm. across, is seen to be underlain by columnar basalt on a small, steep, eastward-facing exposure on the eastern fringe of the main outcrop. It is quite clear that the columnar basalt is intruding the other rock. While there is a possibility that the breccia belongs to an isolated diatreme, it is more probably in continuity with one of the reddish "tuff" layers, probably that of Volcanic Horizon (1).

<u>Other Volcanic Layers</u>. The most extensive development of volcanic rocks about Igaliko is the rhomb-shaped area of basalt which lies just north of the southern boundary fault. It has an area of ca. 1 square km.. Exposure is very limited around the northern and north eastern sides of the body, at the lower

topographical level. A rather coarse, aphyric, structureless grey basalt was observed in stream (S) at 300m.. Although deeply weathered, the rock is quite different in appearance from the olivine basalts of the volcanic horizons above Igaliko. Olivine (pseudomorphed) has been tentatively identified. In the headwaters of stream (N), basalt is exposed above 345m.. The variety is olivine-bearing, micro-porphyritic, with clusters of tiny plagioclase phenocrysts. Vesicular texture is common and various structures characteristic of effusive lava were seen. The rock resembles the basalt of Qagssiarssuk shore and the effusive basalts at Musartût. Since the stratification is inclined toward the north, the micro-porphyritic olivine basalt is presumably overlain by the aphyric variety.

The total thickness of the basalt horizon cannot be determined accurately. The map does not adequately convey the structure of the fault block, in which the strata are folded as well as tilted. A straightforward construction based on an east-west strike, a 50° dip to the north and an outcrop width of 600m. would indicate a true thickness of ca. 350m.. This is certainly incorrect and the base of the horizon is probably curved with the dip angle decreasing northward. A similar construction, based on an outcrop width of 140m. (the minimum width in a north-south direction) yields a thickness of 90m., which is considered to be more realistic, but possibly still excessive (see Fig. 4.8).

The two narrow volcanic horizons which lie to the east have not been visited. Specimens collected by Poulsen (44438 and 44442) indicate that both layers have affinities with the compact basalts.

Little is known about the volcanic horizons in the west of the area. Three specimens are available, 44452, 44453 and 61801. Of these, two are of compact basalt, the third (44453) of metamorphosed olivine basalt. A rather extensive succession is displayed on the narrow fault block north of the southern boundary fault. To the west, the Basement is exposed, overlain by Gardar sandstone. The narrow, sinuous volcanic layers are presumably the local equivalent of the volcanic horizons on the hillside above Igaliko, but no correlation is possible at present.

Observations on the Geology of Iganek.

A brief visit was paid to Iganek during a helicopter reconnaissance in 1960. The following observations were made on this occasion.

On the south side of the fault which traverses the hill, about 250m. of sediments underlie the lowest meta-basalt horizon. Intense thermal metamorphism by the adjacent intrusion has transformed the sandstone into quartzite and the volcanic strata to black, glistening hornfels.

The sandstone below the volcanic horizons contains centimetre-thick layers of a fine-grained black material, parallel to the stratification. Four principal volcanic horizons were recorded; the thicknesses recorded are only a rough approximation.

The top two layers were between 10 and 20m. thick, the next layer down about 10m. thick and the lowest less than 5m. thick. The fabric of the volcanic horizons along this flank of the intrusion has been totally recrystallised and no features have been observed which would indicate whether the layers were intrusive or extrusive.

(b) PETROGRAPHY

Compact Basalt. The degree of alteration varies; in the least altered specimens pyroxene remains; even in the most altered the igneous texture is usually preserved and a little plagioclase generally escapes obliteration. The compact basalts are characterised by an undirected fabric of plagioclase laths in which no particular lath size is dominant. The group is distinguished from the olivine basalts by lack of olivine and absence of platy feldspar phenocrysts. Small, blocky phenocrysts of vitreous-looking feldspar occur rarely. Iron ore is sometimes an important constituent.

Pyroxene is usually altered to chlorite, iron ore and carbonate. The plagioclase is usually sericitised to some extent, sometimes very heavily; occasionally other alteration products, in particular carbonate, are developed. When alteration of the rock is strong, the twinning of the plagioclase becomes indistinct and the lath margins ragged. In extreme cases refractive index becomes lower than that of canada balsam.

The most intensely altered specimens (44438 and 44442) are from two narrow horizons in the extreme south-east of the area and in 44442 the original minerals are almost totally obliterated, although texture is just distinguishable. Sphene is developed .

Two varieties of compact basalt are distinguis hed:

(i) (e.g. 61787) a coarse, feldspathic type with 10 - 15% of primary ore. The plagioclase laths are ½ - 1mm. long. Pyroxene, which is interstitial, is scarcely more abundant than the ore. The compact basalt of Volcanic Horizons (1) and (4) and of the two most easterly horizons on the narrow, southern faulted block, are of this type.

(ii) (e.g. 61790) plagioclase laths are of all sizes up to 1mm.. The pyroxene grains are sub-ophitic and extensive, perhaps as much as 5mm. across. Plagioclase and pyroxene are in approximately equal quantities. Primary ore is not abundant.

Meta-Olivine Basalt. A strongly transformed olivine basalt is found in Volcanic Horizons (1) and (3) and it also outcrops in the west of the area.

In thin section, the nature and relationships of the original minerals can sometimes be distinguished. There has been a marked size-sorting in the plagioclase grains, with two sizes of laths predominating: (i) microlites, 0.2 - 0.5 mm. long, (ii) microphenocrysts, 2 - 5 mm. long, often grouped in small clusters. Pyroxene was sub-ophitic or ophitic; its abundance cannot be determined. Olivine has been identified in pseudomorphed form in a few sections (e.g. 44444); it has been a rather prominent constituent, making up 10% or more of the rock in some cases. In general there is little variation in texture and it is likely that the mineralogy was rather constant. In texture and in original mineralogy, the rock is very similar to the effusive olivine basalt at Qagssiarssuk (Chapter V).

The original minerals are now completely replaced by haematite and alkali feldspar. Iron ore occurs along the original grain-boundaries, preserving the texture. The mafic minerals are replaced by irregular aggregates of ore and alkali feldspar; the plagioclase laths, as a rule, have been made over to a mosaic of tiny anhedra of alkali feldspar ca. 0.01mm. in diameter. Investigation of the 61738 by X-ray diffraction shows that a single, monoclinic feldspar phase is present. Analysis of the same specimen for alkalies gave the following result:

	Wt.%
Na_2O	0.50
K_2O	11.6

The alkali feldspar must be sanidine or orthoclase.

Olivine Basalts. The basalts of the large volcanic outcrop on the narrow southern block are olivine bearing. They have escaped the metasomatism to which the above group has been subjected and the alteration pattern resembles that of the compact basalts.

The lower aphyric basalt is rather coarse and even-grained with plagioclase laths ca. 1mm. long. Pyroxene, of which a little has been preserved, has probably been subsidiary to feldspar in amount. Pseudomorphs after olivine have been identified with fair certainty, making up ca. 5% of the rock (e.g. 61892).

The other variety of olivine basalt, developed at a higher topographical level, is a finely feldsparphyric variety with a texture similar to that of the metasomatised basalts. The specimens available are unfresh and yield little information.

<u>The Fragmental Rock</u>. (e.g. 61791 and 44445) In thin section it is apparent that this rock has been subjected to the same metamorphic processes as the accompanying meta-olivine basalt and, like it, has been extensively replaced by monoclinic alkali feldspar (X-ray identification). The groundmass is just recognisable as a heavily altered lava in which the original feldspar laths had moderate flow direction. The replacive minerals are the same as in the meta-olivine basalt, but apart from the feldspar laths, the original mineralogy is unknown. The general appearance of the rock and its close association with the olivine basalt suggest a similar composition.

The inclusions are of five kinds:

(i) Rounded pellets of chilled lava.

(ii) Angular fragments of coarser lava.

(iii) Large rounded quartz grains.

(iv) Angular fragments of fine tuff, cf. "tilestone".

(v) Angular fragments of feldspar derived from the basement rocks.

The chilled pellets or lapilli and the coarser lava fragments have been subjected to wholesale replacement by opaque ore, relieved only by slender, rectangular pseudomorphs after laths of feldspar (of possibly melilite), now replaced by fine alkali feldspar or chloritic material. The iron ore replacement recalls the alnöite lapilli at Qagssiarssuk (Chapter V), however, in the present instance there are no pseudomorphs after euhedral olivine and the texture of the coarser fragments is comparable with that of the associated olivine basalts.

The quartz grains, usually quite well rounded, have been wholly or extensively replaced by rather clear alkali feldspar. The surrounding matrix is pigmented red with very tiny haem[illegible] inclusions which become increasingly concentrated toward the grains. In a number of cases some quartz remains; despite intricate intergrowth with a number of replacive grains of alkali feldspar, the ramifications of the quartz skeleton may maintain optical continuity (Fig. 4.9).

The fine tuff or sandstone consists of rather closely packed, angular grains in an obscure matrix which appears to be of alkali feldspar heavily dusted with fine inclusions. The average diameter of the grains is about 0.1mm.; most of the grains are now of alkali feldspar, but a few quartz grains remain and there are some opaque grains.

The grains of feldspar, believed to have been derived

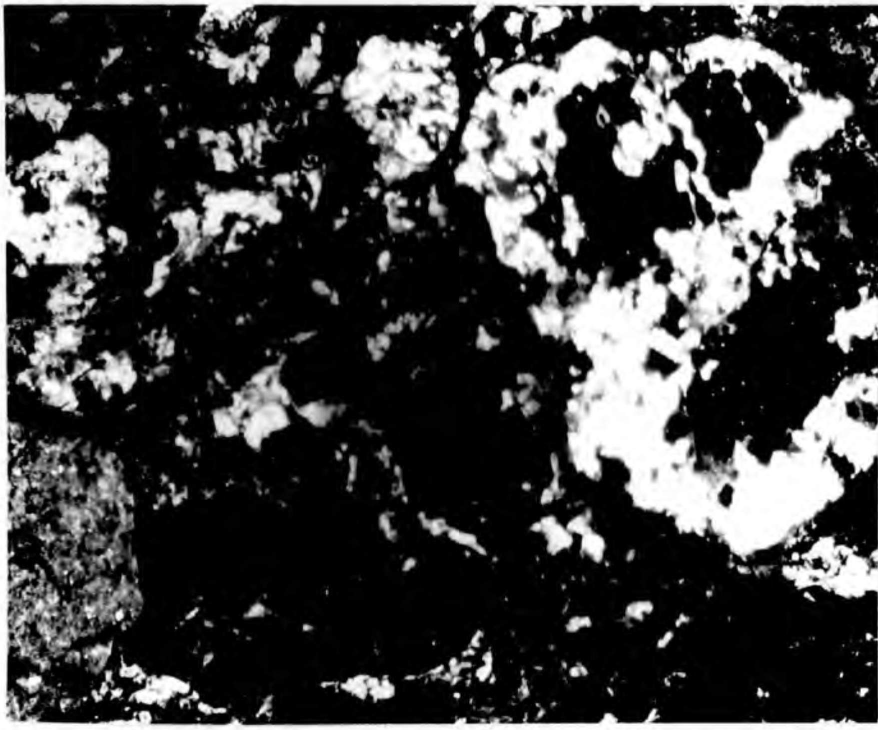


Fig.4.9. Photomicrograph of 44445, x40, under crossed polars, to show quartz grain (right) extensively replaced by alkali feldspar. The quartz is white, the alkali feldspar dark grey.

from the Basement, are angular and often several millimetres across. Most were probably microcline, originally. Cleavage is usually preserved and traces of fine perthite-like structure can sometimes be seen. The grains are generally quite turbid and tend to maintain optical continuity in contrast to the replaced sandstone grains which are made up of a number of clear alkali feldspar grains with different orientations.

Monchiquite. (61802) This rock appears to be identical with the carbonised monchiquite found in intrusive sheets and diatremes in the Qagssiarssuk area (Chapter V). Euhedral pseudomorphs after olivine are set in a fine groundmass of carbonate and chlorite.

"Conglomerate". (61799) The groundmass consists of rather clear, anhedral grains of carbonate 1 - 2 mm. across. The following types of inclusions have been found:

(i) Monchiquite, similar to that described above. Size ranges from several decimetres down to single, isolated pseudomorphed olivine grains.

(ii) Rather obscure, highly carbonatised types a few millimetres in diameter, sprinkled with fine ore. Lath-shaped carbonate pseudomorphs, probably after melilite, are occasionally quite abundant. Rarely, traces of a dark mica may be seen. Another variety of this rock type is heavily impregnated with iron oxide; rounded bodies of opaque material, several millimetres in diameter, contain spherical vesicular structures up to ca. 0.2 mm. in diameter filled with material cf. zeolite arranged as radiating fibres. In a few instances there are indications of lath-shaped crystals and possibly also of pseudomorphs after olivine.

(iii) Well to poorly rounded grains of quartz, mostly less than 1 mm. in diameter. Some are rather strained; there is no indication of replacive alkali feldspar.

(iv) Pebbles of quartz and sandstone. A small pebble of sandstone was sectioned. The groundmass is of very fine-grained quartz which shows signs of minor recrystallisation. The sand grains ar e generally poorly rounded; many have rather extensive zones of secondary quartz around the periphery, often showing numerous concentric growth lines. X-ray investigation of the pebble showed that alkali feldspar was not present in detectable amount.

All of the inclusions have a coating of opaque material a fraction of a millimetre thick.

"Tilestone". This rock is comparable to other "tilestones" on the Ilímaussaq Peninsula, although the grains are packed unusually closely. Most of the grains are of quartz, some with an internal growth line. Rounding and sphericity are moderate to high. The grains range up to 1.0 mm. in diameter, but the average size is nearer 0.2 mm.. A fragment of calcareous rock about 1 mm. across has been observed which may have affinities with the carbonatised melilitites of the Qagssiarssuk area; there is a suggestion of parallel lath structure and there are some square grains believed to be skeletal sphene pseudomorphing perovskite. A number of microcline grains and a euhedral zircon are presumably derived from the basement granite. The matrix is so heavily impregnated with fine ore dust as to be almost opaque. There is a considerable amount of interstitial carbonate, some in small vug-like structures and some apparently replacing the matrix. There is no sign of monoclinic alkali feldspar tending to replace the quartz or the microcline.

(c) GEOLOGICAL HISTORY.

At Igaliko, the deposition of water-laid, arenaceous sediments has alternated with the eruption of volcanics under terrestrial conditions. The sediments contain frequent conglomerate horizons; volcanic detritus is seemingly absent. Subsequently, other igneous material has been intruded into the sedimentary and volcanic sequence.

Three principal volcanic episodes have been distinguished. They are listed below in order of decreasing age.

(i) The extrusion of olivine basalt, represented by parts of

Volcanic Horizons (1), (2) and (3). The fragmental rock probably indicates an explosive phase at the close of the third period of extrusion, associated with the same magma. Further extrusion of aphyric and micro-porphyritic olivine basalt is evinced by the large area of volcanic rocks on the southern fault block. These must belong to a stratigraphical horizon above the succession of the main Igaliko block (Fig. 4.10).

(ii) The intrusion of tuffisite. The "tuff" found adjacent to the olivine basalt of Volcanic Horizons (1) and (3) is believed to be intrusive. At Qagssiarssuk (Chapter V), intrusive micro-breccias (tuffisites) associated with ultramafic carbonatite vulcanism are accompanied by potash metasomatism. Thus, at Igaliko, it is assumed that the potassic feldspathization of the olivine basalt was related to the emplacement of the tuffisite.

The monchiquite body and the "conglomerate" are certainly connected genetically to the lamprophyre-carbonatite vulcanism (cf. Sitdlisit, Chapter I), but they do not appear to have associated potash metasomatism.

(iii) The intrusion of the compact basalt. All the layers of compact basalt are probably intrusive and of the same age. The magma type was quite different from that of the extrusives, being essentially aphyric and olivine-free.

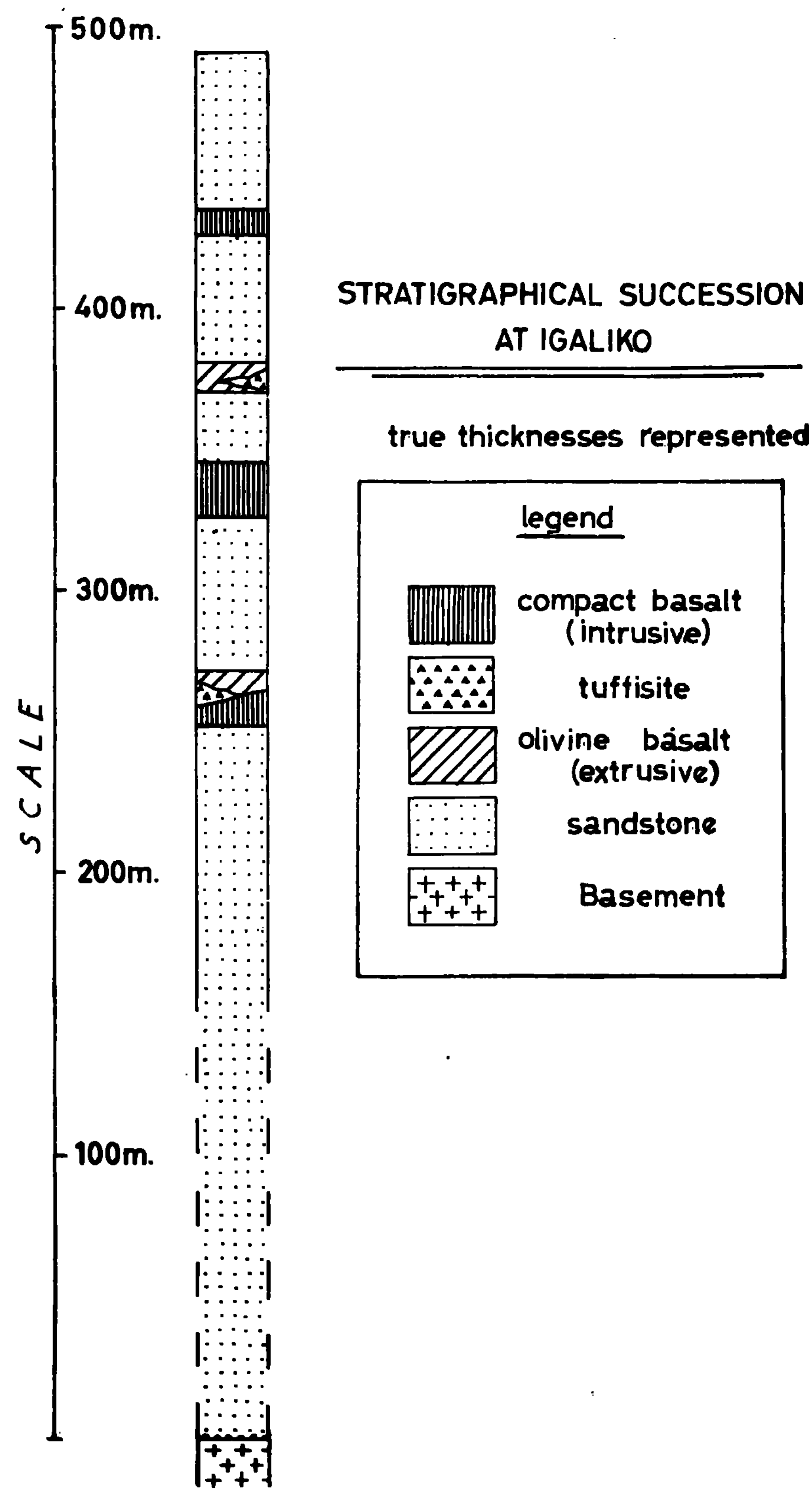

500m.
400m.
300m.
200m.
100m.
SCALE
STRATIGRAPHICAL SUCCESSION
AT IGALIKO
true thicknesses represented
legend
compact basalt
(intrusive)
tuffisite
olivine básalt
(extrusive)
sandstone
Basement

Fig 4.10

V. THE QAGSSIARSSUK AREA.

(With notes on the country north of Narssarssuaq)

(a) GEOLOGY

1. Minor Intrusions in the Basement North of Qagssiarssuk.

At the northern end of Qagssiarssuk settlement, rocks of the Gardar Continental Series give way to basement granites and gneisses. The boundary is at least partly defined by a 60° fault with downthrow to the south-east. The granite country to the north of the boundary forms a series of rounded hills, rising to a fairly well -defined erosion level at 300 m. to 400 m.. There is extensive soil cover, supporting a good growth of low herbage, and exposure is limited to shore and stream sections and to sporadic outcrops, the latter being more common on hill tops.

Viewed from a distance, the most salient features of an otherwise repetitive landscape are:

(i) the dikes, which tend to be more resistant to erosion than the country granites,

(ii) scattered patches of limonitic soil with colours ranging from ochre to dark brown, which indicate the presence of carbonatised ultramafic intrusions.

The dikes often protrude like walls above the granite surface and, viewed from vantage points, their courses can sometimes be followed by the eye for several kilometres (cf. Wegmann, 1938, pp. 68 and 69). Many of the dikes display a characteristic colour; the alkaline dikes weather to shades of red, the basic dikes to black or brown and the "Big Feldspar" dikes are whitish. Most of the dikes strike at ca. 60°, but very thick dolerites of an early intrusive phase, striking 80°-100°, occur in the north of the region.

In the field, the ultramafic intrusives were provisionally classified as carbonatites because of their resemblance to thin dikes of "carbonatite" seen by the author some years previously in the vicinity of the Mbeya (Panda Hill) Carbonatite, Tanganyika. In their description of that complex, Fawley and James (1955, p. 577), referring to brown and yellow carbonatites of their dolomitic group, remark that some of these are beforsite dikes. They continue ----- "Others are various types of carbonatised dikes, some of which may have been alnöite". James (1958, p. 7) subsequently confirmed the presence of alnöite.

The ultramafic intrusions are of two structural types,

(i) Thin intrusive sheets, usually inclined at low angles

(ii) Steep, pipe-like bodies.

Both the sheet intrusions and the pipes may contain coherent intrusive volcanic rock (i.e., magma which has

Specimen number	Appearance on weathered surface	Appearance on fresh fracture	Identification from thin section.
61607	Warm-brown coloured rock of homogeneous appearance, cut by 5cm. thick nodular band of same colour. (fig.5.3)	Both units are white, marble-like. The host rock contains numerous black specks, the nodules are dark grey.	Mica peridotite cut by nodular micro-uncom-pahgrite. (The black specks are dark mica).
61682	Warm-brown, very rough knobbly surface with protruding, large black ore grains.	Dark grey, compact, fresh-looking rock, resembling pale dolerite.	Biotite monchiquite. The ore grains are corroded magnetite phenocrysts.
61685	Pale brown, fine-grained rock. Flow structure is indicated by parallel allignment of tiny, rectangular pits and dark, elongated vesicles.	Very pale grey, with white, rectangular phenocrysts and dark green vesicle fillings.	Monchiquite; the rect-angular pits are weathered-out carbonate pseudomorphing olivine phenocrysts.
61630	Small black nodules, closely packed in a dark grey matrix.	Black, tough, flinty rock. The nodules are scarcely distinguishable from the matrix.	Nodular uncompahgrite. The nodules which are of "lam-prophyric" material, are partially disintigrated, merging into the groundmass.

Table 5.1.

solidified *in situ*) or fragmental intrusive types of which both igneous and country rock may be constituents. In some cases coherent and fragmental igneous rocks coexist in the same intrusion.

The same igneous rock types are common to both the sheet-like and pipe-like intrusions. These are:

(i) Lamprophyre

(ii) uncompahgrite (melilite-rock)

The term lamprophyre embraces a range of ultramafic, chrysophyric rock types; monchiquite, mica-monchiquite, alnöite and mica-peridotite (? kimberlite) have been identified in thin-section, but in the field it is seldom possible to make this distinction. Both the lamprophyre and the uncompahgrite are invariably heavily carbonatised and again separation of the two types in the field is often difficult or impossible. Typical specimens of the principal rock types are listed in Table 5.1; the appearance of the weathered surface of each specimen is tabulated against the appearance of the freshly broken surface and against the thin-section identification.

In a number of instances there is evidence of intrusion at more than one period. Where the intersecting types have been identified, the older has proved to belong to the lamprophyric group and the younger to be of the melilite-rock. Some characteristics of the field appearance of the two types are compared in Table 5.2.

The ultramafic intrusives are occasionally cut by dikes of the 60° swarm, but no intersections with the east-west dolerites have yet been recorded. The present investigation is confined to the ultramafic rocks.

The carbonatised ultramafic rocks tend to weather rather readily and the resulting, characteristically coloured limonitic soil spreads rapidly; accordingly, extensive areas of this soil often prove, on closer examination, to emanate from intrusions of very limited outcrop area.

Table 5.2

Characteristics seen in outcrop	Lamprophyre	Uncompahgrite
Large ore grains, mica, indications of pseudomorphs after olivine	May be present	Absent
"Ultrabasic" weathering pattern	May be present (See Fig. 5.3)	Absent
Small, well rounded, nodular inclusions.	Absent	May be present
Pronounced "flow" structure	Rare	May be present

The Sheet Intrusions.

The majority of these are sill-like bodies about a metre thick, striking east-west and dipping south at an angle of 25° - 30°. Steeply inclined sheets also occur, but these are thin and numerically unimportant. Few dip and strike measurements were taken away from the shore section and there is not sufficient data available to build up a regional pattern of the disposition of the sills; in particular it is not known whether there is an overall concentric (cone-sheet) arrangement as at Alnö.

In detail, the intrusive sheets show considerable irregularity in disposition and thickness. The lower and upper surfaces of an individual sheet are seldom plane or parallel. In general, the disposition of the sheets cannot be related to any visible structure in the country rock. The sheets are impersistent strikewise, thinning, transgressing, splitting and generally tending to form an anastomosing complex more or less confined to a particular plane (Fig. 5.1). There are indications that preferred planes of intrusion occur in the country rock at intervals.

A well-exposed, kilometre-long section of such a zone outcrops in the river immediately inland from Qordlortoq. Anastomosing is pronounced and successive outcrops along the strike may display a single thick sheet (maximum thickness recorded is 15 - 20 m.), or a number of parallel thin sheets. There are occasional stretches where intrusion is restricted to mere veinlets, or is wholly suppressed. A few thick sills outcrop in this vicinity with an unbroken outcrop of about half a kilometre. They weather to a very dark brown colour and are visible from a considerable

Fig. 5.1. Anastomosing sheets of uncompahgrite in gneiss.

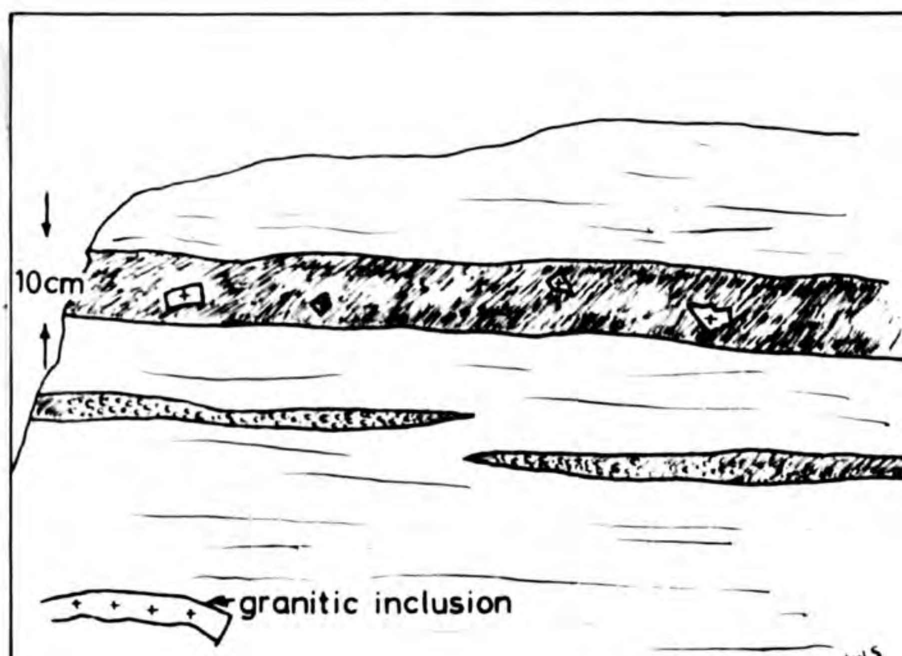


Fig. 5.2. Nodular uncompahgrite sheets intruding ultramafic sill, Qordlortoq River.

distance as prominent dark lines along the hillsides. One such sill outcrops on the hillside south of the Qordlortoq river between 100 m. and 200m. Another linear outcrop can be seen high on the west side of the deeply incised tributary valley which comes in from the north-east. It inclines gently to the south. Numerous outcrops of similar material on the lake-studded, 400 m. plateau immediately to the west, may result from the intersection of this body by the present topographical surface. A similar structure is indicated at about 300 m. altitude, three to four kilometres west of Qagssiarssuk, where such rocks outcrop abundantly over about two square kilometres. Low angle, planar contacts are displayed in some cases.

Some 40 sills, half a metre or more thick, are exposed on the shore between Qagssiarssuk and Umiussat. Approximately the same number is judged to be concealed by drift. Thicknesses of 15 - 20, 10 and 5 metres were noted in single instances; such values are exceptional, however, and the greatest number of sheets have thicknesses in the range 0.5 m.- 1.5 m..

Many sections of the sills show screens of gneiss wholly or partly detached from the wall rock. Gneiss fragments of varying shape and size occur locally in the sills. These inclusions are almost invariably sharp and angular.

There is a tendency for sheets of uncompahgrite to be emplaced preferentially in lamprophyre sheets and such composite intrusions are quite common. Excellent examples can be seen in the Qordlortoq River at ca. 70 m. where sheets

Fig. 5.3. Carbonatised uncompahgrite cutting mica-peridotite.

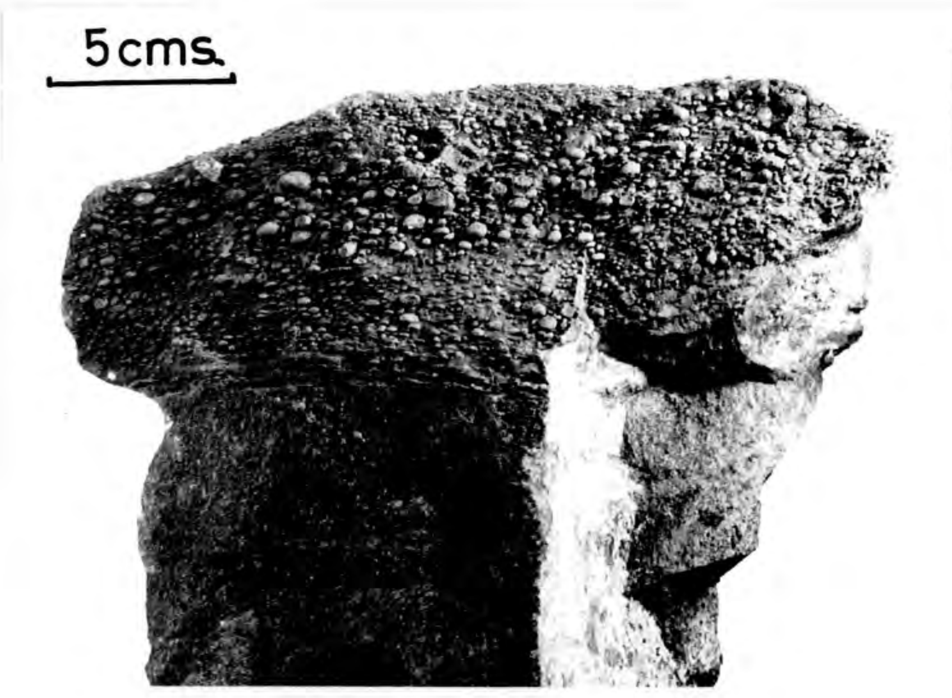


Fig. 5.4. Close-up of nodular uncompahgrite.

and stringers of nodular uncompahgrite up to 20 cm. thick are intruded into a lamprophyre sill (Fig. 5.2). Uncompahgrite is also intruded directly into the country rock.

Nodular Uncompahgrite.

This distinctive variety of uncompahgrite is widely distributed throughout the area. Particularly good examples can be seen in sills 30 cm. to 1 m. thick which outcrop in the Qordlortoq River at 40 m.. Small, smooth oblate spheroidal or ellipsoidal bodies stand out prominantly on the weathered surface, (Fig. 5.4). The largest dimension of these nodules seldom exceeds 1 cm.. Size-sorting is generally excellent, also, the nodules tend to be closely packed, orientated with the largest dimension parallel to the sill contacts. They weather to a dark colour while the matrix may have any colour within the usual range (i.e. pale yellow to dark brown or black). The superb rounding of the nodules contrasts markedly with the angular nature of the gneiss or granite fragments which are often present in the same intrusion. Generally the nodules are not evenly distributed throughout an intrusive sheet, but are concentrated in bands parallel to the contacts.

Nodular, Lamprophyric Breccia.

A 1.m. thick intrusive sheet, choked with well-rounded fragments of lamprophyre, outcrops on the shore at Umiussat. The rock is black and very little weathered so that there

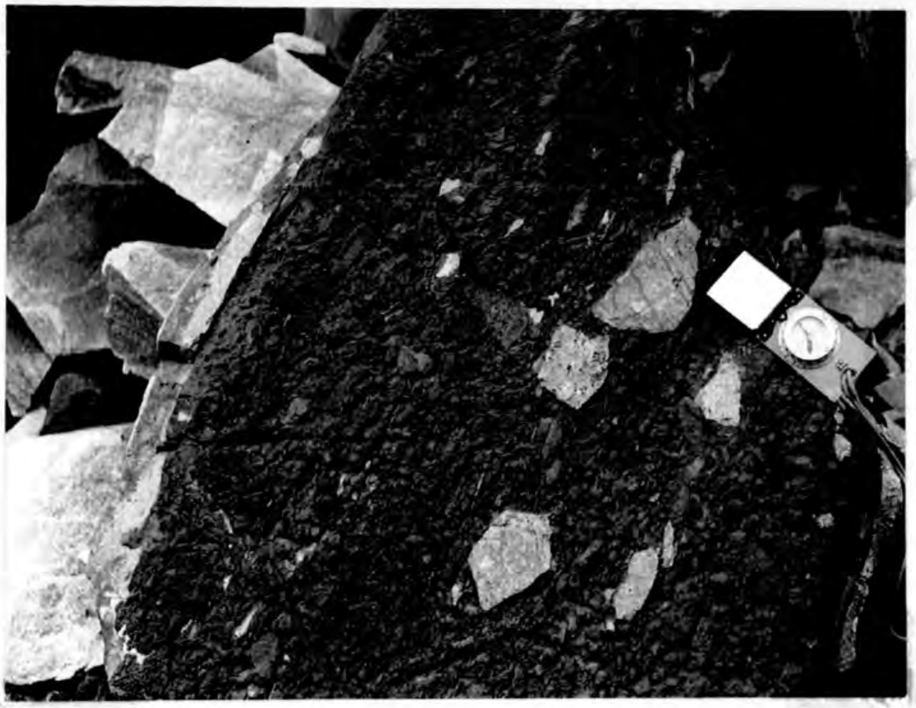


Fig. 5.5. Sheet of nodular lamprophyric breccia.

Fig. 5.6. Close-up of nodular lamprophyric breccia.

are only minor traces of limonite on the surface. The fragments or nodules are of all sizes from a fraction of a centimetre in diameter up to more than 5 cm.. They are accompanied by angular fragments of gneiss up to 10 cm. across, (Fig. 5.5). Many of the nodules show traces of pseudomorphed olivine phenocrysts and dark mica can be seen in some. The inclusions are closely packed right to the margins of the body and even the smallest interstices are filled with tiny nodules (Fig. 5.6). There is no sign of a matrix other than carbonate.

The Volcanic Pipes.

All the pipes that have been examined have steep sides with contacts seldom inclined at more than 20^{o} from the vertical. In the majority of cases the cross-section is elongate, ranging from broadly elliptical to dike-like. Length ranges from a few metres to ca. 300 m., in some cases, perhaps, to 500 m.. Certain of the more attenuated dike-like outcrops of intrusive volcanic breccia recorded on the accompanying map (Fig. 5.7) are indifferently exposed and there are indications that some of these may consist of a row of small, roughly circular diatremes only a metre or two in diamter. It is evident that the emplacement of many of the pipes has been controlled by linear fissures; the strike of the elongation is so variable, however, as to appear to be unsystematic.

Most of the pipes contain intrusive volcanic breccia

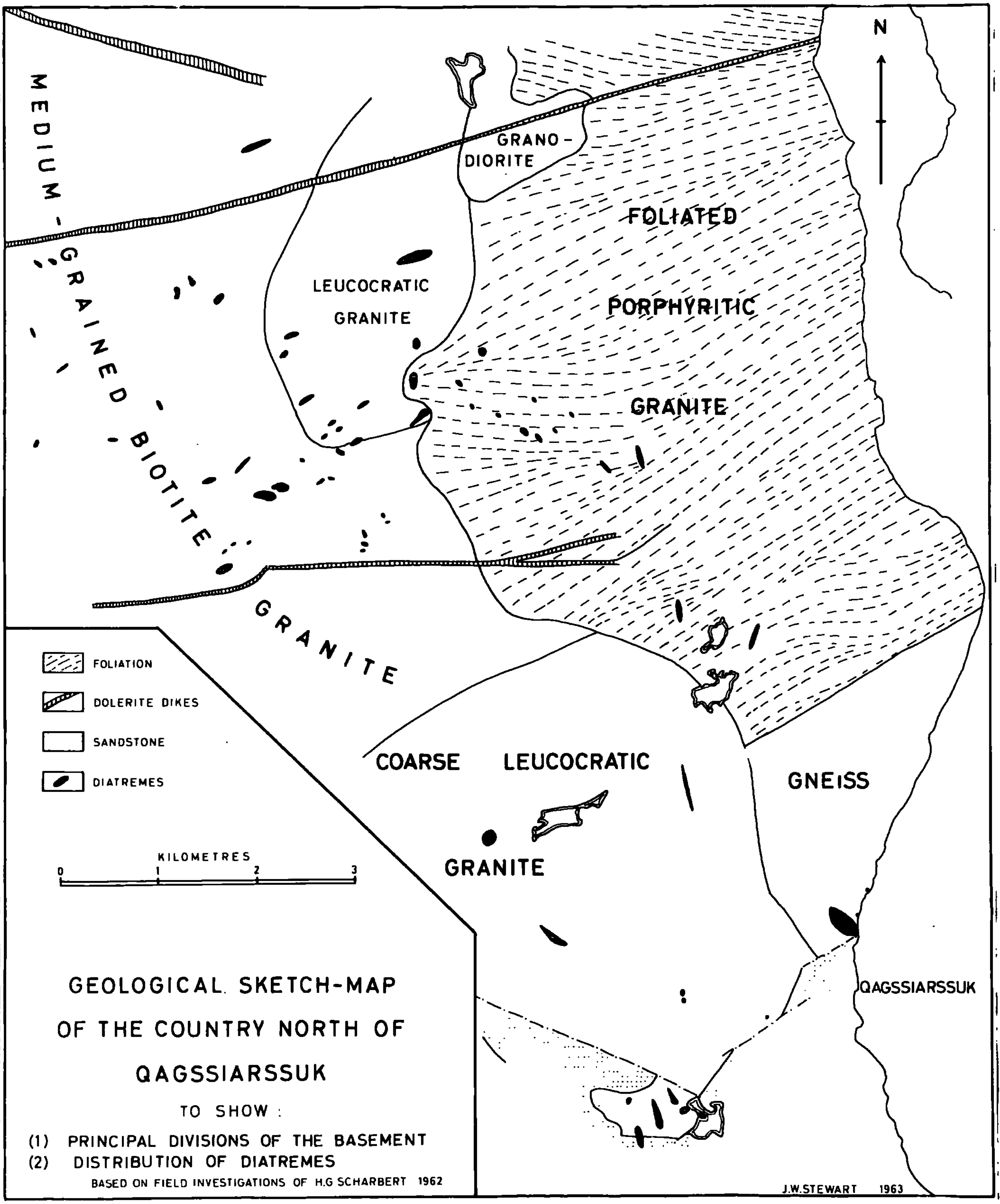

N
MEDIUM - GRAINED BIOTITE GRANITE
GRANO - DIORITE
FOLIATED PORPHYRITIC GRANITE
LEUCOCRATIC GRANITE
COARSE LEUCOCRATIC GRANITE
GNEISS
QAGSSIARSSUK
FOLIATION
DOLERITE DIKES
SANDSTONE
DIATREMES
KILOMETRES
0 1 2 3
GEOLOGICAL SKETCH-MAP OF THE COUNTRY NORTH OF QAGSSIARSSUK
TO SHOW :
(1) PRINCIPAL DIVISIONS OF THE BASEMENT
(2) DISTRIBUTION OF DIATREMES
BASED ON FIELD INVESTIGATIONS OF H.G SCHARBERT 1962
J.W.STEWART 1963

Fig. 5.7.

(Fig. 5.8). The matrix of this rock is a highly carbonated intrusive volcanic microbreccia or tuffisite, usually deeply weathered. Colour is usually deep brown or red. In most instances the nature of the matrix is obscure. Hand specimen 61616 (Fig. 5.9) is an example of unusually fresh material from the large pipe just beyond the 60° fault at the northern end of the settlement. The groundmass consists of the following constituents, closely packed in a base of yellow carbonate:

(i) dark, well-rounded pellets of lamprophyre 1-3 mm. in diameter,

(ii) rare, anhedral grains of iron ore up to ca. 5 mm. across,

(iii) occasional angular grains of feldspar and, less commonly, quartz, derived from the country rock.

In a few cases the matrix of the pipe breccia is of coherent lamprophyre. An example occurs on the shore a short way north of the large pipe referred to above. Lamprophyre is clearly seen at the edge of the diatreme. Towards the marginal contact the inclusions (mainly of granite) become smaller, down to 1.0-0.5 cm., although they are still very sharp and angular. The colour of the matrix changes from dark brown to ochre. Finally, there is an inclusion-free, grey, vesicular band ca. 15 cm. thick, chilled against the gneiss. It is not possible to determine whether the lamprophyric magma filled the pipe partially or

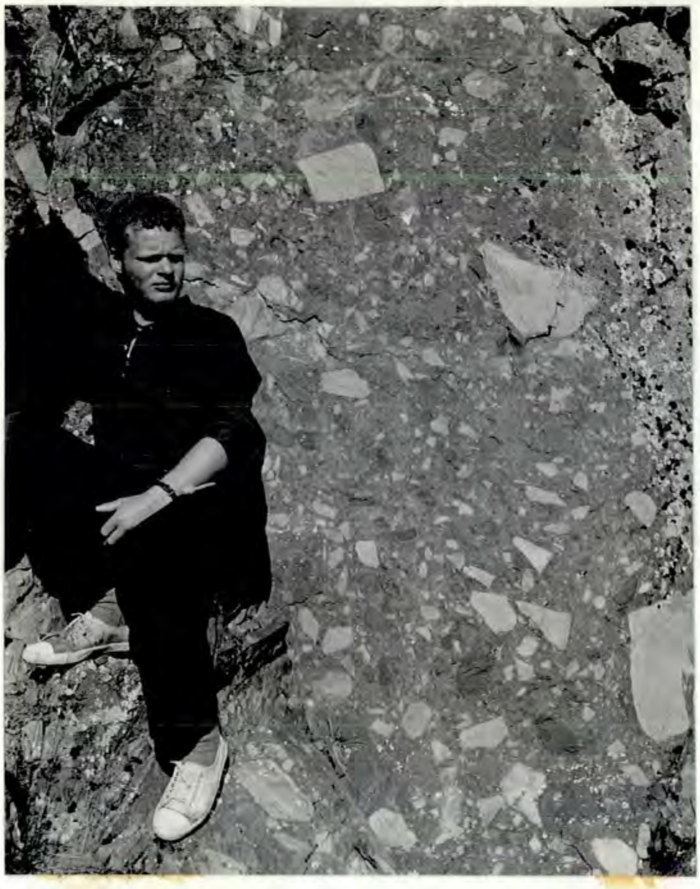


Fig. 5.8
Typical pipe-breccia

Fig. 5.9. Specimen 61616; close-up of tuffisite matrix of pipe-breccia. Angular gneiss fragment to right of scale is mantled by alnöite.

completely in this instance.

Varying amounts of rock fragments occur in the pipes, set in tuffisite or coherent lamprophyre. Country gneisses and granites are the rock types by far the most abundantly represented. Inclusions of lamprophyre, though comparatively rare, are very widely distributed and some can be found in nearly every outcrop of breccia. Other material, in particular sedimentary or basaltic rocks from the Gardar Continental Formation, appears to be entirely absent. The granitic inclusions are nearly always sharp edged. Rounded blocks have been found in very few instances. In a few breccia outcrops some granitic inclusions were seen to have a dark, fine-grained, possibly glassy border ca. 1.5 cm. thick. In the least weathered outcrops it is clear that liquid or plastic lamprophyre has sometimes become moulded onto small granitic fragments, occasionally completely enclosing them in a thin envelope of dark igneous rock (Fig. 5.9). In one instance a large inclusion of lamprophyre was seen to enclose a small, angular fragment of gneiss (Fig. 5.10).

The lamprophyre inclusions are almost invariably well rounded. Typically, they have a diameter of 5 - 10 cm., but individual blocks up to 30 cm. in diameter have also been found. It is probable that inclusions also occur in a whole range of sizes from 5 cm. down to the tiny lamprophyre pellets of the matrix. The rock type of the inclusions is quite fine grained, with a speckling of small, black pseudomorphs after olivine phenocrysts. Colour varies from pale grey to dark brown, red and black and usually contrasts with the colour of the matrix.

In some of the diatremes, the breccia is quite homogeneous, with fragments of similar size evenly distributed throughout. In other cases size-sorting is less in evidence and fragments may range from a size where they lose their identity in the matrix up to (exceptionally) 50 m. across. Packing of the fragments in the matrix likewise varies from one pipe to another, ranging from inclusion-free tuffisite to closely packed, coarse volcanic breccia.

Vertical flow-lineation has been observed in breccia adjacent to the pipe margin in a few instances. Fig. 5.11 shows one of the best examples which occurs at the edge of a small pipe just south of the elongate diatreme 3 km. west of Qagssiarssuk. Low angle stratification has not been recorded anywhere in the intrusive breccias of the Basement country.

Contacts of pipe-breccia against country rock are seldom seen. An exception is to be found where the large diatreme north of Qagssiarssuk outcrops at the shore. Here, contact relationships are well seen about a great block of gneiss which has become detached from the wall rock. The block measures ca. 7 m. across and is largely or wholly surrounded by volcanic breccia. Near the block, the number of inclusions in the breccia diminishes rapidly. A few centimetres from the block, the tuffisite grades into a nearly pure, yellow, carbonate rock (ankerite) by a gradual decrease in the amount of lamprophyre pellets and fine,

Fig. 5.10. Dark, lamprophyric block in pipe-breccia, enclosing fragment of gneiss.

Fig. 5.11. Flow lineation in pipe-breccia.

attrited granitic material. The ankerite penetrates the gneiss intimately in a zone some decimetres broad, forming a mosaic or in situ breccia in which many of the gneiss fragments are but little displaced. A 20 cm. thick sheet of ankerite penetrates through the block and grades out into the marginal ankerite zone. Its disposition (75°/ 60°N) is parallel to the foliation of the block.

In the field it is seldom possible to distinguish any aspect of the adjacent country rock which can be ascribed with certainty to contact effects. At the locality just described, the gneiss, which is usually red, often has a leached appearance and may be almost white, particularly in the centres of detached fragments. Some of these are very fine grained and have a streaked appearance, closely resembling rhyolite.

Isolated Areas of Gneiss Breccia.

About 3.5 km. west of Qagssiarssuk there are a few outcrops of deep red, rather fine grained gneiss. The rock is intensely brecciated into fragments up to ca. 10 cm. across, with random orientation and close packing (Fig. 5.12). The interstices between the blocks are occupied by yellow ankerite. When weathered, the ankerite is dissolved away, leaving a sharp, angular scree of gneiss blocks. The blocks are deeply pitted due to the removal of ankerite which had replaced part of the fabric. Neither lamprophyre nor tuffisite is present in the vicinity and it is suggested

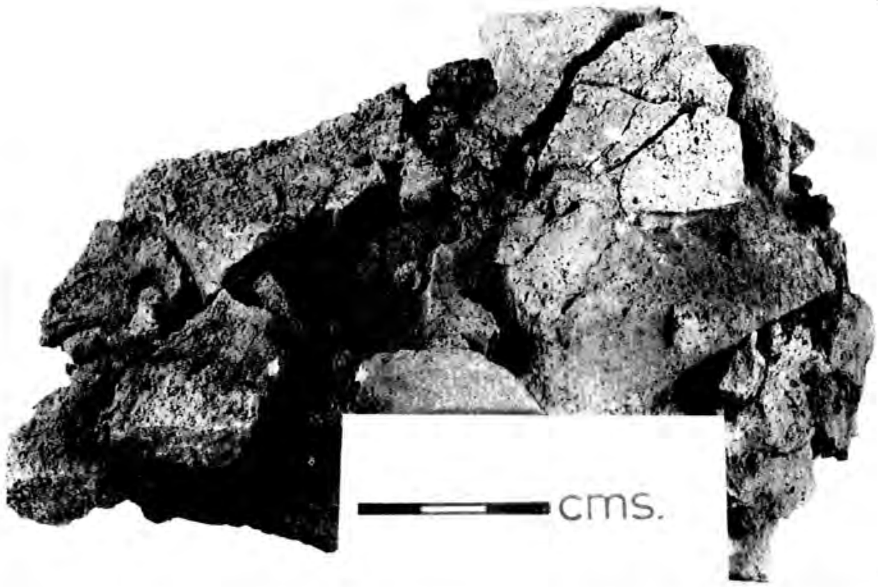


Fig. 5.12. Feldspathised, brecciated granite with ankerite veins. Above: weathered surface; Below: freshly broken surface.

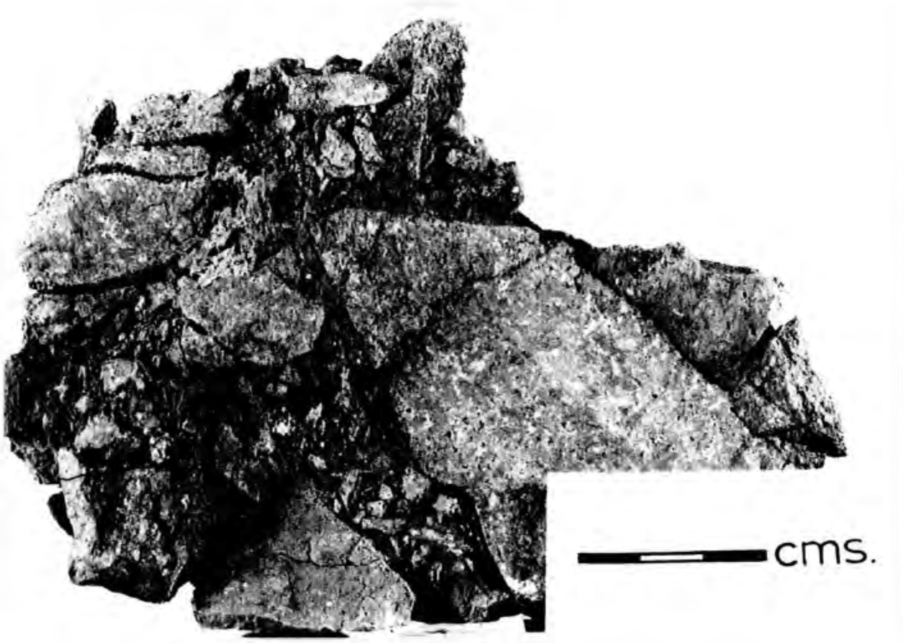
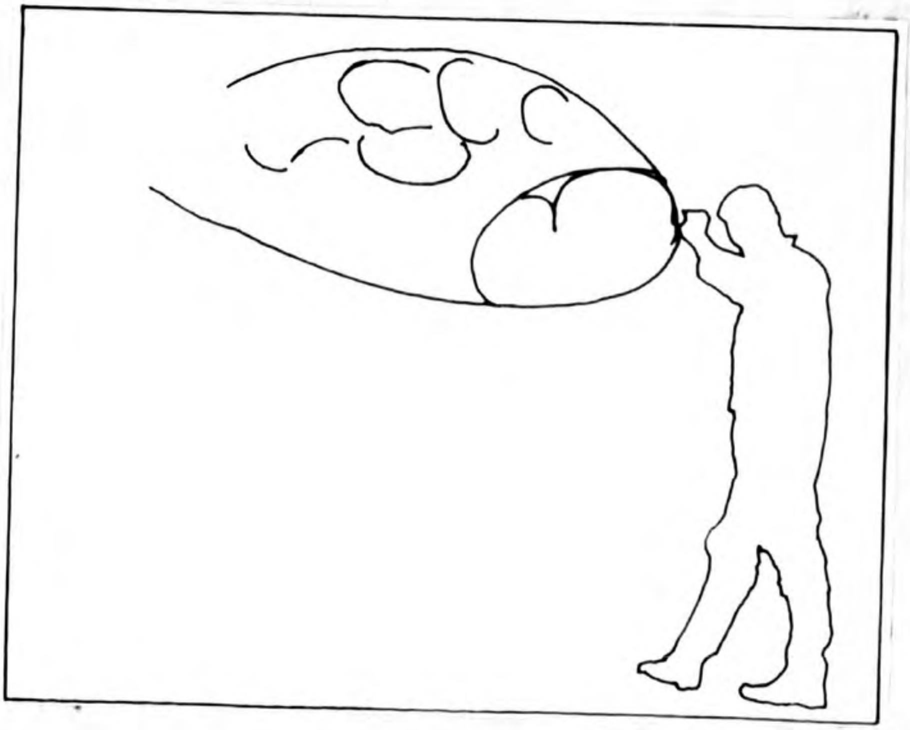


Fig. 5.13.
Exfoliation ellipsoids
in country granite.(a)

Fig. 5.14.
Exfoliation ellipsoids
in country granite. (b)

Fig. 5. 15. Exfoliation ellipsoids in country granite. (c)



that the breccia may represent the roof above a concealed diatreme.

Exfoliation Ellipsoids in the Country Rock.

An unusual effect associated with both sheet and pipe intrusions is the development of exfoliation ellipsoids in the country granite or gneiss. The structure may be found for some tens of metres from the contact. Most are very regular in shape, consisting of near perfect ellipsoids of granite enclosed in a series of concentric shells of even thickness (Fig. 5.13). The size of the cores ranges from ca. 10 cm. on the major axis up to ca. 50 cm. and occasionally beyond. Farther from the contact, the development of the concentric shells becomes less pronounced, being replaced by a single ellipsoidal fracture. (Fig. 5.14). A number of such fractures may be closely packed within a very large ellipsoidal fracture (Fig. 5.15). Nearing the contact, yellow ankerite becomes visible in the fractures. There is a gradual transition into a breccia in which ellipsoids of granite are set in a matrix of small, angular fragments and granitic rubble. Ankerite impregnates the matrix.

2. Minor Intrusions in the Basement North of Narssarssuaq.

A number of ultramafic sills and pipes intrude the Basement rocks in the country east of Tunugdliarfik, north of the Kiagtut River. A small number of diatremes and sills on the shore are of pyroxenite and have not been

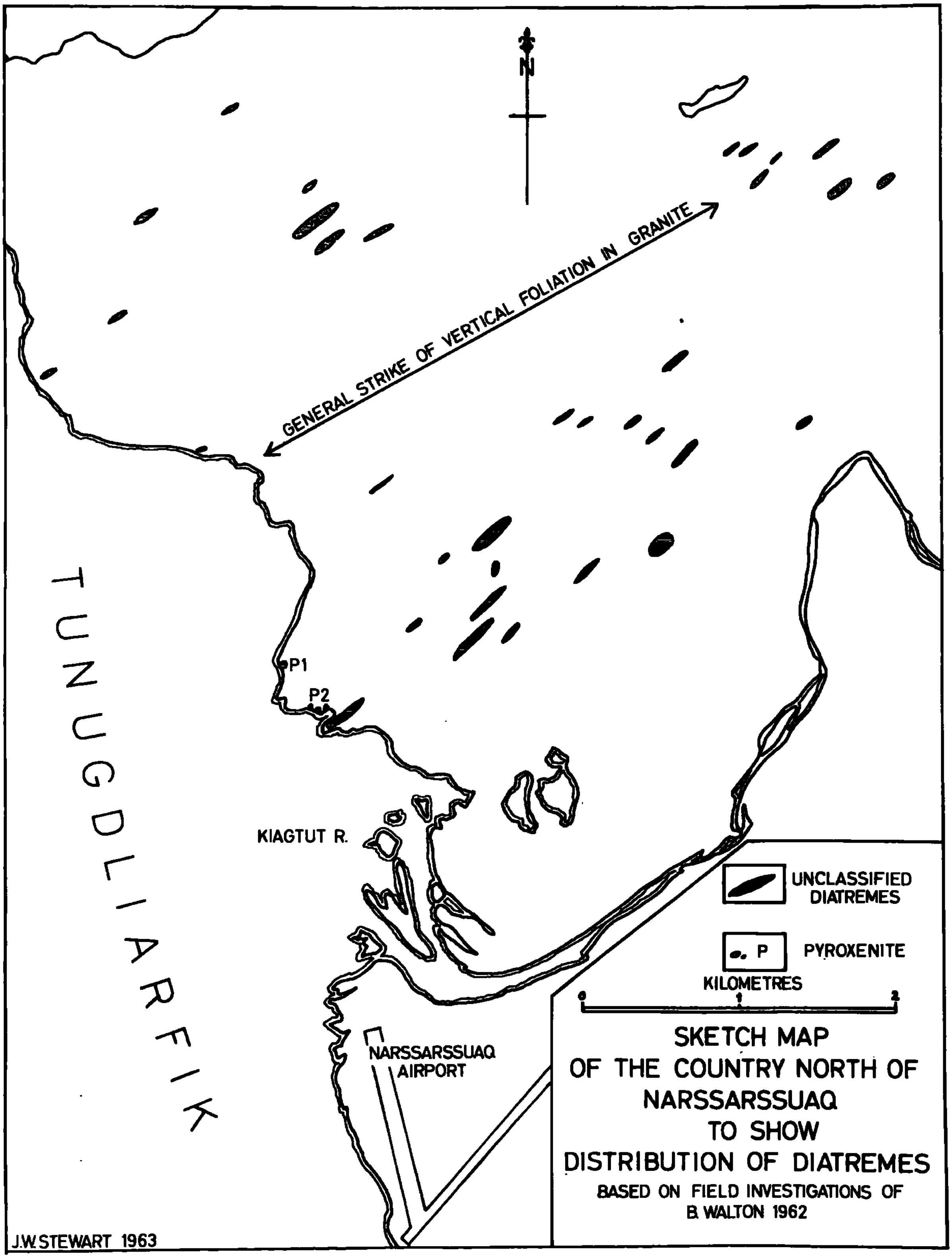

N
GENERAL STRIKE OF VERTICAL FOLIATION IN GRANITE
TUNUGDLIARFIK
P1
P2
KIAGTUT R.
NARSSARSSUAQ AIRPORT
UNCLASSIFIED DIATREMES
P PYROXENITE
KILOMETRES
0 1 2
SKETCH MAP
OF THE COUNTRY NORTH OF
NARSSARSSUAQ
TO SHOW
DISTRIBUTION OF DIATREMES
BASED ON FIELD INVESTIGATIONS OF
B. WALTON 1962
J.W. STEWART 1963

Fig. 5.16.

carbonatised. The remainder have affinities with the lamprophyric suite. The inland diatremes have been mapped by B. Walton (1962). It is apparent from the accompanying map (Fig. 5.16) that their strike agrees closely with that of the foliation in the country rock. Walton (<u>in litt</u>) states that most of the diatremes occur as several small, almost contiguous, cylindrical pipes which, superficially, give the impression of a single large pipe of elliptical cross-section.

<u>The Lamprophyric Intrusions.</u>

These are closely similar to the minor ultramafic intrusions north of Qagssiarssuk and, like the latter, are highly carbonatised. In the very limited material collected, only lamprophyric types are represented and it is not known whether uncompahgrite also occurs. The diatremes are filled with intrusive volcanic breccia which has a tuffisite matrix, with the exception of the most southerly pipe, ca. 1.5 km. north of the Kiagtut Estuary, where the matrix of the breccia is partly or wholly of coherent lamprophyre. Here, at the contact with the country rock, the gneiss is intensely brecciated, and has become white and rhyolitic in appearance. The breccia grades out into gneiss with ellipsoidal exfoliation.

The Intrusions of Mica Pyroxenite.

Intrusions of this material have only been recognised on the coast. Two possible necks of the rock are marked "P1" and "P2" on Fig. 5.16; the remainder of the intrusions are sheet-like and outcrop sporadically over ca. 0.5 km., north of P1. These sheets are from 10 cm. to 2 m. thick; in one instance a strike of 120° and dip of 20° toward the south was recorded. The rock is rather coarse, greenish-black, with a characteristic, deeply grooved, weathering pattern. Dark mica is clearly visible and appears to be an abundant constituent.

At P1 there is an outcrop of pyroxenite with a maximum dimension of 7 - 8 m.. The rock, although similar to the type of the sills, is finer grained and has a porous weathered surface. In some parts of the outcrop inclusions are numerous, while in adjacent parts inclusions are absent. To the east, a vertical contact is exposed. There is a pale green, chilled, marginal zone a few decimetres wide, free from inclusions. On the western side there is a breccia, implicating sharp, angular pieces of the country rock. This is probably an intrusion breccia, marking another contact. The parts of the outcrop which contain inclusions have a peculiar weathered appearance (Fig. 5.17); the fragments stand out with a relief which is emphasised by a deep, marginal groove in the adjacent host rock. The inclusions are mostly of pyritous granite; the maximum dimension is typically ca. 10 cm.. The granite fragments are angular,

Fig. 5.17. Neck of pyroxenite with rounded inclusions of country granite.

but the edges and corners are considerably rounded. There are also some smaller, well rounded inclusions of a very fine grained, black, heavy, magnetic rock. This intrusive body is probably a neck.

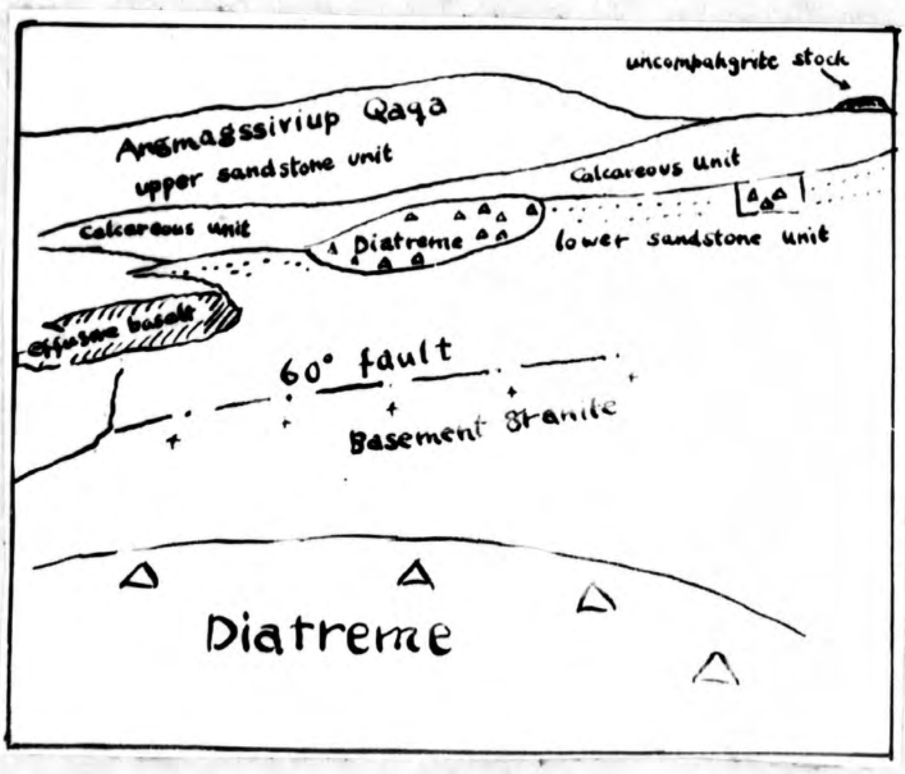
Three smaller, poorly-exposed outcrops on the shore at P2 may have steep contacts. They are of dark pyroxenite, contain granitic inclusions and are crossed by veins or narrow pods of a coarse, micaceous rock which are resistant to weathering and stand up as ridges on the outcrop surface. Although these outcrops are only ca. 100 m. from the southernmost , carbonatised, lamprophyric diatreme, there is no sign of carbonatisation.

3. The Qagssiarssuk Triangle.

An extensive area of Gardar sedimentary and volcanic rocks extends across the Ilímaussaq Peninsula from Qagssiarssuk to Tasiusaq. Field investigation, with particular emphasis on the sandstones, was carried out in this area by V. Poulsen in the 1958 and 1959 seasons. A triangular area south of Qagssiarssuk, shown by Poulsen to contain a high proportion of igneous rocks, was selected by the author for more detailed investigation in 1962.

The triangular area (hereafter "the Triangle"), is well defined topographically. The NE - SW side is defined by a river valley, north of which the basement rocks rise quite steeply; the east-west trending side is formed by the steep, north-facing cliff of Angmagssiviup Qáqâ.

Fig. 5.18. View of Qagssiarssuk from the north.



The exposed succession is subdivided as follows:

TOP

(iii) an upper sandstone unit.

(ii) The Calcareous Unit, a group of highly igneous rocks, mainly pyroclastic.

(i) a lower sandstone unit with intercalated basalt.

BASE

An unknown thickness of Gardar strata may underlie these rocks. It is unlikely that the basal unconformity of the Gardar Continental Series occurs within the Triangle. At a few places in river sections sandstone and basement granite are seen in juxtaposition, separated by a steep fault plane, strike 60°. Elsewhere, due to alluvial deposits, the possibility of a sedimentary contact cannot be overruled.

Exposure in the Triangle is often poor, particularly on flatter ground. Raised beach deposits occur up to 20 m. above sea level, concealing a considerable area at Qagssiarssuk and immediately to the south and, in particular, wholly obscuring the relations of the large coastal outcrop of basalt with the rest of the area.

The faulting along the north-west boundary of the Triangle has resulted in downthrow to the south-east. Other faults, within the Triangle, with strikes of approximately 50° and 80°, have a downthrow on the northerly side, causing local repetition of the succession. The fault system was not specifically investigated and it is possible that the effects of dislocation are greater than the accompanying map would indicate.

It will be evident from these considerations that only a provisional stratigraphical succession can be drawn up at this stage and that thicknesses of units, while intrinsically variable, are also subject to serious errors.

<u>The Lower Sandstone Unit.</u>

The principal rock type is a white, medium grained sandstone, extensively cross-bedded. Conglomerate is absent, ripple marks are occasionally seen. A horizon of basalt is intercalated within the unit (see below). Dip and strike measurements taken in the sandstone area are rather inconsistent, partly due to cross-bedding, partly to tilting of the strata and partly to distortion of the stratification by intrusives.

The Gardar strata in the area have a general strike of 30° and dip at about 20° to the south-east. Based on this disposition, the part of the lower sandstone which underlies the basalt layer has a minimum thickness of 110 m., if the possible effects of concealed faulting are ignored. Ca. 60m. of sandstone occurs below the Calcareous Unit and above the basalt layer. It is possible that an additional thickness of up to 90 m. of strata occurred in the site now occupied by the tuffisite intrusion. These figures apply to the western part of the area, along the line of section A - B (Fig. 5.19).

The Basalt Layer.

This horizon can be followed from Forest Lake to Grassy Lake, with occasional interruptions due to faulting and younger intrusions. The north-west - south-east fault which crosses Angmagssiviup Qáqâ does not appear to have displaced the layer. Although no fully exposed section through the basalt is recorded, thickness is known to lie between 10 m. and 20 m.. On the slope south of Forest Lake the layer appears to be repeated by an east-west fault. The rock is a greenish, compact, aphyric type, frequently of very fresh appearance (belied by thin-section examination). No structures indicative of extrusive origin have been seen; columnar structure has not been recorded. A rather poorly exposed upper contact on the edge of Grassy Lake appears to be intrusive.

The Basalt of Qagssiarssuk Shore.

This basalt covers an area of ca. 250 square metres. No contacts are exposed. The rock is unfresh, greenish weathering, vesicular and in places finely feldsparphyric. It is unmistakably extrusive. The outcrop is built up of flow-units, 0.5 - 1.5 m. thick. Planes between the flows have a disposition ca. $10^{\circ}/25^{\circ}$E. A minimum total thickness of about 20 m. is indicated. Many of the flows show classical tripartite division into a compact centre with porous upper and lower zones. The basal part of the thinner units may have a close, parallel cleavage. Bases of flows are often penetrated by pipe vesicles about a decimetre long. The uppermost portion usually has a porous, oxidised appearance and corded surfaces are occasionally seen.

A polygonal jointing system can be observed on the surfaces of some flow-units; this may be a cooling phenomenon. Iron staining along the joints has produced a reddish colour at the margins of the polygons, which contrasts with the green colour of the circular or elliptical centre sections. The structure could be confused readily with pillow lava; however, close inspection shows that the texture of the basalt does not change, passing from one polygon to another and it can be demonstrated that the jointing is restricted to a thin surface layer.

Assuming a strike of 30° in the sandstone unit, and setting aside the possibilities of dislocation, this basalt would occupy a stratigraphical horizon some 80 m. below the base of the Calcareous Unit. On the other hand, the strike of the planar structures in the basalt contrasts with the 30° value more usual in the area, but agrees quite closely with a north-south strike in the sandstone ca. 0.5 km. inland. This suggests the possibility that the basalt is part of a small fault block and represents a part of the Gardar succession not seen elsewhere in the Triangle.

The Qagssiarssuk basalt differs from the other basalt layer in being demonstrably effusive, in having a considerable content of olivine and in being much more intensely altered. Where not too strongly weathered, the two types are quite unlike in appearance.

The Calcareous Unit.

Rocks of this unit cover rather more than half of the Triangle. Much of the material, which is predominantly of pyroclastic origin, shows evidence of stratified deposition.

A considerable number of distinct rock types are developed; these tend to be impersistent laterally, also, vertical sequences change rapidly from place to place. With the exception of the rather well exposed basal succession along the northern margin, no persistent horizons have been observed. The discovery of a marker horizon well within the Unit would be invaluable for demarcating the faults; however, exposure is probably too limited to permit this. Based on an outcrop width of 1100 m., a strike of 45^{o} and a dip of 20^{o}, the maximum thickness of the Unit would be about 375 m. near the coast. The localised intercalation of coarse ejectamenta at the top would account for some 40 m. of this; the remaining figure of 335 m. is probably exaggerated to some extent by faulting and tilting.

The small outcrops of sandstone on the south-eastern side of the uncompahgrite stock appear to lie on top of the

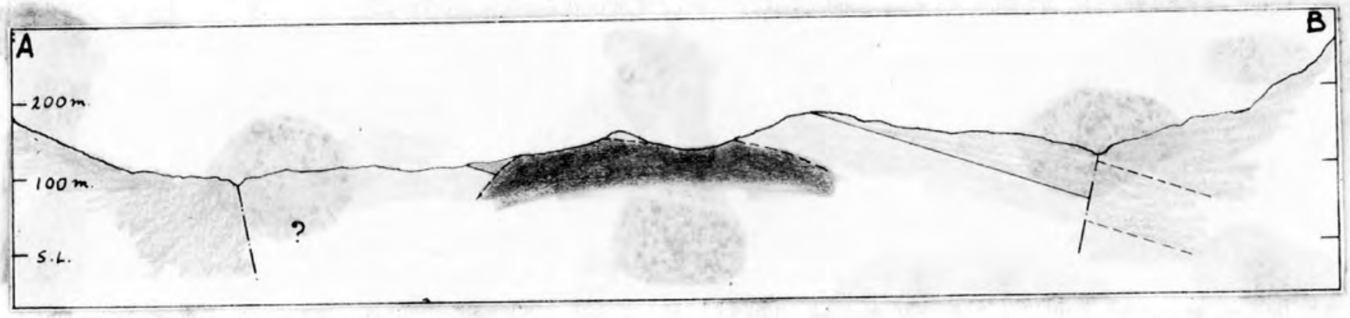


Fig. 5.19. Cross-section A - B. (Refer to Plate II).

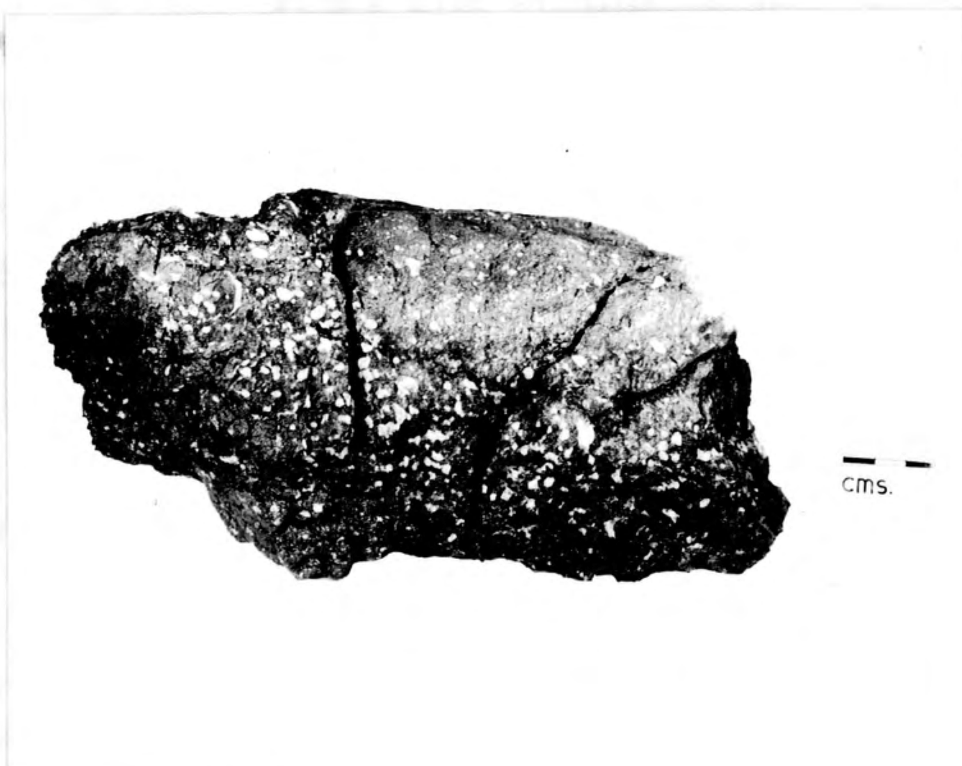


Fig. 5.20. Close-up of "amygdaloid" (carbonatised uncompahgrite lava).

Calcareous Unit. They may represent a local intercalation of sandstone within the Unit; alternatively, they may be outliers of the succeeding sandstone unit. Were this the case, the true thickness of the Calcareous Unit at this point would be only about 40 m.. Where the Unit outcrops above Forest Lake, thickness increases over a distance of less than one kilometre, from one metre in the east (where the horizon terminates against a fault), to about 10 m. to the south-west, where mapping was discontinued.

The Calcareous Unit is a stratified sequence of pyroclastic material and lavas. All the rocks are heavily carbonatised. The pyroclastics consist of coarse and fine tuffs, locally agglomeratic. Distinctive varieties are "tilestone", martite tuff, lapilli tuff and alnoitic tuff.

The lava is of a single type, given the field name "amygdaloid" on account of its highly amygdaloidal nature; it is a carbonatised uncompahgrite (Fig. 5.20) Some of the amygdaloid layers, at least, are of extrusive origin. In several instances upper surfaces of flows were seen where rubbly scoriae from the flow-top were incorporated in the succeeding pyroclastic bed (Fig. 5.21). Few of the flows are more than 2 m. thick. The bulk of the pyroclastic material vastly exceeds that of the lavas.

The lowest part of the Unit is rather well displayed on the steep scarp which overlooks Qagssiarssuk from the south. A basal group of rather distinctive pyroclastics and lava outcrops over about 600 m. in the strike direction.

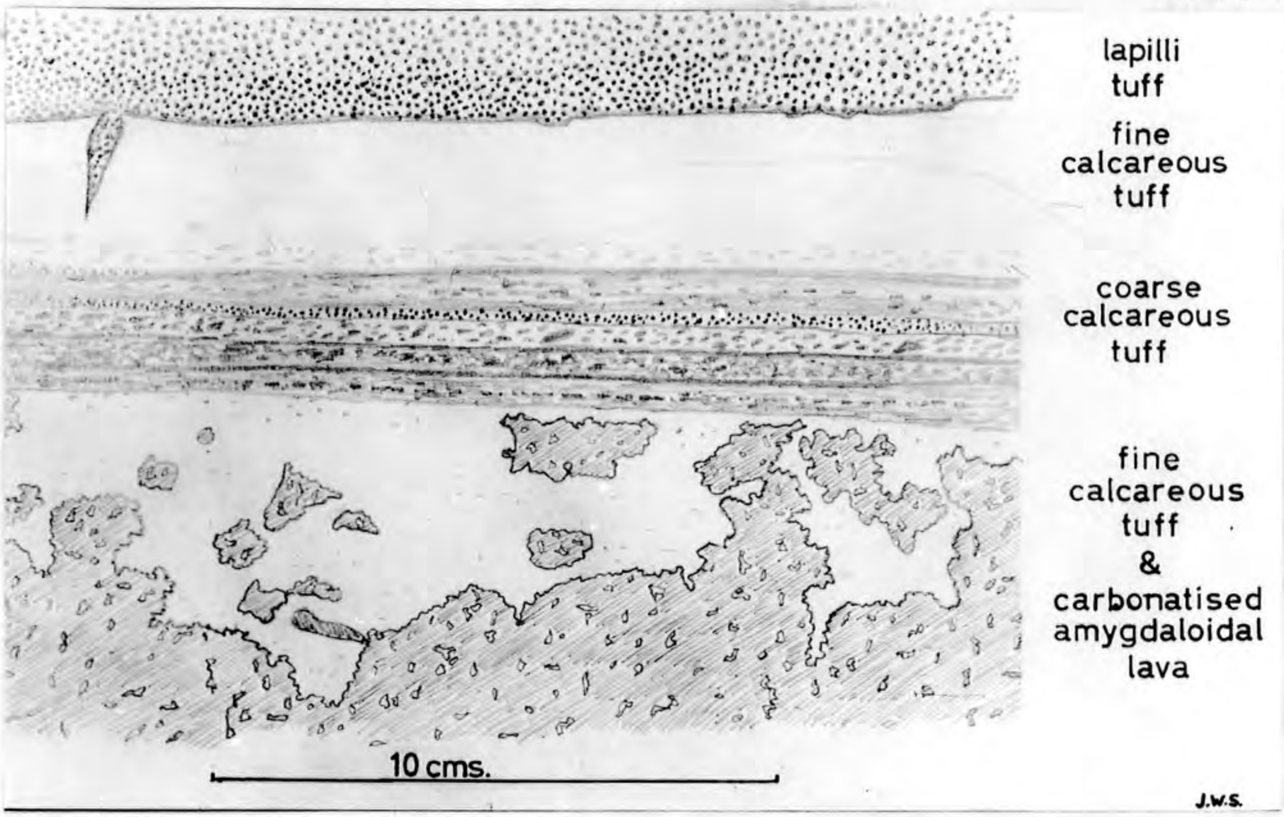


Fig. 5.21. Sketch of upper surface of "amygdaloid" flow.

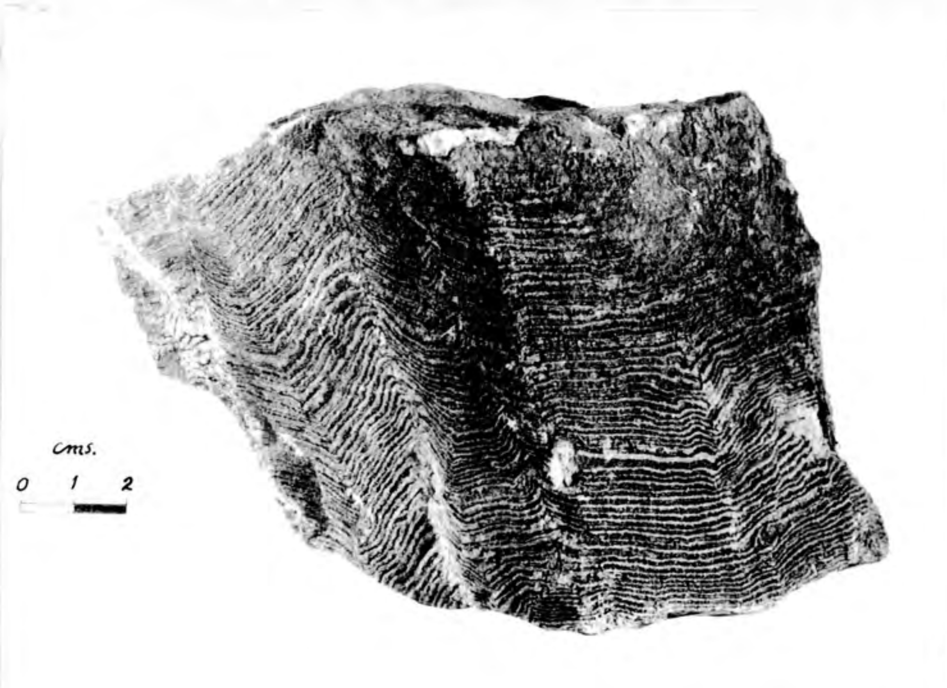


Fig. 5.22. Folded, fine grained sediment. Layers of quartz and calcite alternate.

The succession is as follows:

TOP

Amygdaloid.	At least 2 m.
Coarse, reddish tuff with graded bedding, containing small, angular fragments of red, crystalline rock derived from the Basement.	4.3 m.
Amygdaloid.	2.5 m.
"Tilestone".	0.5 m.
Fine grey calcareous tuff.	0.5 m.
"Tilestone".	5.5 m.

BASE

The "tilestone" is a fine grained, very compact, deep red rock in which bedding is seldom prominent. The freshly broken surface resembles terracotta. Large quartz grains can be distinguished in the fine base.

At the top of this section, the main development of the Unit begins. This consists of a rapidly deposited succession of calcareous tuffs with occasional agglomeratic and extrusive horizons.

Followed west along the scarp, the lower members of the sequence ("tilestone", coarse tuff, etc.) are overlapped by the upper part of the Unit. A structure is seen, apparently consisting of pillow-shaped bodies of amygdaloid, about one metre across, set close together. The interstitial material seems to be a brown calcareous tuff. Nearby, a small outcrop of a finely stratified, intensely contorted sediment occurs between layers of amygdaloid. It is composed of millimetre thick, alternating layers of quartz and carbonate in tiny granules (Fig. 5.22). The settings of the two structures described in this paragraph are obscure.

On the shore, south of Qagssiarssuk, the base of the Unit is concealed by recent littoral deposits. The lowest part exposed is a succession of amygdaloid with fine and coarse tuffs, similar, generally, to the basal succession recorded above. Beyond this, to the south, higher parts of the Unit are exposed. While the possibility of repetition by faulting is sufficiently real to preclude the use of this shore section as a standard succession, the rock types developed in the Unit are much better displayed here than anywhere else and permit an overall assessment of the lithology of the Unit.

The basal beds are followed by 5 - 10 m. of well bedded fine and coarse tuff. There are occasional partings a few millimetres thick formed by layers of particularly fine-grained, calcareous tuff. The rocks are predominantly mauve in colour. Throughout the section there are numerous layers of inclusions, believed to be ejected bombs and blocks.

In addition, sporadic inclusions may occur at all levels. Certain of the layers resemble conglomerate and the stratification of the sequence is often excellent. The overall picture of the distribution of the inclusion indicates a succession of showers of ash containing a variable amount of coarser ejectamenta. The possibility of subaqueous deposition of some of these pyroclastics cannot be discounted.

The inclusions are of five principal kinds:-

(i) Red, angular, coarse grained syenitic rock (altered basement granite).

(ii) Fine grained, pale grey, massive carbonate rock.

(iii) Amygdaloid.

(iv) Coarse calcareous tuff.

(v) Saccharoidal, coarse, crystalline carbonate rock.

With the exception of (i), shape is generally spheroidal; size ranges up to 10 - 15 cms., except in the case of (ii) where size may be up to 25 cms. or greater.

The succession continues with a 0.5 m. bed of a bright red, fine grained calcareous tuff, containing angular fragments of amygdaloid. At this point, the section is interrupted by a volcanic vent, "V1".

South of the vent, well bedded calcareous tuffs outcrop once again and the distinctive variety martite tuff is found. Octohedra of martite up to 1 cm. long occur in this, impersistent layers parallel to the bedding plane. Barytes and fluorite are present. The rock is a deep red colour. Beyond, calcareous tuffs, sometimes with inclusions of the types enumerated above, alternate with sheets of amygdaloid and occasional thin layers of fine tuff. A 0.5 m. thick sheet of amygdaloid penetrates these strata, partly at right angles to the bedding, partly concordantly. Further south the tuff beds have bright red and yellow colours, while the amygdaloid becomes purple. A marked cleavage develops parallel to the bedding and there is a considerable amount of shattering as the next vent, V2, is approached.

The succession is once more interrupted by transgressive vent material. The distance between the two vents (as exposed on the coast) is a little more than 400 m.. Coarse, irregularly stratified vent material outcrops along the coast for some 300 m.. Toward the southern end of the vent, the irregularly disposed breccias, etc., are overlain by another, more variable tuff succession, with agglomerate horizons. Cross-bedding with large sets is common; colours are red, brown, blue etc.. Coarse alnöitic tuff is most common at first; this may account for the darker colours to some extent. The inclusions in the agglomerate layers are of sandstone, granite, alnöite and amygdaloid. The alnöite occurs as well rounded, dark brown bodies 10 - 15 cms. in diameter which are penetrated by radial veins of white carbonate. These are probably bombs (Fig. 5.23).

Some tens of metres below the top of the Unit, a cavernous weathering red sandstone (similar to the lowest

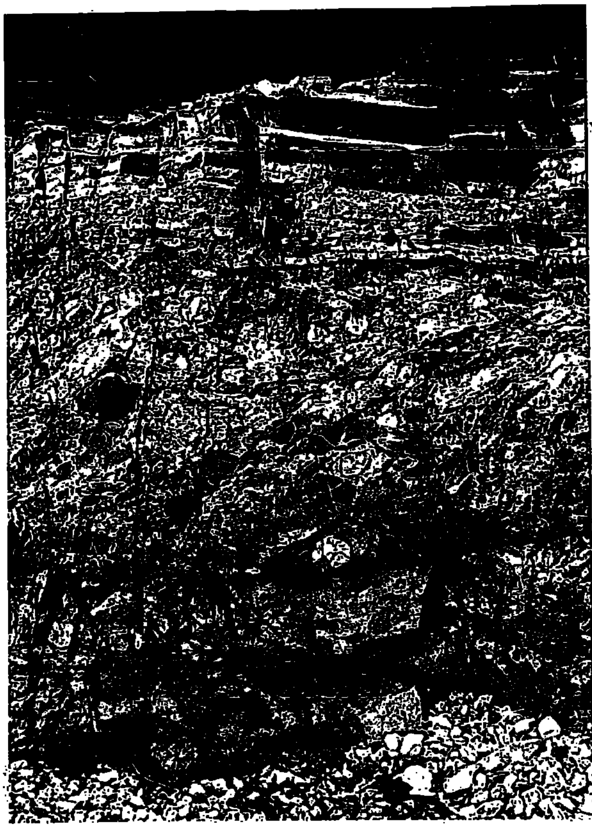
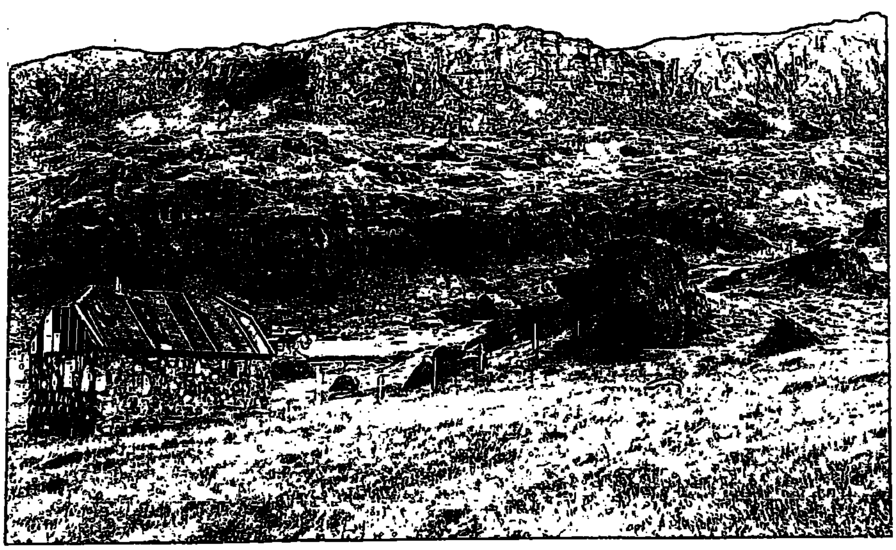


Fig. 5.23. Section of agglomerate and bedded pyroclastics. Note alnöite bombs with carbonate veining.

Fig. 5.24. Angmagssiviup Qáqâ. The crags in the foreground are of lapilli tuff.



part of the next unit) is found as fissure fillings up to 10 cm. thick penetrating as much as two metres through agglomeratic tuff. These sand "veins" are nearly vertical and do not appear to have any preferred strike.

The topmost beds of the Calcareous Unit include thin layers of soft, red shaly material believed to be a very fine calcareous tuff.

South of Forest Lake there is a thin development of the Unit. The rock is principally pink calcareous tuff with a considerable admixture of rounded blocks of white, massive carbonate rock.

The Lapilli Beds.

Beds of lapilli tuff with a maximum thickness approaching 40 m. outcrop on the southern face of Angmagssiviup Qáqâ and form a number of small hills on the flat ground below the cliffs (Fig. 5.24). The beds do not outcrop on the shore, probably because of interruption by the southern vent V2; fragments of bedded and unbedded lapilli tuff figure prominently in the vent breccia, however. The rock is of very localised development. Its margins are not sufficiently well known to permit a decision on whether it is an intercalation within the Unit or whether it is wholly contained within the circumference of V2.

The lapilli are dark red, well rounded, highly oxidised pellets of alnöite, mostly 2 - 3 mm. in diamter. They are closely packed in a groundmass of white, calcareous tuff

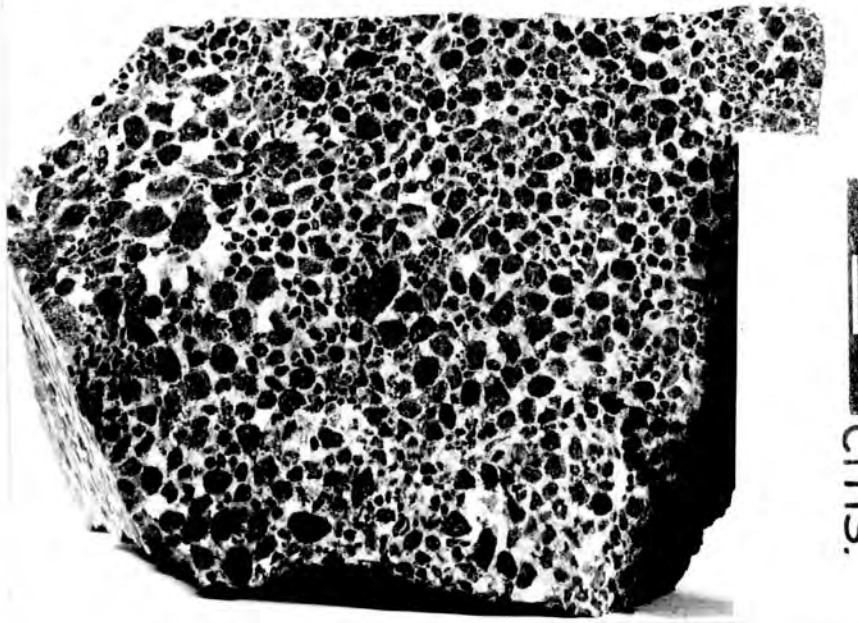


Fig. 5.25. Close-up of lapilli tuff. Dark, oxidised alnöite lapilli are set in a matrix of fine carbonate.

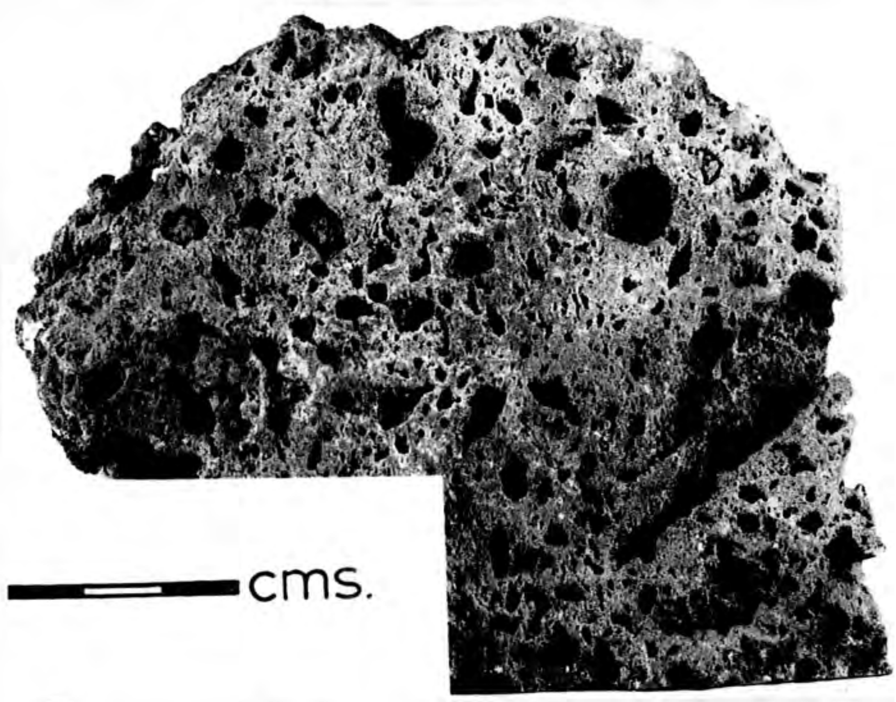


Fig. 5.26. Close-up of weathered surface of "sandy tuffisite".

(Fig. 5.25). Sometimes the tuff shows excellent bedding structures, occasionally with vertical size-grading. Coarser ejectamenta, with a diameter exceeding 1 cm., are rare or absent.

The Upper Sandstone Unit.

In some places a thin lens of conglomerate may be developed at the base of the unit. More usually, the base rests on a red shaly horizon (fine calcareous tuff). The lowest few metres are of a reddish sandstone with a notably cavernous weathering pattern. This feature may reflect a high content of carbonate derived from the preceding unit.

Investigation of this sandstone unit has not been taken any further.

Tuffisite Intrusions of Irregular Shape.

An area of tuffisite measuring 600 m. east-west and with a maximum north-south dimension of 750 m. extends south from Grassy Lake. Another body with a narrow outcrop ca. 800 m. long occurs on the hillside south of Forest Lake.

The tuffisitic rocks are not well exposed, generally, and the following observations are based on examination of a limited number of outcrops. The tuffisite is variable in appearance. The most usual type "sandy tuffisite", is fine grained, reddish brown, with a glassy sheen on the freshly broken surface due to the abundance of quartz grains present. The weathered surface is deeply pitted, a consequence of the high content of carbonate (Fig. 5.26). Coarser varieties, with a smaller content of quartz grains, are identical in appearance to the tuffisite in the three diatremes south and west of Qagssiarssuk. Stratification is recorded at a few localities, involving tuffisite of this kind; the structure has a general resemblance to cross-bedding in sediments. Dip and strike readings are too rare to permit any structural deductions.

Near the western edge of the northern body, ca. 200 m. east of Square Lake, a greenish rock type is exposed which contains carbonate inclusions several centimetres across. There are also cavities of similar size, containing large euhedral calcite crystals. The greenish rock has been identified as a highly carbonatised and chloritised alnöite or alnöitic tuffisite.

With the exception of the marginal sandstone breccia described below, large inclusions have not been recorded in the outcrops visited. All of the country rock types known to underlie the intrusion are represented, including basement granite, lamprophyre, sandstone, and olivine basalt. Lamprophyre inclusions up to ca. 10 cm. in diameter are the most common; micro-inclusions of basaltic types may be abundant locally, but are only recognisable in thin section. The bulk of the tuffisite is of medium to coarse sand grade and inclusions more than a few centimetres in diameter are widely distributed and rather rare.

Along the eastern side of the northern body, about 100 m. south of Grassy Lake, a contact against the sandstone is

Fig. 5.27. Eastern contact of tuffisite intrusion, looking south from near Grassy Lake. Fig. 5.28 shows point A, Fig. 5.29 shows point B and Fig. 5.30 shows a point just east of B.

Fig. 5.28. Upper contact of tuffisite body against bedded sandstone. The contact is nearly conformable and the strata are arched upwards.

Fig. 5.29. Eruptive upper contact of tuffisite body into sandstone with coarse breccia.

well exposed, striking 25° and dipping eastward at 45°. The contact is concordant with the bedding of the sandstone; the latter appears to have been somewhat displaced by the intrusion, causing a local steepening of the dip. Towards the margin, the tuffisite grades into an ankeritic breccia which closely resembles the structure described at the edge of the diatreme in the Basement just north of Qagssiarssuk. There are numerous small, angular fragments of deep red, altered granite and larger blocks of sandstone (see Fig. 5.28).

Proceeding south-west, the contact transgresses gradually upward into the Calcareous Unit. The upper surface of the tuffisite appears to be dipping south at a rather low angle. Where the roof rock is sandstone, a breccia of great blocks of the country rock is formed. Some of these blocks, which may measure a metre across, are wholly detached and isolated within the tuffisite; others remain close together, more or less _in situ_ (Fig. 5.29). A small, isolated area of such a coarse breccia rests on tuffisite about 100 m. south of Grassy Lake and is an outlier of the sedimentary roof.

Where the roof rock belongs to the Calcareous Unit, a contrasting type of eruptive contact is developed in which rather rounded blocks of carbonate pale, fine grained, are set in a tuffisite matrix (Fig. 5.30).

The western boundary of the intrusion is not exposed; at the extreme north-west corner, a tiny, isolated outcrop shows very fine grained tuffisite, full of sand grains,

Fig. 5.30. Eruptive upper contact of tuffisite body in calcareous volcanics.

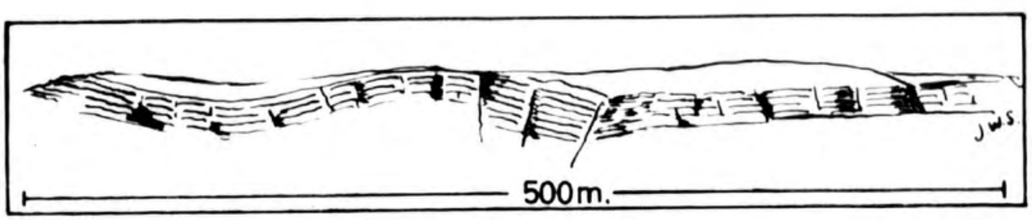


Fig. 5.31. Folded and faulted sandstone overlying the tuffisite body, south side of Forest Lake.

penetrating normal country sandstone which, near the contact, becomes ochreous and crumbly.

An isolated area of tuffisite outcrops a small lake about 100 m. south of the principal part of the northern body. The two masses are separated by a strip of sandstone about 100 m. wide which forms a low ridge. It is very probable that the tuffisite masses are in continuity and that the strip of sandstone is a remnant of roof.

It seems certain that the present level of erosion coincides quite closely with the roof of the intrusion, which must have been rather flat or slightly domed; the general shape of the boundary is hardly characteristic of the cross section of a steep sided intrusive body. The sharp projection at the north-east corner outcrops in a narrow, steep sided valley, suggesting a low angle roof; the isolated inlier to the south is similarly suggestive. In the north, close to Grassy Lake, a small area of sandstone roof overlies the tuffisite and immediately to the west the intrusion appears to dip under sandstone and basalt. The inclination of the eastern contact has already been described.

Bowes and Wright (1961) describe comparable partial roofing of a pipe of volatile rich lamprophyre and appinite in Argyllshire and suggest that the upward penetration of the intrusion halted at this level (which originally was at a considerable depth below the surface).

The only rocks against which intrusive relations are exposed are sandstone and basalt of the Lower Sandstone Unit and the lowest part of the Calcareous Unit. Since there is no evidence as to the depth of the intrusion it is not possible to decide whether it is a large diatreme which failed to penetrate fully to the surface, or a flat-lying, laccolithic sheet.

About 50 m. above Forest Lake, on the steep hillside to the south, there is a steep step or plateau extending laterally for some hundreds of metres. Below the step, there is a smooth, steep slope of reddish brown gravel, weathered detritus from an underlying intrusion of tuffisite. At the south-west end of the feature, a few outcrops of solid rock occur. The rock here is the coarser variety, similar to the material in the three diatremes south of Qagssiarssuk. A structure similar to cross-bedding is developed. No contacts with the country rocks are exposed. This intrusion may have been in continuity with the tuffisite body south of Grassy Lake and suffered sinistral displacement along the east-west fault on the north side of Forest Lake. A tiny outcrop of tuffisite just north of Forest Lake might also be connected with the concealed part of such a body.

The well bedded sandstone which overlies the elongate tuffisite body on the south side of Forest Lake is buckled and faulted (see Fig. 5.31).

Wilshire (1961) describes a group of tuffisite diatremes of comparable size near Sydney, New South Wales, which share the following characteristics with the tuffisite bodies described above.

(i) The tuffisite is of very variable composition and grain size (op. cit. pp. 473 and 474).

(ii) The tuffisite is locally stratified (op. cit. pp. 474-478).

(iii) The tuffisite is locally carbonatised with a concentration of the carbonate upwards -- "All inclusions in the breccia are intensely altered by hydrothermal processes, and induration was effected by compaction of abundant interstitial clay and by sporadic carbonate cementation, particularly in upper exposure of the intrusions" (op. cit. p. 473).

(iv) The tuffisite is extensively roofed by country rocks.

(v) The overlying strata are folded and faulted in some places (op. cit. p. 474).

The remarkable layered structures in the New South Wales diatremes have features incompatible with surface eruption. In particular, the layering continues below roofed parts of the diatreme and there is an absence of size-grading at right angles to layer planes.

Wilshire considers that emplacement of the New South Wales diatremes occurred by wedging and lifting of the country rock, and that the layering was caused by flow of a very viscous aggregate during forceful injection into the country rock (op. cit. p. 482).

In the present instance, evidence of "wedging" or arching of the country rocks is limited; on the other hand, there is ample evidence that the country rock was attacked by the tuffisite and incorporated in it (Figs. 5.29 and 30). The folding and faulting of the sediments above Forest Lake (Fig. 5.31) may be due to collapse following subsidence of the underlying tuffisite. This could be caused by withdrawal of magma in the underlying magma column; alternatively, if the tuffisite were in the form of a fluidized system (cf. Reynolds, 1954) decrease in the velocity of the fluid below a critical level would lead to a sudden substantial reduction in volume as the particles came to rest.

Tuffisite Diatremes.

Three bodies of tuffisite and volcanic breccia with very steep, arcuate, intrusive contacts outcrop on the face and top of the cliff south of Qagssiarssuk. In each case the northern contact is concealed. The largest, most easterly body is better exposed than the others and its boundary, when mapped, forms the greater part of a circle about 200 m. in diameter. Viewed from the east, it is apparent that the adjacent country sandstone has been considerably disturbed with minor faulting and tilting of the strata. The two eastern diatremes cut right through the Lower Sandstone Unit and the bedded tuff sequence at the base of the Calcareous Unit. In the western diatreme, the tuffisite filling is overlain by well bedded, coarse, red tuff. In none of these occurrences are contacts seen against rocks higher in the stratigraphical sequence.

The middle diatreme is about 100 m. in diameter, while the western one, which is poorly exposed, has an outcrop width of only 10 m.. All three diatremes are filled with similar brownish tuffisite which may be locally stratified and/or fragment-bearing. With respect to these characteristics, the pipe-filling changes rapidly both horizontally and vertically. Inclusions are most abundant in the largest body and are perhaps rather concentrated towards the margins in the two smaller bodies; some large blocks of sandstone, a metre or so across, occur in this position. In addition to blocks of sandstone, the immediate country rock, there are fragments of granite (which may be rounded or angular), rounded blocks of carbonatised lamprophyre and saccharoidal carbonate. The two smaller pipes have few inclusions. In the middle pipe, there are some large blocks of sandstone, restricted to the eastern side; in the western pipe sandstone is unimportant as fragmental material, although the country sandstone along the western margin is strongly brecciated. There are some small, rounded inclusions of pale, fine grained calcareous rock.

600 m. south of Forest Lake, there is another intrusion of tuffisite. It appears to have the form of a vertical cylinder about 80 m. in diameter, partly roofed by calcareous tuff. Upper contact relations are similar to those described at the eastern contact of the large, irregular tuffisite body, where it is roofed by the Calcareous Unit (cf. Fig. 5.30).

Volcanic Vent V1.

About 1 km. south of Qagssiarssuk, a 15 m. long transverse section through a volcanic pipe is exposed on the coast. The northern edge of the structure is very steep at the water's edge; upwards, it inclines outward at an increasingly shallow angle. It is distinctly transgressive against the country rock. The rock type at this edge of the vent is a deep red, coarse, even grained crystalline variety, of syenitic aspect. Southwards, it is intensely brecciated by ankerite veins and a mosaic structure is produced consisting of small, angular fragments of "syenite" in a matrix of brown carbonate (Fig. 5.32). The "syenite" contains numerous large, irregular blocks of fine grained, pale grey calcareous rock of non-amygdaloidal uncompahgrite; these blocks are up to 0.5 m. in diameter. Some contain small inclusions of "syenite".

Southwards, the pipe filling grades into material more characteristic of the vent described below; viz: a fine-grained, dark red matrix containing angular fragments of bedded and unbedded lapilli tuff.

Volcanic Vent V2.

This structure outcrops on the coast about 1.5 km. south of Qagssiarssuk, over a distance of about 300 m.. Inland, exposure is lacking. The northern edge of the vent, which is well exposed in the coastal section, is steep and transgressive. Within the vent, bedded pyroclastics,

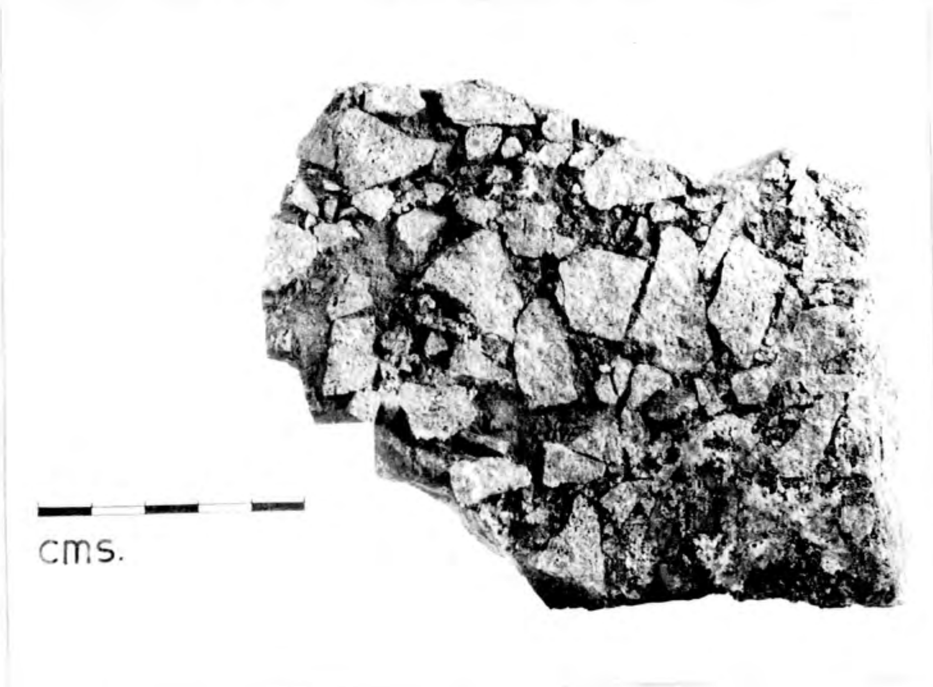


Fig. 5.32. Intrusive red syenite, brecciated and veined with ankerite.

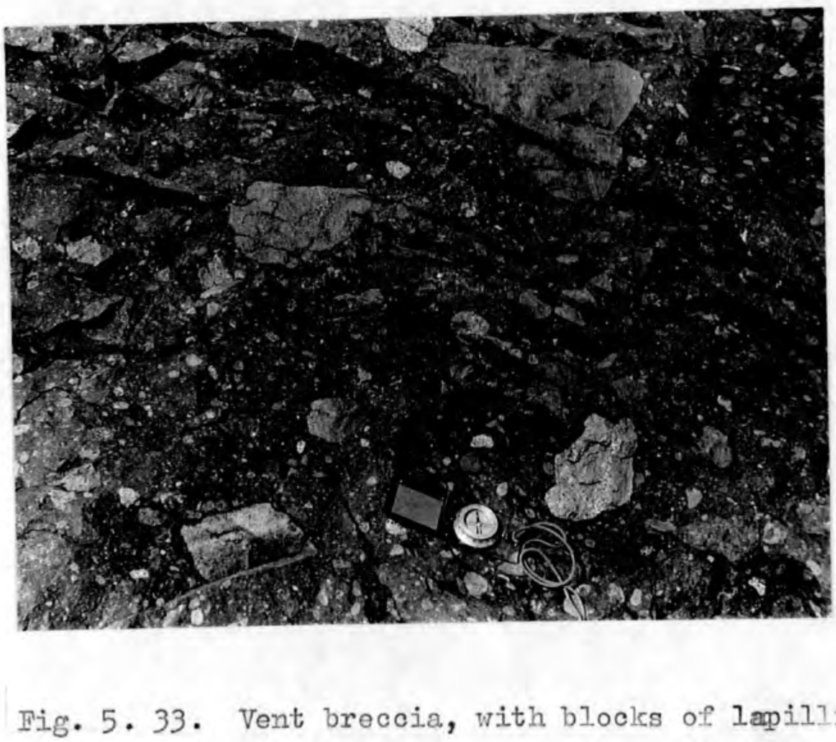


Fig. 5. 33. Vent breccia, with blocks of lapilli tuff.

principally lapilli tuff, are inclined steeply against the margin. These are overlain unconformably by a sheet of amygdaloid with a scoriaceous upper surface. Scoria have been caught up in the succeeding cross-bedded pyroclastics.

Thin stringers of very fine, red, calcareous tuff occur at intervals. Centimetre-thick sheets of this material are split up into numerous fragments by vertical fractures which are penetrated by the surrounding fine lapilli tuff. The individual pieces have a dish-like form, with the concave side upward. This structure has been formed in the same manner as mud-cracks, viz., by the shrinking of a wet, fine grained sediment on dessication. (cf. Pettijohn, 1949, pp. 143 and 144).

These rocks are overlain to the south by volcanic breccia. A fine, even, deep red matrix contains angular fragments of bedded and unbedded lapilli tuff up to about half a metre across (Fig. 5.33). There are also rounded blocks of fine grained carbonate rock up to 2 m. in diameter. Examination of thin sections of the matrix shows it to be a micro-breccia formed by the comminution of lapilli tuff. For the greater part of 300 m. breccia of this kind alternates with cross-bedded coarse tuffs. The matrix of the volcanic breccia or agglomerate is rather sandy in places. Locally, there are inclusions of carbonatised lamprophyre, well rounded dark brown bombs with radial veins of white carbonate. Dip and strike measurements in the bedded pyroclastics, though somewhat variable and occasionally anomalous, are generally about $45^{o}/20^{o}$ S. E.

The southern edge of the vent has not been located and some of the strata included in the account of the upper part of the Calcareous Unit may occur within the vent.

Diatremes of Basaltic Tuffisite.

The larger of the two intrusions of basaltic tuffisite outcrops at the western end of Grassy Lake. Although the marginal contact is nowhere exposed, the relations of the boundary to topography make it clear that the body is steep sided. The rock weathers light brown with orange coloured inclusions. The freshly broken surface is greenish-grey due to the presence of abundant chlorite. The groundmass is composed of tiny fragments of olivine basalt with a variable admixture of quartz grains and small pieces of sandstone. The rock tends to be fairly homogeneous in outcrop and inclusions are rather evenly distributed. Small, angular inclusions of olivine basalt, a centimetre or two across, are very abundant. There are also rarer ellipsoidal inclusions about 10 cms. across. They appear to be of similar composition.

In a few places stratification is seen, e.g. $110^{o}/40^{o}$N, near the centre of the body. At this point, notably angular blocks of basalt, which weather to an orange-red colour, are set in a fine, dark red, quartzose tuffisite matrix.

A smaller intrusion at the south-western end of Forest Lake contains similar material. On the eastern side, the body shows a sharp, intrusive contact against red, calcareous tuffisite.

The basaltic tuffisite of both intrusions weathers very readily. It is difficult to collect fresh material.

Stocks of Carbonatised Uncompahgrite.

Half a kilometre south of Grassy Lake, a steep sided intrusion of carbonatised rock, some 300 m. long, cuts the Lower Sandstone unit, the Calcareous Unit and the large, irregularly shaped body of tuffisite. The rock is very dark, purple-brown in colour and has a peculiar weathering pattern probably related to vertical vesicular structures (Fig. 5.34). There are sparse inclusions, some of them severely altered. Most are of basement granite. Affinities with the extrusive amygdaloid are not very obvious in the field; in thin section, however, the two rocks are of almost identical mineralogy.

About 400 m. to the south, there is a small oval outcrop of purple amygdaloid which seems to have steep sides. It may be another stock.

Sill of Carbonatised Uncompahgrite.

About 100 m. south-west of Square Lake, a 5 m. sill of fine grained carbonatised rock is intruded conformably into sandstone, close to the NE - SW fault. The rock has typical grooved weathering and resembles material from the larger of the stocks described above.

Fig. 5.34. Carbonatised uncompahgrite of stock.

Fig. 5.35. Dome structure in sandstone. Circled figure gives scale.

Sandstone Dome.

At ca. 100 m. altitude on the north slope of Angmagssiviup Qâqâ, strata of the upper sandstone unit are bent upward into a very regularly shaped dome about 50 m. across. The strata maintain their thickness over the dome and there is no sign of rupture. The structure recalls the disposition of sediments above some salt domes (cf. De Golyer et al., 1926) and very strongly suggests the presence of a concealed pipe-like volcanic intrusion.

Barytes Mineralisation.

Barytes is common throughout the Calcareous Unit, partly occurring as local pods of coarse crystals (Fig. 5.36) partly disseminated throughout the intergranular interstices of the rocks. It also occurs microscopically in the intrusive breccias and tuffisites.

Even where the mineralisation is heaviest, no single cubic metre of rock containing more than 25% barytes has been found. Concentrations which even approach this figure are rare, sporadic and of small extent. There is no evidence to suggest the presence of an economic deposit.

Fig. 5.36. Barytes mineralisation in calcareous tuff.

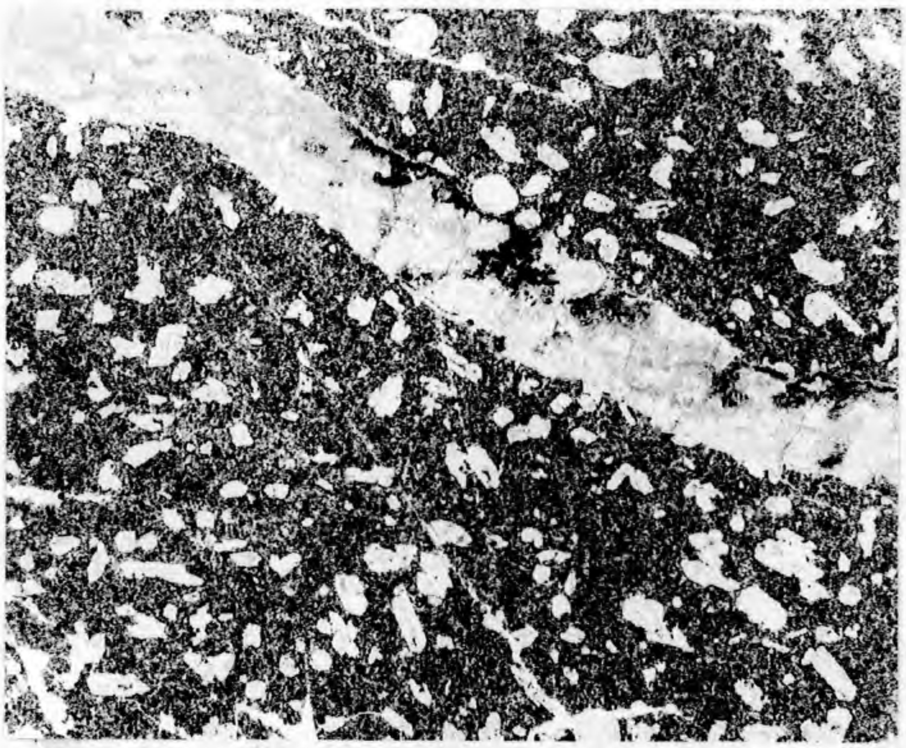


Fig. 5.37. Photomicrograph of 39903, a monchiquite, x6, in ordinary light. Note euhedral phenocrysts with pointed terminations (pseudomorphed olivine).

(b) PETROGRAPHY

1. Minor Intrusions in the Basement North of Qagssiarssuk and the Kiagtut River.

The following ultramafic types have been tentatively identified in thin section:

(i) Monchiquite
(ii) Mica-Monchiquite
(iii) Alnöite
(iv) Mica-Peridotite (? Kimberlite)
(v) Uncompahgrite
(vi) Mica-Pyroxenite

The degree of carbonatisation in types (i) - (v) varies considerably both from one intrusive body to another and also within any given intrusion. The degree to which the "original" (probably dominantly silicate) mineral assemblage may be preserved is quite unpredictable.

The petrography of this superficially unpromising material is based largely on a series of deductions from the shape of pseudomorphs and the nature of the replacing minerals. In general, a composite picture of each particular rock type is built up from the examination of a number of specimens in which specific textural or mineralogical features are particularly well preserved.

One of the primary aims of the petrographical investigation has been to establish, as far as possible, the nature and proportions of the minerals in the several rock types, prior to alteration, and to classify them accordingly. Since the original mineral assemblage is never wholly preserved, the classification is of necessity based on a partly inferential mineral assemblage and is liable to modification in the event of less altered material being found.

The "original" mineral assemblages have been subjected to some or all of the following alteration processes:

(i) late magmatic processes -- autometasomatism.
(ii) Metasomatism after consolidation

-- mainly carbonatisation; only the pyroxenite has escaped this effect.

(iii) Thermal metamorphism.

The second of these processes would almost inevitably obliterate evidence of the first.

There is little doubt that all the rocks have undergone thermal metamorphism imposed by the plutonic intrusions of the region; metamorphic effects, usually of low grade, have been recorded in Gardar volcanic rocks of most of the areas investigated. Since the minerals by which these effects are usually judged are either absent from the suite (e.g. plagioclase) or already broken down by the first two processes (e.g. olivine, pyroxene), it has not been possible to investigate this aspect of the alteration fully.

The term lamprophyre is used in the sense of Knopf, i.e. "mesotype (= mesocratic) or melanocratic rocks carrying solely ferromagnesian phenocrysts in an aphanitic or microgranular groundmass, and in which the ferromagnesian minerals in the groundmass show notable idiomorphism" (Knopf, 1936 pp. 1748 and 1749). Other characteristics of lamprophyre such as the abundance of volatiles (H_2O, CO_2, P_2O_5, S) and of the elements Ba and Sr (Turner and Verhoogen 1960 p. 251) are masked by the carbonatisation. Mica-peridotite (?kimberlite) falls within Knopf's definition and is here included with the lamprophyres (cf. Watson, 1955, p. 567). The lamprophyres described below are ultramafic (feldspar-free) varieties containing phenocrysts of olivine. The only petrographic terms in common use which can be applied to such rocks are "monchiquite" and "alnöite". The former is characterized by an obscure, often aphanitic groundmass; the latter contains melilite.

Both of these types are distinguished. A third variety, mica-monchiquite, is recorded, in which melilite cannot be distinguished. Otherwise, the rock appears to be virtually identical to the alnöite. In view of the readiness with which all traces of melilite can be removed by alteration, it is not considered advisable to make an important distinction between mica-monchiquite and alnöite and the two types are discussed together.

In the various rocks of the ultramafic suite, olivine, melilite and perovskite are always completely altered and are identified from their pseudomorphs.

MONCHIQUITE

This rock type has the widest spatial distribution of all the ultramafic varieties considered. It is intruded into some of the volcanic pipes, constitutes the most common kind of igneous inclusion in the pipe breccias and forms many intrusive sheets in the basement granite. Small intrusions have been found in other areas, viz. near Igaliko and at Sitdlisit, while there is a thin flow in the Nunasarnaq Sandstone Unit, 1 km. north of the inner end of Tunuarmiut.

All the monchiquites from the Qagssiarssuk area are heavily carbonatised and the primary silicate minerals are mostly altered. The occurrences at Sitdlisit and Tunuarmiut have escaped heavy carbonatisation, although they have been considerably altered by other processes. Exhaustive comparisons of material from these occurrences with samples of the monchiquites from the Basement north of Qagssiarssuk and the Kiagtut River show that the monchiquite of the southerly occurrences is quite representative of the group, differing only in its superior state of preservation.

Monchiquite from Sitdlisit & 1 Km. north of Tunuarmiut.

Specimen 39903, from Sitdlisit, is taken from a sill 2-3 m. thick, closely associated with intrusive volcanic breccia. In hand specimen, the rock has a greyish-green, aphanitic groundmass containing small black vesicles and phenocrysts. The latter show a moderate degree of alignment.

In thin section, most of the phenocrysts are seen to be pseudomorphs after olivine (Fig. 5.37). They constitute about 15% of the rock modally. These pseudomorphs preserve the outline of idiomorphic olivine crystals; they are seldom more than 1 mm. long and have an average length of ca. 0.6mm. The pseudomorphing minerals are chlorite and carbonate in roughly equal quantities. While the distribution of the two minerals within the pseudomorphs is mainly quite disorderly, chlorite always persists around the perimeter of the grain, though often as a very attenuated zone. The vesicles, which are nearly spherical and similar in size to the phenocrysts, are filled with aggregates of fine chlorite.

A few phenocrysts of unaltered, pale, pinkish-brown pyroxene occur. They present elongate, rectangular sections a millimetre or so in length and may show simple twinning parallel to the elongation.

Alteration of the groundmass is rather far advanced. The mesostasis is an obscure, amorphous mixture of carbonate and chlorite, with a little quartz. Some slender, pale yellow needles may be amphibole, judging by rare, lozenge-shaped cross-sections. Crystals of clinopyroxene with a marked acicular habit are set in this groundmass; some of them are relatively unaltered. They are commonly 0.1 - 0.2 mm. long, with a length:breadth ratio of 20 - 30:1, or, occasionally, much greater. Some of these crystals are twinned parallel to the length, most show transverse cracks. Locally, the needles may be arranged in radiating groups or packed parallel to one another in sheaves. Minor tangential arrangement around the phenocrysts is sometimes seen, but there is no evidence of a similar disposition around the vesicles. In general, the needles show little tendency to conform to any orderly system of alignment. Alteration of the rock is too far advanced to permit any accurate estimate as to the original abundance of the mineral; it probably constituted 25% of the groundmass, ± 15%. All of the fresh pyroxene has a very pale pinkish-brown colour. The grains show signs of marginal corrosion.

Clusters of small, square sections of an iron ore are abundant throughout the rock. Larger grains occur, particularly adjacent to pseudomorphed olivines and pyroxene phenocrysts. One or two tiny, reddish-brown grains may be partly altered perovskite. Within the groundmass there are a few corroded remnants of elongate grains of a colourless mineral of moderate relief and low refringence which shows straight extinction. The narrower of these sections are comparable in size with shorter pyroxene needles and have a similar transverse fracture. Rare, accompanying hexagonal cross-sections suggest that this mineral is probably apatite in a state of partial alteration. Relicts of broader, rectangular grains may be a different mineral; relief seems too low for apatite or melilite.

With the exception of a minute, fresh-looking flake of brown mica adjacent to granules of ore within a pseudomorph after olivine, biotite is wholly absent. As a general rule, mica is seldom wholly obliterated in rocks of the suite and it is unlikely that it was present in the original rock in significant quantity (cf. Kranck, 1929, p. 28).

There is a sprinkling of tiny granules of a mineral of high relief and high birefringence, probably sphene.

No feldspar has been observed.

It is evident that a considerable proportion of the groundmass, possibly as much as 70%, was originally occupied by a mineral, a number of minerals, or glass now totally altered.

Specimen 39959 from the monchiquite flow (39959) is very similar to 39903, both as regards the identifiable primary minerals and the degree of alteration. Rather more pyroxene is preserved, however, some as prismatic phenocrysts up to 2 mm. in length. In the groundmass, there are corroded needles and tiny prisms of similar pyroxene; the majority of the grains have a length in the range 0.1 - 0.25 mm., however, all sizes from this range up to that of the nominal phenocrysts are represented. Where fresh, the mineral has a pale yellow colour. In parts of the rock pyroxene may occupy nearly 50% of the groundmass. The abundant vesicles are filled with fine grained carbonate.

Monchiquite north of Qagssiarssuk and the Kiagtut River.

Specimen 61620, from a small intrusion at the edge of a diatreme a short distance north of Qagssiarssuk, is highly vesicular, with flow-banding developed towards a chilled contact. Appearance in thin section agrees essentially with the description of the Sitdlisit rock; vesicles are more abundant, however, and no fresh pyroxene is preserved. The vesicles are elongated and filled with coarse grains of anhedral carbonate.

Two distinct types of olivine pseudomorphs can be distinguished. The first is euhedral, with characteristic pointed terminations; the other has rounded anhedral form, similar to that of olivine phenocrysts found in olivine basalts of the area.

Pseudomorphs after groundmass pyroxene, largely composed of carbonate, are readily recognised; their form and arrangement are reminiscent of the Sitdlisit rock, but they are rather more abundant. There is no sign of any tendency toward tangential arrangement around the vesicles, and many of the needles penetrate well into the interior of these.

Small groups of grains of a colourless mineral of moderate relief, low refringence and straight extinction occur sporadically. The grains have an elongated rectangular habit and are comparable in size to the pyroxene pseudomorphs. Almost every grain is bisected longitudinally by a thin line of some fine grained dark material. The structure recalls the median parting often present in melilite crystals. While there is a possibility that the mineral may be melilite, the small size and rarity of the grains preclude positive identification.

Specimen 61685 is from a 0.5 m. thick intrusive sheet which outcrops at 400 m. in a stream section approximately 7 km. north of Narssarssuaq harbour. (For macroscopic description, see Table 5.1). While the principal original silicate minerals have been transformed to obscure, amorphous alteration products, and even the pseudomorphs after olivine are composed of this material instead of the usual crystalline carbonate and chlorite, texture is well preserved. Investigation by X-ray diffraction showed quartz and ankerite to be the principal constituents. Chlorite is also present, occurring as rather large crystals in the vesicles. The X-ray study also revealed the presence of barytes in small quantity. This is predictable, as analysis shows the rock to have a BaO content of 0.5%. (Table 5.3).

Table 5.3

Analysis of 61685, a carbonatised monchiquite.

SiO_2	39.3
TiO_2	2.7
Al_2O_3	7.9
Fe_2O_3	2.7
FeO	10.2
MnO	0.2
MgO	7.1
CaO	9.8
Na_2O	trace
K_2O	0.9
P_2O_5	1.3
CO_2	13.8
H_2O	3.3
BaO	0.5
SrO	0.2
ZrO	trace
Total	99.9

Locality: 400 m. altitude, 7 km. north of Narssarssuaq Harbour, South Greenland.

Analyst B. I. Borgen.

Petrography of the Monchiquites - General.

Pseudomorphed olivine phenocrysts of similar shape and size occur in all specimens, constituting a rather constant modal proportion, viz. around 15%. The anhedral pseudomorphs in 61620 are exceptional. Fresh pyroxene phenocrysts and groundmass grains are preserved only in 39903, and 39959. Unmistakable pseudomorphs after groundmass needles of pyroxene are found in 61620 and 61685; in all the other specimens the mineral has been obliterated. Groundmass pyroxene is judged to occupy 25% $\pm$ 5% by volume of the groundmass in 39903; in 61620 and 39959 the figure is probably nearer 50%. In 61685 the mineral is very heavily altered; the percentage present probably resembles that in 39903 rather than 61620.

Comparison of the specimens in thin section indicates that the iron ores which crystallised from the magma have been liable, subsequently, to considerable redistribution. In 39903, the distribution of the ore grains suggests that some have been derived from the breakdown of mafic silicates; in 61620 there is such a heavy dusting of ore that secondary introduction of iron oxide seems probable. The same general pattern is followed in most of the specimens from monchiquite inclusions in the diatreme. Some of these inclusions, typified by specimen 61622, are purple, instead of the more usual grey or black. In thin section, fine hematite dust is seen to impregnate the groundmass and there are localised build-ups of hematite around the peripheries of the vesicles and within the larger pseudomorphs.

It is likely that 61685 nearly shows the distribution of the ore minerals as it was in the original rock. Opaque ore occurs as small, scattered clusters of euhedra, individual grains measuring ca. 0.025 mm. across. Modally, the ore makes up about 4% of the rock. An unknown proportion of this may be altered perovskite.

Although perovskite has not been identified with certainty in any of the monchiquites, the former existance of the mineral is not precluded. Comparison with other rock types of the suite, in which pseudomorphs after perovskite have been identified with some confidence, suggests that the mineral would tend to be altered partly to iron ore and partly silicated to form sphene. In view of the small grain size the mineral would be expected to adopt in such a fine grained rock, recognisable pseudomorphs could easily be missed.

A few partially corroded slender prisms of a mineral resembling apatite occur in 39903. There is no trace of apatite in any of the other specimens. In view of the high P_2O_5 content of the rocks (1.3% in 61685), the presence of apatite might be expected. The norm of 61685 contains 3% apatite. The present location of the P_2O_5 is unknown.

Primary constituents. In a hypothetical typical specimen the modal proportions of the primary minerals must have been approximately as follows: olivine 15%, pyroxene 30%, titanomagnetite and perovskite 5%, apatite 3%. Almost half the volume of the rock, now occupied by carbonate, chlorite and silica, consisted of glass or of some mineral or minerals no longer identifiable.

MICA-MONCHIQUITE AND ALNÖITE.

It is probable that the majority of the intrusive sheets belong to these categories; samples of mica-monchiquite from either side of Tunugdliarfik show the closest petrographic similarity (e.g. 61609 and 61682). In a single instance an inclusion of mica-monchiquite (or alnöite) has been found as an inclusion in a diatreme (61612).

The most outstanding difference between these rocks and the monchiquite is their comparatively high content of dark mica. Grain size tends to be rather coarser, as a rule, and it is probable that the rocks were holocrystalline prior to carbonatization.

In thin sections extensive carbonatization is evident. 61682 contains 20.8% CO_2 (Table 5.5). With the exception of mica, the original silicate minerals nearly always have been wholly replaced. Commonly, carbonatization is accompanied by recrystallization and the only distinctive pseudomorphs preserved areamong the phenocrysts.

Olivine has certainly been the principal phenocryst mineral and two generations are tentatively distinguished from the pseudomorphs in some cases e.g. 61609. (The assumption is made that all pseudomorphed broad, prismatic phenocrysts with pointed terminations are after olivine.

In 39903 and 39959 the pyroxene phenocrysts are narrow, with poorly developed terminations, while the pseudomorphed olivine phenocrysts have the form of broad prisms with well developed brachydomes.) The earlier generation, forming less than 5% of the rock modally, is represented by large euhedra 2 mm. or more in length. Judging by the rather complicated (though euhedral) outline, there was a tendency for compound crystals to develop. Olivine of the second generation formed simple idiomorphic prismatic grains ca. 0.8 mm. in length, which are much more abundant, constituting ca. 20% of the rock modally.

The pseudomorphs are composed of carbonate, quartz, serpentine and chlorite. The carbonate is in the form of small, anhedral granules; the quartz is in tiny, interlocking grains with shadowy extinction; the serpentine is made up of spindle-shaped fibres orientated parallel to the elongation of the pseudomorph in most instances and the chlorite occurs as a felty aggregate of minute flakes of very low birefringence.

The volumetric composition of the pseudomorphs in 61609, is outlined in Table 5 (the percentages given rough, visual estimates).

Table 5.4

Location and relative amounts of replacive minerals in pseudomorphed olivine grains, specimen 61609.

Carbonate	Quartz	Serpentine	Chlorite
55% peripheral	35% internal	- -	10% central
15% peripheral	15% peripheral	70% overall	- -

- - - - - - - - - - - -

The occurrence of two kinds of olivine in the same rock (sometimes crysolite and monticellite) is a rather common feature of kimberlites and alnöites (e.g. Wagner, 1914, pp. 54, 82; Bowen 1922 p. 2).

In more heavily carbonatized material, typified by 61682, the proportions of the secondary minerals show a distinctly different pattern and there is a consider able enrichment in quartz. Serpentine is much less prominent in the rock, partly because of the extensive alteration of the smaller pseudomorphs.

Mica forms 20 - 30% of the rock as a rule. The flakes are usually well shaped with straight-cut terminations. The average length is about 0.2 mm. and the length:breadth ratio 3:1. Most of the flakes conform rather closely to these values. Colour is a rather pale pinkish orange; weak pleochroism is evinced by a greenish tinge associated with the direction. It is possible that some mica has broken down completely and merged into the groundmass. Two distinct alteration processes have been active - - (i) marginal alteration to chlorite, (ii) development of carbonate along the cleavages. The mica is not zoned, nor does it enclose any other mineral consistently.

Phenocrysts of magnetite are very conspicuous in their sporadic occurrences but do not constitute an important modal element of the average rock. Sufficient original crystal faces remain on some grains to suggest that at an earlier stage in their history they were highly idiomorphic with octahedral habit. Mostly, the original habit has been entirely suppressed and in thin section the outline is sinuous and/or finely denticulate (Fig. 5.38). It is apparent that the grains have been out of equilibrium with their environment and been vigorously attacked; the attack has been both physical and chemical.

The physical process has led to the extensive development of internal cracks within the grains. At times, these cracks show a tendency toward concentric arrangement about local foci. The relation of the cracks to the internal crystallographic structure of the grains is very casual and can be seen where the fissures become rectilinear or zigzag for short distances. Around the margins of the grains there is often a spongy porous zone of rather constant width. In the outer part of this zone fragmentation is very heavy. The lines of weakness are closely related to the crystallographic structure; this is emphasised by the euhedral shape of many of the detached fragments.

Chemical attack on the exterior of the grains has caused deep, smoothly curved embayments, modified in detail by fragmentation (see above). The corrosive medium has also penetrated the fissures and enlarged and smoothed them by solution. This process accounts for the numerous tiny, elongate cavities within the crystals, and has accelerated the marginal disintegration. Large grains of iron ore in a thin section of āillikite (Kranck, 1939) show identical marginal corrosion and fragmentation. (The slide was made available by the courtesy of Dr. O. von Knorring of the Department of Geology, University of Leeds).

Groundmass grains of magnetite form some 10 - 15% of the rock, mostly ranging from 0.02 - 0.05 mm. across. Marginal disintegration is not important and nearly all the grains are approximately euhedral with octahedral habit. Some of the grains are cracked and all show the spongy,

Table 5.5

Analysis of 61682, a carbonatised mica-monchiquite with magnetite phenocrysts.

SiO_2	22.5
TiO_2	3.4
Al_2O_3	4.2
Fe_2O_3	7.5
FeO	9.7
MnO	0.2
MgO	12.7
CaO	13.1
Na_2O	trace
K_2O	1.1
P_2O_5	0.5
CO_2	20.8
H_2O	2.1
BaO	0.4
SrO	0.5
ZrO	trace
Total	98.7

Locality: 550 m. altitude, 8 km. from Narssarssuaq Harbour, 350° bearing.

Analyst: B. I. Borgen.

Fig.5.38.Large magnetite grain in thin section of 61682, x 33, to show modification of original euhedral form by corrosion.

Fig. 5. 39. Photomicrograph of 61627, a carbonatised alnöite, x 40, in ordinary light, to show carbonatised pseudomorphs after olivine (phenocrysts) and melilite (small, lath-shaped grains). The dark circles represent air bubbles in the slide.

porous texture seen around the margins of the phenocrysts. The effect persists to the centre of the smaller crystals.

Magnetite is the only ore mineral seen in polished section, despite the high normative ilmenite content in the analysed specimen 61682, (6.5% Il). Investigation of some of the phenocrysts from specimen 61683 by X-ray diffraction showed magnetite to be the only phase present in detectable quantity. The unit cell edge size, "a_o" was calculated and the determined value, 8.39 Å, agrees closely with the value for pure magnetite recorded by Basta. (Basta, 1957).

61627 is critical to the petrology of the suite since it contains unmistakable pseudomorphs after melilite in considerable quantity (Fig. 5.39). In the field, the weathered surface is identical in appearance with that of the mica-peridotite (see Table 5.1). The freshly broken surface is medium grey, basalt-like.

In thin section it is at once apparent that the alteration pattern differs from that of the other specimens examined and it is presumably to this chance that the pseudomorphed melilite grains owe their preservation. Carbonatization and recrystallization have been relatively moderate. In common with most of the other rocks of this group, pseudomorphs after olivine are plentiful and there is abundant mica and iron ore in the groundmass. The pseudomorphs after olivine are composed of a felt of minute flakes of chlorite, sometimes arranged to pseudomorph earlier serpentine.

The pseudomorphs after melilite show the lath-like habit characteristic of the mineral. The laths have an average length of ca. 0.4 mm. and a length:breadth ratio of about 6:1. Squarish cross-sections are occasionally seen and the typical median parting is often preserved in the replacive chlorite. The chlorite fibres are arranged normal to the elongation of the grains, as is usually the case with fibrous alteration products of melilite. The laths tend to be arranged parallel to one another and there is a moderate overall direction of the rock fabric, shown up by the orientation of the olivine and melilite.

61604, from a thin, intrusive sheet on the hillside above Umiussat seems to have escaped the usual strong carbonatization. Perhaps because of this, some small relicts of pyroxene remain; the original mineral may have been quite abundant as rather stout prisms ca. 0.2 mm. long. Apatite occurs as sheaves of small prisms. It seems to have crystallised later than the pyroxene and mica. It has been subjected to corrosion. Fine, granular sphene is abundant, forming 2 - 3% of the rock. In places the mesostasis (a fine, felty intergrowth of chlorite and other alteration products) contains vague, elongated rectangular outlines of a size comparable to that of the mica flakes. The habit of these vestigial pseudomorphs is also suggestive of melilite.

61612, collected from an inclusion in a diatreme, shows a type of alteration different to that encountered in the rocks described above, probably due to the different environment. In particular, most of the mica has been converted to bright green chlorite. In the final stage of alteration, the mica has the following pleochroic pattern:

γ = emerald green, α = orange

There are numerous elongate vesicular structures in the rock, each occupied by large grains of clear carbonate with lamellar twinning.

Small, translucent, brownish sections of an octahedral mineral are pseudomorphs of amorphous sphene (leucoxene) after perovskite. Size rarely exceeds 0.01 mm.. The grains are widely scattered and occupy 1 - 2% of the rock. No granular sphene is present.

Assuming that the primary minerals indicated in the above descriptions have been common to all or most of the rocks of the group, a hypothetical, typical specimen, prior to alteration, might be expected to have approximately the following mineralogical constitution:

Magnetite phenocrysts + olivine of first generation	5%
Olivine of second generations	20%
Biotite	25%
Groundmass iron ore	10%
Melilite	20%
Groundmass pyroxene, accessories (apatite, perhaps perovskite), unknown minerals	20%

LAMPROPHYRIC TUFFISITE.

This material, found in some of the diatremes, is typified by 61616, a highly carbonatised microbreccia of alnöitic composition. Such characteristics of the original rock as can still be distinguished suggest a close affinity with the lamprophyres described above. Phenocrystalline, represented by euhedral, carbonated pseudomorphs, is plentiful. The groundmass is a fine grained mixture of carbonate, chlorite and quartz containing corroded grains of iron ore which are extensively altered to leucoxene. Rather large subhedra of sphene also occur, assembled in small clusters. There are occasional phenocrysts of iron ore closely resembling those in certain of the lamprophyre sheets (cf. 61682). Locally, small, lath-like grains replaced by carbonate can be distinguished. They are suggestive of melilite. Mica seems to be absent. The rock has undergone a kind of auto-brecciation leading to the development of somewhat rounded fragments a few millimetres in diameter set in a matrix of similar composition. The structure is not readily recognised except in favourable conditions, e.g. when the fragments are stained by haematite or the matrix is differentially replaced by carbonate. It is thought that this carbonatised, alnöitic microbreccia might with some justification be classified as an "autoclastic explosion-breccia" which, by the definition of Wright and Bowes (1963) "forms by the disruption of a semi-solid mass of igneous material by the explosion of cognate gases".

Singewald and Milton (1930) describe comparable material from an alnöite pipe near Avon Missouri, and Fig. 3 of their publication shows a rock very similar to 61616, in section. These authors conclude that the alnöitic magma disintegrated into spherules or droplets, following a sudden release of the high associated gas pressure.

The appearance of the Qagssiarssuk tuffisite also invites comparison with kimberlite microbreccia in the South African diamond pipes (cf. Wagner, 1914, Plate XIII, Fig. 25, 4); however, Wagner considers the rock "to be due to the trituration and comminution of masses of solidified kimberlite, rather than to a spattering or pulverisation of the molten rock by the escape from its surface of highly compressed gases and vapours" (op. cit. pp. 27, 28).

<u>MICA-PERIDOTITE</u>. (?KIMBERLITE)

The only specimen of this rock type (61607) is taken from a 2 m. sill on the south bank of the Qordlortoq River at ca. 70 m. The field description can be found in Table 5.1. In thin section (Fig. 5.40), the rock is seen to be heavily carbonatised. While many of the closely packed pseudomorphs are readily referred to phenocrysts of olivine, others have broken down; thus it is only possible to state that while ca. 50% modal olivine is definitely established the original amount may have been considerably more. The pseudomorphed olivine grains are mostly from 0.5 - 1.0 mm.

in length although some exceed 2 mm.. The larger grains tend to be rounded, but more idiomorphic habit is common in the smaller individuals (cf. Verhoogen, 1940). Both pseudomorphed phenocrysts and groundmass are largely formed of fine grained, turbid carbonate. A fine form of silica is a subordinate constituent of the phenocrysts and in the groundmass there are localised aggregates of very fine chlorite.

The amount of mica in the rock is somewhat variable. In places flakes are closely packed among the pseudomorphed olivine grains. The distribution may be partly original and partly a consequence of uneven alteration. Most of the grains maintain an idiomorphic habits as books with a breadth:thickness ratio of 2.5:1. Pleochroism is pale pinkish brown, slightly greenish, medium brown. Carbonate has developed quite often along cleavage cracks and in a relatively few instances marginal alteration to chlorite can be detected.

Small opaque grains, mostly of squarish shape, are scattered throughout the groundmass. The majority are sections of octahedra of iron ore and may show marginal alteration to leucoxene. A few consist of a square rim of ore enclosing carbonate. These latter, may pseudomorph perovskite. No other original minerals can be distinguished.

There are a few interstitial, vug-like structures, less than 1 mm. across. Small grains of water-clear carbonate form a denticulate peripheral fringe, euhedral against a filling of fine, turbid carbonate.

UNCOMPAHGRITE (MELILITE ROCK).

Melilite has been highly susceptible to carbonatisation in all the rocks under review. The uncompahgrite, on account of its high original melilite content, is now the most highly carbonated rock-type of the ultramafic suite. Some specimens must contain 60% of normative carbonate, (the analysed specimen, 61606, a nodular variety, and therefore less melilite-rich than many examples, contains 24.5% CO_2 - - see Table 5.6). Some of the intrusive sheets are free of inclusions, others contain quantities of nodules; a few are vesicular. The rock is occasionally contaminated by the breakdown products of nodular inclusions.

The mineralogy of inclusion-free uncompahgrite is simple, consisting of melilite (pseudomorphed), biotite (now usually chlorite), apatite and iron ore. The melilite grains have been replaced by carbonate; often, a single, turbid crystal of carbonate occupies the site of a melilite grain. These pseudomorphs average ca. 0.4 mm. in length. They have a length:breadth ratio of ca. 6:1 and are arranged with a strong, parallel flow-structure (Fig. 5.40). The pseudomorphs are referred to melilite by consideration of the associated minerals and rock types and by comparison with published descriptions. (Cf. Von Eckermann, 1958, Plate VIII, Fig. 2, and McCall, 1963, Plate XII).

The finer details of texture are now obscured due to various alteration processes and the exact limits of the original melilite grains are no longer clear; thus, a reliable volumetric estimate of the original melilite cannot be made and the volume of the associated intergranular areas is likewise uncertain. Undoubtedly the modal percentage of melilite was very high, probably over 60%. The remaining recognisable minerals hardly rise above accessory status. Olivine is absent, other than as grains of accidental derivation from associated lamprophyric material. Narrow laths of chlorite, conforming closely to the strong flow direction of the fabric, are presumed to be altered dark mica. These laths, which range from ca. 0.4 mm.- ca. 1.0 mm., are pleochroic from pale green to colourless and have an abnormal purple interference tint. The chlorite, in turn, may be altered to clear carbonate with trails of fine ore grains parallel to the elongation.

Sections of an opaque mineral of octahedral habit are scattered throughout the rock. They range from 0.2 mm. across down to tiny granules. Most are markedly euhedral, many also show considerable evidence of corrosion. In the more altered specimens there is a rim of leucoxene. Perovskite has not been identified. There are a few scattered prisms of apatite which conform to the flow structure of the rock. They are often intensely corroded and replaced by carbonate.

There is absolutely no sign of any primary mineral apart from those already recorded. Locally, there are small areas of secondary quartz, up to ca. 1 mm. across, which have an intricate, interlocking relationship with the surrounding carbonate grains.

Fig. 5.40. Photomicrograph of 61607, mica-peridotite (left) cut by nodular uncompahgrite, x 7, in ordinary light. Flow structure in the uncompahgrite is emphasised by laths of carbonatised melilite. The large nodule near the centre shows partition structure, the pseudomorphed olivine phenocryst (bottom centre), has a thin coating of alnöite.

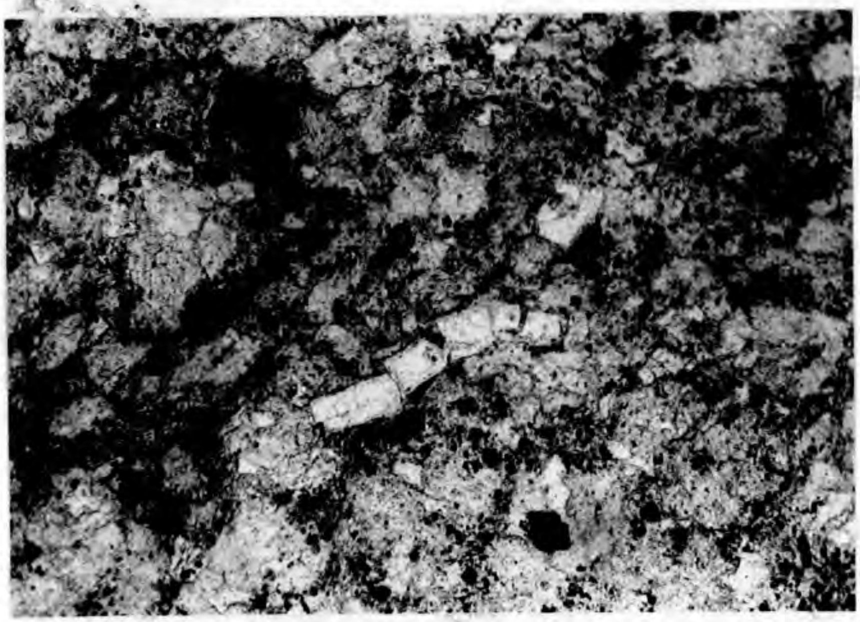


Fig. 5.41. Photomicrograph of 61626, carbonatised uncompahgrite, x 100, in ordinary light, to show fractured apatite prism.

Specimen 61626 is a highly calcareous variety with some unusual features. It contains vesicular structures of very regular ellipsoidal form, up to ca. 1 cm. long. These are filled with flakes of chlorite identical to that of the groundmass, but much larger, spanning the cavity. The chlorite is accompanied by varying quantities of carbonate and quartz. The carbonate grains of this rock occur as very short, rectangular sections and various anhedral shapes. A general directed fabric is present, but only occasionally do the usual elongate pseudomorphs appear. A fractured apatite prism may provide the key to this texture (see Fig. 5.41); it strongly indicates mechanical granulation.

NODULAR UNCOMPAHGRITE.

Since the nature of the groundmass and the nodules, as well as the kind and degree of alteration, are all variables in this subordinate rock type, it is convenient to discuss the petrography in terms of a number of typical specimens.

61607. Melilite pseudomorphs, which constitute less than half of the host rock, emphasise a swirling flow structure around the nodules (Fig. 5.41). The other half consists of turbid, amorphous carbonate, occasional small laths of biotite and grains of ore. The nodules are a fine grained mixture of carbonate, quartz and small, anhedral clusters of euhedral ore grains are set in this matrix; their size and abundance are reminiscent of the phenocrysts of the monchiquite and alnöite. The pseudomorphs are composed principally of turbid, anhedral carbonate occasionally pierced by tiny biotite laths. In a number of instances the pseudomorph is partially or wholly replaced by a large grain of quartz. The octahedral ore grains are strongly altered to leucoxene. The smallest nodules often consist of an olivine pseudomorph or a cluster of ore grains, usually with a small amount of matrix adhering. There are a few small phenocrysts of biotite in the host rock.

61605 The host rock is largely recrystallised and melilite pseudomorphs are rarely distinguishable. There is a considerable quantity of interstitial quartz, against which carbonate grains are often euhedral. Other minerals present are biotite and ore; there are occasional phenocrysts of brown mica in broad flakes up to more than 0.5 mm. across. The matrix of the nodules is made up of mica, with minor amounts of interstitial quartz and scattered ore grains. The pseudomorphs after olivine are of carbonate and quartz with a sprinkling of small sphene euhedra. Dark mica is decidedly the dominant mineral of the nodules. Towards the periphery, the elongated flakes have a very strong tangential orientation and the outermost part of many nodules is a nearly monomineralic mica shell (Fig. 5.43).

61630 The macroscopic characteristics of this rock appear in Table 5.1. In thin section it is apparent that the nodules are of very similar composition to the groundmass and locally merge into it. The rock is principally an amorphous mixture of carbonate and chlorite with a little

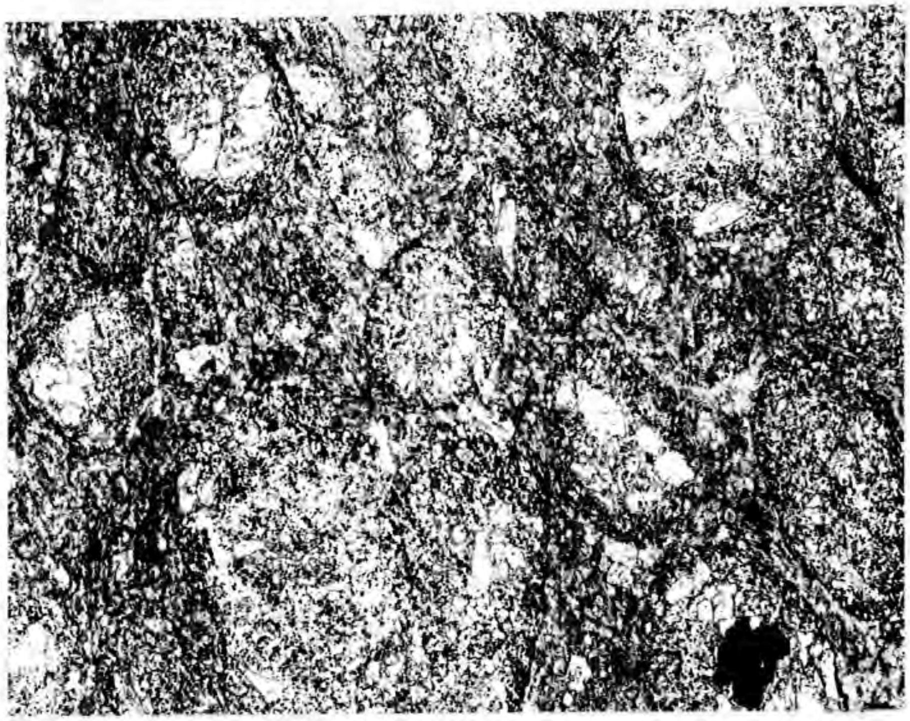


Fig.5.42. Photomicrograph of 61606, a carbonatised, nodular uncompahgrite, x 10, in ordinary light.

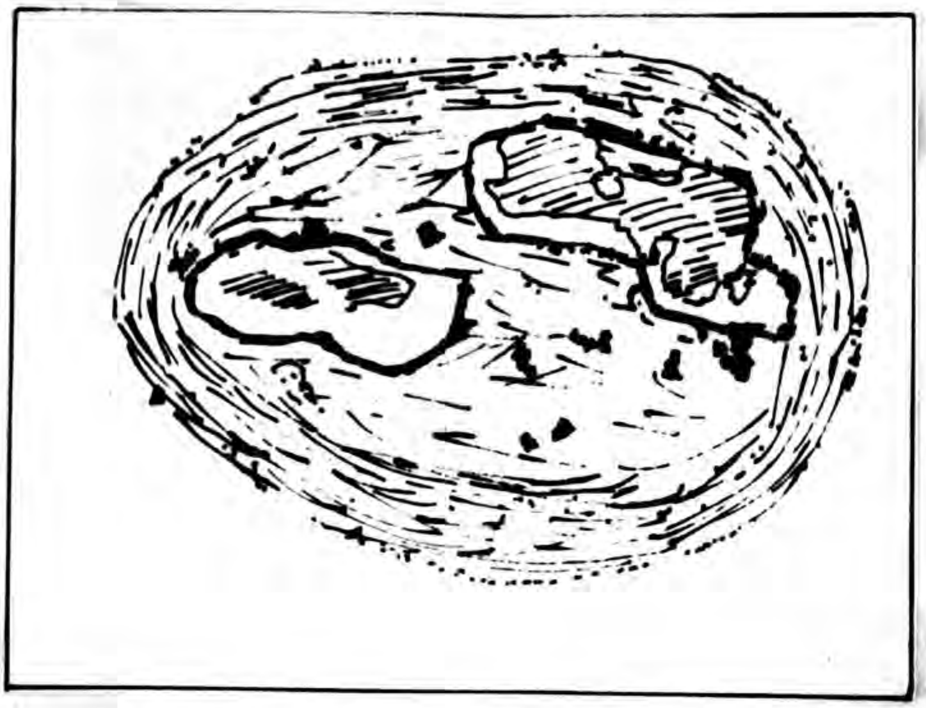


Fig.5.43. Sketch from thin section of 61605, x 55, to show shell of mica arranged tangentially around alnöite nodule.

biotite and a sprinkling of fine ore. In the groundmass, lathy texture is faintly suggested in a few places. There are rare microphenocrysts of biotite, in addition to the usual small laths.

There is a slightly heavier concentration of ore granules in the nodules. Pseudomorphs after olivine are transformed almost beyond recognition. The site of these structures is usually marked by a patch of clear carbonate which sometimes contains small laths of mica. The mica is of late crystallisation and is idiomorphic where enclosed in the clear carbonate.

In some of the intrusions, nodules with an internal partition structure have been observed. A particularly fine example occurs in 61607, (see Fig. 5.40). Within a nodule of rather irregular form an extremely narrow line of tiny quartz grains forms a perfect ellipse which is approximately concentric with the exterior. The mineralogy on either side of the ellipse is identical. In specimen 61608 there are numerous examples of a concentric structure. The composition of the rock is similar to that of specimen 61630 and the structure is formed by a slight concentration of ore grains along an ellipsoidal plane concentric with the exterior surface. It is assumed that the structures in specimens 61607 and 61608 represent the same phenomenon. The difference in appearance is a consequence of different alteration histories. The cause of the structure is unknown; alternative explanatory theories are: (i) the structures are

Table 5.6

Analysis of 61606, carbonatised nodular uncompahgrite.

	Wt.%
SiO_2	13.0
TiO_2	3.8
Al_2O_3	6.3
Fe_2O_3	3.9
FeO	18.7
MnO	0.5
MgO	11.9
CaO	10.4
Na_2O	trace
K_2O	0.7
P_2O_5	0.5
CO_2	24.5
H_2O	2.8
Ba_2O	1.3
SrO	0.9
ZrO_2	trace
Total	99.2

Locality: 40 m. altitude in Qordlortoq River, Qagssiarssuk, South Greenland.

Analyst: B. I. Borgen.

"growth rings", implying that the outer zone of the nodule grew as a mantle about the inner part, (ii) the structures are concentric tension cracks, in the one case filled by secondary quartz, in the other emphasised by metamorphic differentiation.

MICA PYROXENITE.

In specimen 61638, the normal medium grained variety is cut by a seam of coarse "pegmatitoid". In the more usual textural type, dark mica constitutes about half of the rock. It occurs as untidy assemblages of ragged, broad flakes up to ca. 1.5 mm. long. The colour is pale, pinkish orange; pleochroism is so faint as to be masked by the change of relief on rotation of the section in plane polarised light.

Alteration of the mica is not obvious. Thin films of carbonate occasionally penetrate cleavages and locally part of the edge of a crystal may grade to the pleochroic scheme α = colourless, γ = pale green, probably indicating chloritisation. The margins are generally far from straight. Inclusions of iron ore and sphene are quite abundant; their location seems to conform to the general pattern of distribution of the two minerals throughout the rock and it is likely that the mica encloses them poikilitically. Occasionally there is a narrow zone of dark brown discolouration in the mica around the sphene - - this is not a pleochroic halo.

There is a rather uneven scattering of subhedral grains of iron ore in a range of sizes from ca. o.1 mm. downwards. Sphene often accompanies the ore, although not invariably. when the mineral occurs alone, it tends somewhat toward idiomorphic habit, otherwise it forms clusters of anhedral granules. The largest grains are 0.4 mm. across, pleochroic from rose pink to colourless. There is no sign of perovskite.

Apatite occurs as small corroded prisms in the groundmass.

The bulk of the mesostasis consists of an aggregate of elongated grains ca. 0.04 mm. long with a very pale greenish-yellow tinge. The maximum interference tint is first order red, extinction is strongly inclined ($Z \wedge c$ = ca. 45^{o}, 2V is moderately large and positive). The mineral is probably pyroxene. Within this groundmass, there are some small areas of a water-clear mineral with a more prominent cleavage and slightly higher birefringence. These areas are thought to be relics of larger grains of clinopyroxene.

ALTERED MICA-PYROXENITE.

This variety is represented by the analysed specimen 61634. When this rock was submitted for analysis, it was believed to be the least altered pyroxenite material available. Specimen 61638 which was sectioned later, proved to be much less altered.

Alteration of the rock has been a localised, rather than an overall process. Areas in which the original mineralogy has been substantially preserved lie adjacent to areas in which it has been almost totally obliterated.

A dark mica is the most abundant primary mineral. In the less altered parts it may constitute as much as 70% of the rock and it may originally have been even more abundant. The grains have been well formed, averaging about 0.4 mm. across, with a breadth:thickness ratio seldom exceeding 2:1. Pleochroism is α = straw, γ = chestnut brown. Apparent zoning, producing a darker rim in sections orientated to show moderate to low absorption, is an alteration effect. Strong zoning is restricted to severely altered grains isolated in the altered areas.

Many of the flakes are pierced by small prisms of apatite. Except in the freshest parts of the rock, these are replaced by carbonate.

Alteration of the mica proceeds both marginally and along cleavage cracks. The resulting material is a very fine grained aggregate of tiny chlorite flakes.

In addition to mica and apatite, iron ore is probably another of the primary minerals. Together with the associated sphene, the small opaque euhedra are confined to the less altered portions of the rock. Here they are rather evenly distributed, forming about 10% of the material present. Sphene fringes some of the ore grains as tiny anhedral granules and also occurs as discrete grains (occasionally euhedral) in the groundmass. The close association of this titania rich mineral, in considerable quantity, with the iron ore, suggests that the ore has been a titanomagnetite or an intergrowth of magnetite and ilmenite. The exceptionally high TiO_2 value in the analysis (6.2%) further supports this idea (the C.I.P.W. norm calculated for the rock contains 11.9% Il).

The mesostasis of the less altered areas of the rock is almost wholly of fine chlorite similar to that derived from the alteration of the mica. There are also occasional slender needles of ? actinolite. Carbonate is a negligible constituent.

There is a marked contrast in petrography between the altered and less altered areas and the transition is rather abrupt. The principal constituents of the altered areas are chlorite, ? actinolite and calcite (X-ray identification) The calcite occurs as rounded bodies up to about 1 mm. across, consisting of a few clear, interlocking grains, set in a matrix of the other two minerals. The chlorite is partly in units which show an aggregate extinction effect suggesting a spherulitic structure; ? actinolite occurs as a felt of disorientated needles. The two minerals are most closely associated and their distribution appears to be unsystematic.

MICA-PYROXENITE PEGMATITOID.

In thin section, the junction between the normal variety of mica-pyroxenite and the pegmatitoid appears to be quite sharp (61638). In the pegmatitoid, there is a striking contrast in size between the mica plates, which are several millimetres across, and the groundmass, which is fine grained, similar to that of the normal rock.

The mica is rather unevenly distributed; the average

Table 5.7

Analysis of 61634, altered mica-pyroxenite.

SiO_2	37.5
TiO_2	6.2
Al_2O_3	6.2
Fe_2O_3	5.9
FeO	12.0
MnO	0.2
MgO	13.1
CaO	7.2
Na_2O	0.2
K_2O	4.9
P_2O_5	1.0
CO_2	2.7
H_2O	1.6
BaO	0.6
SrO	0.2
ZrO_2	trace
Total	99.5

Locality: On shore, 5.2 km. from Narssarssuaq Harbou r on 350° bearing.

Analyst: B. I. Borgen.

proportion must be in the region of 20%. The grains are quite idiomorphic. Colour, pleochroism and alteration agree with the description of the mica in the normal rock.

R.I. is 1.630. Deer, Howie and Zussman (1962) Vol.3, p.48) quote authorities to illustrate that "no accurate correlation can be found between optical constants and composition of the phlogopite-biotite minerals". However, the refractive index, pale colour and weak pleochroism, taken together, do seem to indicate a phlogopitic variety.

While much of the groundmass corresponds to the description of the normal rock, relics of sizeable pyroxene grains are much more prominent here. Under crossed nicols considerable areas have a common extinction position; close investigation shows these areas to have the outlines of sections of euhedral pyroxene prisms several millimetres in length. In instances these prisms are seen closely packed together and it seems possible that at an early stage of its history the rock was essentially a thorough-going, coarse pyroxenite. Most of these large, primary pyroxene prisms are wholly broken down to a felt of undirected, tiny grains of secondary pyroxene. All the intermediate stages of this process are displayed.

Scattered prisms of slightly corroded apatite occur in the groundmass. Iron ore is a minor constituent and occurs as sporadic sprinklings of fine opaque dust in the groundmass. Parts of the rock appear to be quite free of ore.

Granules of sphene are scattered throughout the groundmass without any correlation to the distribution of ore.

The final stages of crystallisation of the rock are represented by small vugs and tiny interstital areas where carbonate and quartz have developed. The two minerals occur both independently and together; carbonate is slightly the more abundant. Grains of sphene occur within the quartz and carbonate in some quantity. The grains are up to 0.25 mm. long, subhedral, and have an unusually strong pleochroism, rose pink to colourless. Adjacent to these areas, the groundmass pyroxene adopts a greenish tinge and at the margin there is a bristling zone of slender, green, slightly pleochroic needles with the straight extinction and brilliant interference colours typical of aegirine. Both the carbonate and the quartz are pierced by the aegirine.

Ore grains are not found within the altered zones. Mica may persist almost to the centres of the zones, becoming progressively altered. In the final stages, all that remains is a few streaks of tiny ore grains, parallel to the original cleavage.

There is not the slightest indication in the rock of any structure which might be interpreted as a pseudomorph after any silicate mineral, other than mica.

It seems quite likely that the alteration zones are the result of a deuteric alteration or autometamorphism active at numerous centres within the rock.

A similar rock, emplaced nearby as a diatreme, (G.G.U. 61637) has a notably porous weathering pattern. This is produced by the differential weathering of an internal structure which appears to be spherulitic. The rock is too intensely altered to allow definite confirmation of this structure.

Dark, Basic Inclusions in Pl.

In thin section, this rock (61636) appears to be intensely metamorphosed and consists of a mass of very fine chlorite with moderate sprinkling of iron ore (magnetic) and some finely granular sphene.

The mica-pyroxenite has certainly escaped the wholesale carbonatisation to which the lamprophyres were subjected. The carbonate which does occur in the rock may be primary, a product of the residual magmatic fraction. The development of pegmatitoid is a strong indication of late, localised concentrations of volatile material. The late stage minerals identified are quartz, calcite, aegirine and sphene, indicating enrichment in SiO_2, CaO, FeO, TiO_2 and CO_2. The pyrite mineralisation of the granite inclusions may have been caused by the same residual fluid, in which case sulphur was another of its constituents.

2. Potash-Feldspathisation of the Country Granite.

Potash-feldspathisation, a metasomatic effect allied to fenitisation, affects the country rocks adjacent to several of the African carbonatite intrusions (cf. Bailey, 1960; Garson, 1962). In the Basement north of Qagssiarssuk, country granites adjacent to the carbonatised ultramafic intrusives have been subjected to a similar process.

Stages in the progressive transformation of the country rocks are illustrated by a small suite of specimens (see Appendix I) collected from within and adjacent to and within carbonatised pipes and sills in the Basement.

Completely unaltered country rock was not available for reference in this study; R. W. Nesbitt (1961) and W. S. Watt (1963), working in Basement country south-east of Tunugdliarfik and north-west of Sermilik respectively, have described basement rocks in ground beyond the influence of these younger intrusives. Their accounts, supplemented by unpublished internal reports of other members of the Survey, indicate that the country rock of the region is most generally of granitic to granodioritic composition. Microcline, albite or oligoclase and quartz are accompanied by muscovite, biotite and hornblende, singly, or in various combinations. Much of the material collected comes from the area designated "Gneiss" in Figure 5.7 and in most cases where alteration permits, the parent rock can be identified as a muscovite adamellite.

In its ultimate development, the metamorphism leads to the conversion of the parent adamellite to a near-mono-minerallic rock consisting principally of highly potassic, monoclinic feldspar. While the transformation is essentially a gradational process, it is convenient to describe it in terms of stages.

<u>Stage 1</u> is illustrated by 61870. Mechanical effects are very prominent at this stage. Mortar structure is developed (Fig. 5.44), with a notable size contrast between the remaining large grains and the fine granules of the comminuted groundmass. The groundmass material can often be correlated with the adjacent large grains; for example, if these are all of plagioclase, the groundmass will be of plagioclase granules, but if both plagioclase and microcline occur together as large grains, the groundmass will be a mechanical mixture of both minerals. Quartz is usually absent from the granulated groundmass. Mafic minerals, if present, may be dispersed as small shreds.

The large grains are of plagioclase, microcline and quartz. While the quartz and microcline are rather clear, the plagioclase is invariably turbid. Most of the large grains show signs of strain, expressed by uneven extinction and intense fracturing. All grain boundaries are very intricate with lobes of a size corresponding to that of the groundmass granules; otherwise, there is no sign of recrystallisation or quartz-feldspar intergrowth.

The plagioclase has at least a slight tendency toward idiomorphic habit and some grains are sub-rectangular. Many grains are intensely strained and show distortion of the twin lamellae; some have a mosaic structure where the grain consists of a number of subdivisions with lamellar twinning developed at a different orientation in each. The plagioclase is distinctly twinned on the albite law (occasionally in combination with the Carlsbad law). There is no evidence of zoning as a rule, although in some cases the distribution of the alteration products may show a slight suggestion of concentric zonal arrangement. All grains are sericitised to some extent, but the intensity of the sericitisation varies somewhat throughout the rock. In individual grains alteration is often less intense at the periphery. The sericite flakes are often quite large and prominent. The refractive indices of the plagioclase embrace that of canada balsam and the extinction angle of albite twins normal to (010) is not more than 15°. Composition thus lies in the range 5 - 10% An.

Relatively few of the microcline grains show the characteristic "tartan" twinning pattern. Very fine blebs of perthitic plagioclase may be present in some grains, but identification is uncertain. The obliquity (cf. Appendix I) is the highest found in this series, $\Delta^{x} = 1.07$

Although quartz is rare in the groundmass, it is abundant as large grains or strings of grains elongated parallel to the general direction of the fabric. These grains are strained and contain numerous lines of tiny inclusions.

Partial analysis of 61870 gave the following results:

	wt.%
Na_2O	5.00
K_2O	5.00

Stage 2 is represented by specimens 61608, 61631 and 61632, rocks of somewhat contrasting appearance. 61608 is an angular fragment of granite, less than half a centimetre in length, set in carbonatised uncompahgrite. Nearly half of the granitic rock has been replaced by carbonate; the carbonatisation has been general, rather than confined to a particular mineral species. Some white mica remains. 61631 is an angular fragment of comparatively melanocratic gneiss in the nodular lamprophyric breccia. Amphibole and dark mica are well preserved; between 10% and 20% of the rock is replaced by carbonate. 61632, a gneissose type representing country rock from close to the nodular intrusion, is very leucocratic, with tiny flakes of dark mica as an accessory. The rock contains no carbonate. Quartz is abundant in 61632 but appears to be absent from 61608 and 61631. In spite of the contrasting mafic-mineral assemblage and the differing degrees of carbonisation, the texture and the nature of the feldspars is similar in these specimens; the following observations are based on examination of all three rocks.

The strongly directed fabric found in stage 1 persists and the contrast between large grains and fine grained groundmass is still pronounced, but there may have been considerable recrystallisation in the groundmass, leading to a rather coarser, allotriomorphic granular mixture of microcline and albite.

The large plagioclase grains show many unusual features. Alteration products are restricted to irregular zones within the grains, and consist chiefly of a scattering of sericite flakes up to 0.05 mm. long. Outside these zones, the

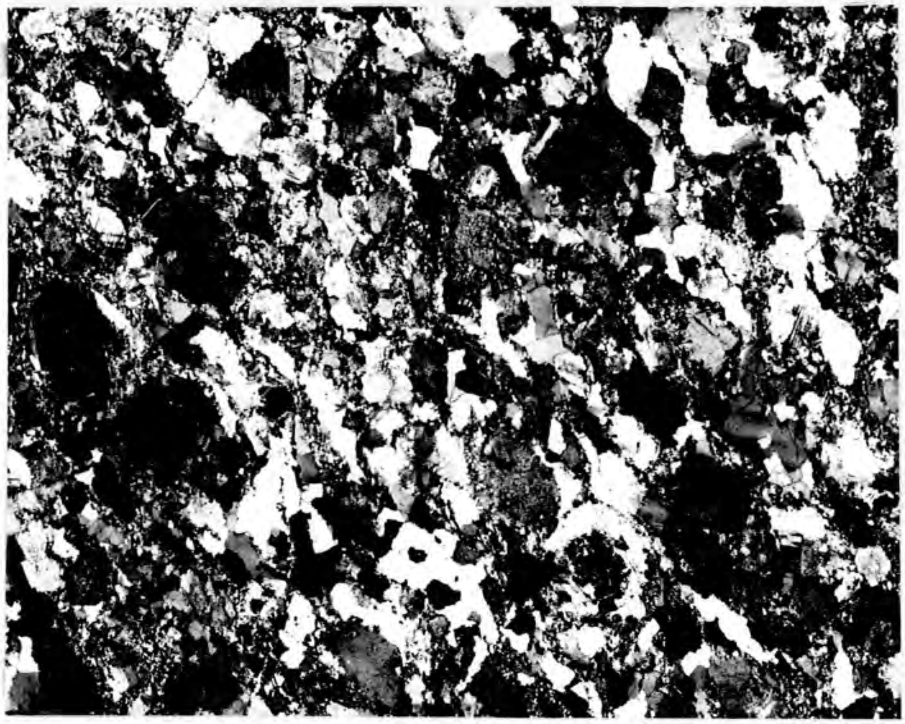


Fig.5.44. Photomicrograph of 61870, basement granite, x ca. 10, crossed polars, to show mortar structure.

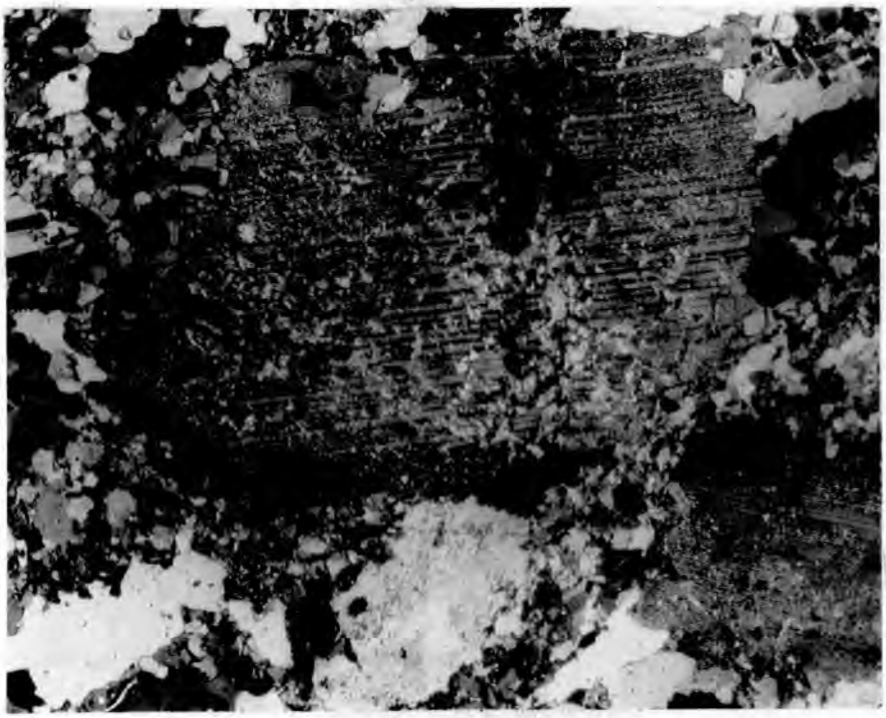


Fig. 5.45. Photomicrograph of 61632, altered granite, x 40, crossed polars, to show altered plagioclase grain. Note large sericite grains and fading out of lamellar twinning toward grain margin.

feldspar is clear. Refractive index is lower than that of canada balsam and hence composition is close to the sodic end member of the plagioclase series. Many of the grains have a peculiar uneven extinction suggestive of gradational zoning; sometimes this is developed about several centres within a single grain. Albite twinning is preserved to a varying degree and is often very faint or entirely absent. The extent to which the twinning is preserved in a particular grain seems to bear some relationship to the degree of cloudiness or amount of alteration products remaining; the most distinct twinning often seems to occur in association with sericite (cf. Fig. 5.45.). In some grains, alteration products and distinct albite twinning occur in the centre while the marginal zone is free of alteration products. The albite twinning, on entering the marginal zone, rapidly becomes very faint and disappears. A number of the sodic feldspar grains contain small replacement patches of microcline. These patches are of sporadic occurrence; their shape and orientation is likewise unsystematic. They occur marginally, along internal fractures, or isolated in the interior of the host grain. Where the albite twinning of the host grain is still distinguishable, one of the sets of twins (probably those on the albite law) of the microcline is orientated parallel to these. Under crossed polarisers at intermediate magnifications the twin lamellae of the two phases may appear to be in continuity and in the absence of a second set of twins in the microcline, the occurrence of the microcline patches may actually be overlooked. Under plain light the strong refractive index contrast between the two alkali feldspars is at once apparent and at higher magnification it can be seen that the microcline twin lamelli do not have parallel sides.

The obliquity of the microcline is substantially lower than in stage 1; Δ^x has values of from 1.00 - 1.02. Small blebs of myrmekite occasionally occur where grains of microcline and plagioclase are in juxtaposition.

The X-ray diffraction traces of 61608 and 61631 (Fig. 5.46) indicate the presence of monoclinic potash feldspar in significant amount. The location of this material is unknown.

Stage 3 is represented by specimens 61614, 61615 and 61616. All these rocks contain in the region of 10% of carbonate as scattered, anhedral, turbid interstitial grains. Foliation is still prominent on a macroscopic scale and appears as thin, parallel streaks of colourless feldspar in the red rock. In thin section the structure can also be seen at low magnification, descernible as alternating, elongated areas of clear and cloudy feldspar. Although clear or cloudy material may be locally dominant, on an average they must be present in roughly equal amounts. The clear grains are probably all of microcline; characteristic twinning is but poorly developed and some grains are devoid of visible twinning. The turbid grains contain no internal structure other than occasional small patches of microcline which show no refractive index contrast against the host grain. The turbidity is caused by fine haematite and some sericite. Investigation by X-ray diffraction shows microcline and monoclinic potash feldspar present in substantial quantity, but there are no reflections from an albite phase. It is assumed that the turbid grains are of the monoclinic phase. Their refractive index is similar to that of the microcline. Quartz is thought to be typically absent from representatives of this stage. Strong silica reflections in 61614 are caused by chalcedony, believed to be a product of secondary silicification. The same specimen contains a considerable quantity of apatite.

Chemical analysis of 61615 for alkalies gave the following results:

	wt.%
Na_2O	0.50
K_2O	11.57

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Specimen 61617 represents another feldspathic rock type derived from country granite. Its position relative to the threeestages described above is uncertain; possibly it occupies a position intermediate between stage 2 and stage 3.

In thin section, the directed nature of the fabric is maintained by strings of grains of turbid carbonate but is not otherwise apparent. The feldspar grains are anhedral, and interlock with one another; grain size is quite even. Under the microscope the whole rock appears turbid. Some larger grains show fairly distinct albite twinning; sometimes the orientation of the twinning changes from one part of the crystal to another, producing a mosaic effect. The majority of the grains in the rock appear to be of a perthite with very fine, parallel exsolution lamelli, however, the altered nature of the rock precludes a definite determination by optical means. The X-ray diffractomer trace of the rock (Fig. 5.46) indicates that while monoclinic alkali feldspar and albite are both abundant, microcline, if present at all, is in very small quantity. Quartz appears to be absent. There is some apatite.

Partial chemical analysis of the rock yielded these results:

	wt.%
Na_2O	6.40
K_2O	7.60

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Summing up, the process of potash feldspathisation, when fully developed to stage 3, converts a granitic rock composed of microcline, plagioclase, quartz and mafic minerals to a syenite consisting of monoclinic potash feldspar and very little else. The intermediate stages in the process are not well documented; a much larger quantity of material would be desirable and optical and chemical data about stage 2 are required. In outline, it is suggested that the transformation process takes place as

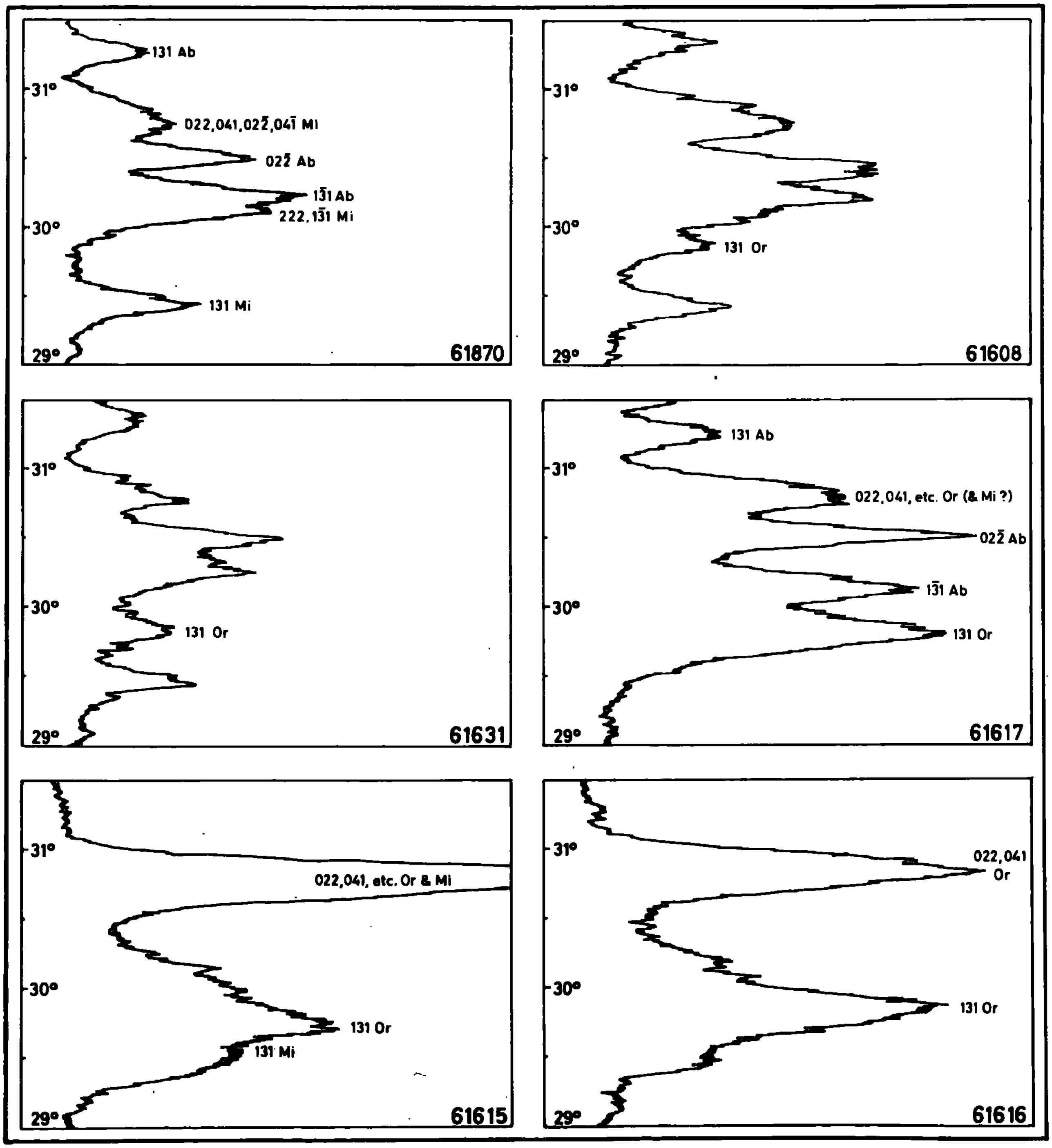

131 Ab
31°
022,041,022̄,041̄ Mi
022̄ Ab
13̄1 Ab
222,13̄1 Mi
30°
131 Mi
29°
61870
31°
30°
131 Or
29°
61608
31°
30°
131 Or
29°
61631
131 Ab
31°
022,041, etc. Or (& Mi ?)
022̄ Ab
13̄1 Ab
30°
131 Or
29°
61617
31°
022,041, etc. Or & Mi
30°
131 Or
131 Mi
29°
61615
31°
022,041
Or
30°
131 Or
29°
61616

Fig. 5.46.

follows:

First, the country rock is crushed and mylonitised. Next, the plagioclase becomes cloudy and sericite develops; lime is expelled and the plagioclase becomes albitic. Small patches of replacement microcline appear in the albite, and cryptic orthoclase develops in the rock. The mafic minerals and quartz are eliminated soon after. (If the rock were heated above the alkali feldspar solvus at this stage and then cooled, with exsolution of perthite, the resulting rock might resemble 61617).

The principal constituents are now presumably albite, monoclinic potash feldspar and microcline. Introduction of potash on a large scale, with loss of most of the soda, is accompanied by recrystallisation. Potash is now the dominant alkali and monoclinic symmetry becomes universal.

In these rocks the stage of the feldspathisation and the degree of carbonatisation are not necessarily related.

3. IGNEOUS ROCKS OF THE QAGSSIARSSUK TRIANGLE.

THE BASALT LAYER.

The basalt consists of an aphyric, undirected mesh of plagioclase laths with interstitial to sub-ophitic pyroxene. Plagioclase is considerably more abundant than pyroxene. The laths range in length from ca. 2 mm. to ca. 0.2 mm. without any particular size fraction predominating. Twinning on the albite law is usual and there is strong, gradational zoning. Pyroxene, which is rarely preserved, is pale pink. Primary iron ore cannot readily be distinguished from ore of secondary origin; there must have been about 5% in the original rock, prior to alteration.

Pyroxene is the first mineral to alter and it is replaced by chlorite with a sprinkling of small jagged grains of ore. Presently flakes of sericite form in the plagioclase. These flakes may be up to 0.3 mm. across, with optical properties characteristic of muscovite. The sericitisation is not an even process - large flakes may be developed at one end of a lath while the other end is quite clear and apparently fresh.

With increasing alteration the pseudomorphed pyroxene breaks down and the rock's original texture is maintained only by the feldspar. Carbonate and chalcedony make their appearance and the amount of chlorite increases. In the most heavily altered basalt, chlorite makes up about half of the rock and replaces much of the feldspar. Discordant areas are completely filled with chlorite, mostly as a very fine grained aggregate with occasional feathery, spherulitic structures. Most of the carbonate is in irregular patches, turbid and amorphous, but there are also some discrete grains, anhedral, clear, with lamellar twinning.

THE BASALT OF QAGSSIARSSUK SHORE.

In mineralogy, texture and alteration pattern this rock is quite distinct from the type described above. Despite heavy alteration the texture is well preserved and the nature and approximate proportions of the original minerals are quite obvious. The feldspar phenocrysts are broad laths about 2 mm. long. The remainder of the feldspar is in the form of slender laths, ranging in length from 1 mm. to 0.2 mm.. Sericitisation is intense and evenly developed throughout the plagioclase as tiny flakes so closely packed that they partly obscure the twinning. The refractive index of the plagioclase is higher than that of canada balsam. The pyroxene has been roughly equal in amount to the feldspar and has been sub-ophitic. It is now completely replaced by chlorite and iron ore, the latter in the form of slender rods and parallel trails of tiny grains. Olivine has also been replaced by chlorite and ore; in this case the ore is disposed around the periphery of the grain and occupies the site of cracks in the original mineral. There is about 10% of these pseudomorphs modally, evenly distributed throughout the rock. The largest are about 0.5 mm. in diameter. All have a well-rounded shape. Carbonate and primary ore appear to be absent. The vesicles are filled with the same aggregated fine chlorite which is found in the pseudomorphs after pyroxene and olivine.

CARBONATISED LAVAS.

(1) Extrusive. The colour of these rocks ranges from pink to purple. The rock is fine grained, but with a hand lens small laths of carbonate can be distinguished. Vesicles are usually abundant; they are a centimetre or two in length, elongate, sometimes dumbell-shaped and filled with rather coarse, white, crystalline material.

In thin section (e.g. specimens 61686, 61740, 61708 and 61724), the main body of the rock is seen to consist almost entirely of carbonate, most of it in the form of closely packed rectangular laths. These laths show considerable evidence of flow alignment, as a rule, and are arranged tangentially around vesicles and inclusions. In some specimens, the laths appear to fall into two principal size groups, one with an average length of ca. 0.3 mm., the other about 1.0 mm.. The length:breadth ratio in both cases is approximately 6:1. Intermediate sizes are also developed (cf. Fig. 5.47).

Recrystallisation has obscured the texture of the rock to a verying degree. Grain boundaries are mostly somewhat irregular in detail. The outlines of the laths have been preserved and emphasised by finely divided haematite which, together with fine carbonate, forms most of the rather

Fig. 5.47. Photomicrograph of 61686, carbonatised uncompahgrite lava, x 8, ordinary light.

Fig. 5.48. Photomicrographs of 61720, martite tuff. Left: x 40, note apatite. Above: skeletal martite grain x 10.

restricted area between the laths. The haematite is responsible for the colour of the rock. The smaller laths are made up of a mosaic of tiny, anhedral granules of carbonate with a diameter of ca. 0.01 - 0.02 mm.. The large laths usually consist of a single crystal of carbonate with its c - axis parallel to the direction of elongation (this is shown by invariably straight extinction). In specimens from the northern edge of the outcrop of the Calcareous Volcanic Unit 61740 and 61708, calcite is the principal carbonate present; dolomite is present in decidedly subsidiary quantity. In the other specimens, taken along the shore to the south and east, the calcite:dolomite ratio is about 2:1.

The remaining primary minerals, viz. apatite, iron ore, mica and possibly perovskite can hardly have occupied other than accessory status, as regards quantity. A number of sections of haematite, ca. 0.2 mm. across replace a mineral or minerals of octahedral habit, presumably magnetite and/or perovskite. Apatite occurs as sparsely scattered small prisms up to 0.5 mm. long. Some show minor signs of corrosion and a few are partially replaced by carbonate. In 61718 a large carbonate lath is pierced by a number of apatite prisms and in the same rock apatite has developed in an altered feldspathic inclusion. Rare, pseudomorphed, narrow flakes of mica occur in some specimens. The replacing minerals are carbonate and haematite.

Table 5.8

Chemical Analysis of Carbonatised Lava 61740

SiO_2	4.4
TiO_2	2.4
Al_2O_3	0.7
Fe_2O_3	4.1
FeO	0.5
MnO	0.5
MgO	7.2
CaO	40.1
Na_2O	0.2
K_2O	0.1
P_2O_5	2.7
CO_2	36.4
H_2O	0.1
BaO	0.1
SrO	0.4
TOTAL	99.9

Locality: 80 m. altitude, 500 m. from K. G. H. stone on 180° bearing, Qagssiarssuk, South Greenland.

Analyst: B. I. Borgen.

The alkalies are probably present in fine, xenocrystalline alkali feldspar. There is sufficient alumina and silica to combine with the alkalies to form normative alkali feldspar (Or 0.44%, Ab 1.26%); the small surplus of alumina can be calculated as anorthite . The small amount of normative silica then remaining (0.16%) is certainly present in the rock as interstitial secondary quartz. The high titania of the analysis would be accommodated in ilmenite and sphene (0.43% and 0.94% respectively) in the norm. It is very probable that these minerals are actually present in the rock in a very finely divided form. Their low concentration has precluded their identification by X-ray methods. Sphene is tentatively identified in 61739 (below) and has been recognised in many of the carbonatised minor intrusives north of Qagssiarssuk.

Barytes is usually quite abundant, occupying interstices between the carbonate grains. A little quartz may also occur in similar locations. Both minerals are thought to be secondary. Carbonate occurs in all the vesicles and in many cases it is accompanied by barytes which tends to occupy the centre. Usually a few large crystals of the minerals occupy the greater part of the cavity and these are surrounded by a single row of smaller carbonate grains. The amygdular minerals are allotriomorphic.

<u>Non-vesicular variety.</u> Specimen 61708 was taken from a massive, homogeneous red limestone which in its field occurrence was judged to be a carbonatised lava flow; the

lack of vesicles was sufficiently unusual to cause a sample to be taken. The rock is composed almost entirely of calcite, and dolomite is not present in significant amount. In thin section it is immediately apparent that the rock differs considerably from the other lavas, for there is no sign of the lath-shaped grains. Instead, there is a hypidiomorphic granular fabric of rather clear calcite crystals. The crystal boundaries, which are often straight, are emphasised by an intergranular film of opaque material. Apart from some interstitial barytes and quartz, the only other minerals are iron ore and apatite. The small sections of the ore are indicative of octahedral habit modified by corrosion. Apatite, which is abundant, occurs as euhedra of varying size. The largest grain seen presents a hexagonal cross section 0.5 mm. across. A corroded ore grain 0.4 mm. long is penetrated by five small prisms of apatite. The texture of this rock is almost certainly a result of recrystallisation. This could have related to one of the younger 60° dikes.

Conglomerate pebble. A pebble of carbonatised lava, specimen 61732 was found in a conglomerate (or agglomerate) near the top of the Calcareous Volcanic Unit, at the shore. Macroscopically the rock appears to be made up of well laminated elongate tablets, 2 - 3 mm. long. In thin section it is seen that the outlines of the tablets are maintained by fine granules of haematite and that the rock is otherwise a structureless mosaic of tiny grains of carbonate. The carbonate proves to be dolomite; calcite is absent. Some dislocation has caused a narrow zone of recrystallisation which runs across the specimen. Apatite is present, the size and quantity of the grains recalling the more typical lavas described above. Ore is present in very small quantity and seems to have suffered heavy alteration. There is a fair amount of secondary quartz and barytes.

(2) Intrusive Carbonatised lava similar to the normal carbonatised extrusive type is found in a neck, a dike and a sill (represented by specimens 61739, 61744 and 61747, respectively). Texture is best preserved in the neck; the outlines of the lath-shaped grains are distinct and there is strong flow direction. In the other two minor intrusions the original texture has been largely obliterated and the outlines of the laths stretched and streaked out. The apatite grains in these rocks are fractured and dislocated (cf. Fig. 5.41). It is evident that these highly calcareous rocks have yielded to slight plastic deformation, not sufficiently strong to wholly obliterate the lath texture or cause recrsytallisation of the carbonate.

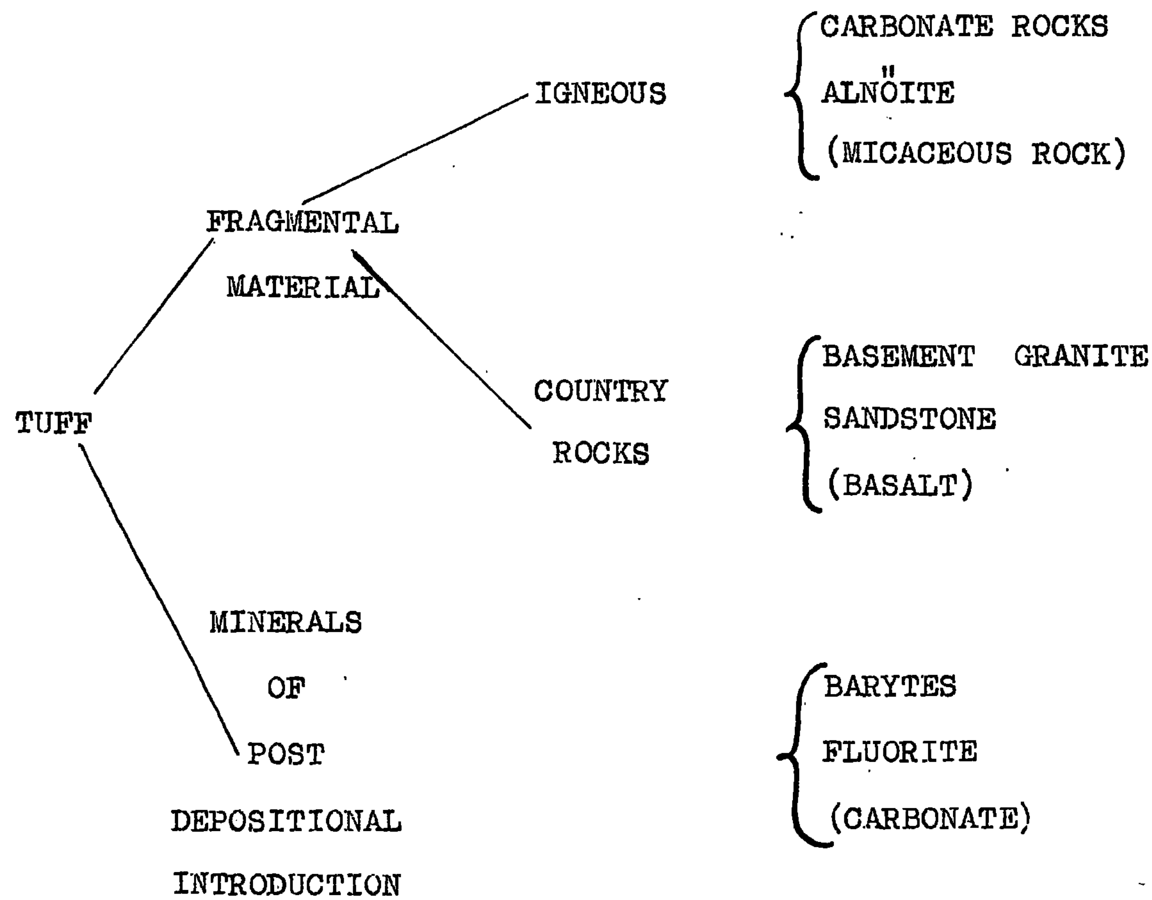
The carbonate of these rocks is dolomite; the sill rock also contains a subsidiary amount of calcite. Specimen 61739 from the neck contains some fine grained interstitial chlorite; this is the only recorded instance where one of these carbonated lavas contains a mineral other than carbonate or ore which might represent the alteration products of original groundmass material developed between the laths. The same rock contains heavily altered inclusions whose original nature is no longer certain. The replacing minerals are carbonate, barytes, chalcedony, chlorite and opaque material. An aggregate of strongly altered dark mica about 5 mm. across is possibly a relic of the material of which the inclusion was originally or wholly or partially composed. Specimen 61739 is further exceptional in containing sparsely distributed structures of ore and carbonate which are believed to be pseudomorphs after euhedral olivine pseudomorphs.

THE TUFFS

The following varieties of tuff are distinguished:

1. Fine Calcareous Tuff
2. Coarse Calcareous Tuff
3. Martite Tuff
4. "Tilestone"
5. Lapilli Tuff
6. Alnöitic Tuff

Constituents of the tuffs



The above diagram summarises the rock types and minerals of which the tuffs are formed and outlines their sources.

Of the igneous rocks which contribute to the tuff fragments, carbonate types are dominant and alnöite considerably less important. "Micaceous rock", shown in parentheses in the diagram, is hardly more than suggested by petrographic examination; there is a considerable development of dark mica in occasional lapilli of the lapilli tuff, suggesting a genetic identity with the nodular inclusions of the minor intrusives north of Qagssiarssuk in which mica is sometimes extensively developed at the expense of alnöite.

The indefinite term "carbonate rocks" covers carbonatised silicate types (such as the carbonatised lavas) and makes provision for the inclusion of hypothetical primary carbonate material derived from carbonatite magma.

(1) Fine Calcareous Tuff

The very small grain size and general lack of any but the tiniest fragments of cognate or accidental material suggests that this variety of tuff formed from the finest carbonate ash fraction which was dispersed into the atmosphere by explosion and accumulated for some distance from the vent. The individual carbonate grains which make up the bulk of the rock are clear, anhedral and less than 0.02 mm. in diameter. Minute, angular grains of quartz and feldspar are sometimes present to a very limited extent. Representative specimens are 61719, 61727, 61731 and 61734.

(2) Coarse Calcareous Tuff

The constituents of this rock, as a rule, resemble those of the carbonatised lavas. The bulk of the groundmass consists of anhedral carbonate grains of various sizes among which entire or fragmentary lath shaped carbonate pseudomorphs are occasionally seen. There is no means of telling whether the original silicate mineral was replaced by carbonate before or after the deposition of the ash. As in the lavas, both calcite and members of the dolomite-ankerite series occur; (the present distribution of the two carbonate varieties probably developed after deposition). Grains of magnetite and apatite similar to those of the lavas are quite common. They do not, in general, appear to have been corroded or fragmented to a greater degree than grains in the lavas.

It is possible that calcareous ash of primary origin (i.e. derived from a carbonatite magma) is a constituent of these tuffs, indistinguishable from carbonatised silicate-lava ash.

Grains of quartz and alkali feldspar, principally derived from the country sandstone and granite respectively, occur in varying quantity. There are also grains and small, angular fragments of a syenitic rock similar to the feldspathised basement granite described below. The most abundant fragmental material in all size fractions is carbonate rock. Often the fragments are vesicular and texturally identical with the lava; other allotriomorphic granular carbonate inclusions may be carbonatised lava or tuff which has been recrystallised, or may represent primary carbonatite material. Representative specimens are 61687, 61688, 61712 and 61734.

(3) Martite Tuff

A sub-variety of the Coarse, Calcareous Tuff, the Martite Tuff is a rock of rather spectacular appearance, characterised by numerous large octahedra of martite with stepped or striated crystal faces, set in a fine grained, deep crimson matrix. These octahedra, which are up to 1 cm. in length, locally make up more than 15% of the rock by volume. Such concentrations are rare, however, and are impersistant vertically and horizontally. There is a considerable amount of haematite present as tiny scales in the matrix of the rock and this mineral, together with the fluorite, is responsible for the striking colour which persists in both weathered and fresh specimens. Barytes is abundant as irregular pods and veinlets of coarse crystals. Fluorite is sometimes visible in the hand specimen; under the microscope it proves to be unexpectedly abundant, constituting a large proportion of the groundmass (the fluorite lines are the most prominent in the X-ray diffraction pattern of the rock powder). Only one carbonate mineral is present in this tuff, a dolomite low in iron. Carbonate is developed in two distinct crystalline forms:

(i) As euhedral rhombs, often very tiny, with a rusty appearance due to fine, goethite-like material arranged in concentric rhombohedral zones. These grains occur singly or in groups and are enclosed in fluorite.

(ii) as groups of allotriomorphic grains of which the individuals are up to 0.5 mm. across. This type of carbonate is usually quite clear.

The martite grains are much more corroded than would be anticipated from macroscopic examination and many are dendritic skeletons due to deep cavernous erosion (Fig. 5.48). No narrow solution channels comparable with those of the magnetite phenocrysts of the minor intrusions (see Fig. 5.38) are evident; this may merely be because all such incipient lines of weakness have been fully exploited by the corrosive medium and are now eroded beyond recognition. Some of the grains are traversed by sharp sided fractures, unmodified by solution. These must have developed during effusion or after deposition. Many of these fractures are filled with barytes.

Apatite is rather common in this variety of tuff in grains of all sizes up to 1 mm. across. Some grains are broken and some show rounding, but the majority are sharply euhedral. In a number of cases apatite is contiguous to or penetrates martite.

The rock is particularly rich in barytes, most of which like the fluorite, is evidently of secondary introduction. Euhedral crystals occur within fluorite, and form small pods and veins. The mineral appears to show a certain preferential development near martite. Specimen 61720 is typical of the rock type (cf. Fig. 5.48).

(4) Tilestone

Essentially, this rock is a haematite stained, fine, calcareous tuff with a varying admixture of accidental material derived from the country rocks. The carbonate groundmass consists of anhedral granules of dolomite, less than 0.1 mm. in diameter. The non-carbonate grains are predominantly of quartz, but there are also some grains of microcline, a few of albite and a few of what is thought to be orthoclase. These accidental grains occur in two rather distinctive size fractions, the larger ca. 0.4 mm. in diameter, well rounded, and the smaller 0.1 mm. in diameter and very angular. Many of the large quartz grains are believed to be sand grains derived from the country sandstone; this is borne out by the occasional development of a curved, dusty surface within the quartz, marking the limits of the original rounded sand grain against the contiguous siliceous cement with which it is now in optical continuity. 61697 is a typical example of this rock.

(5) Lapilli Tuff

These tuffs consist of lapilli of altered alnöite in an abundant matrix of clear, anhedral carbonate (Fig. 5.49). While the lapilli range up to ca. 5 mm. in diameter, most of the lapilli in a particular layer are of a similar size; size sorting, in fact, is often excellent, and some splendid examples of graded bedding can be observed.

The alnöite has been extensively replaced by haematite, accompanied in most cases by abundant sphene, totally obliterating any original texture.

In some examples, by contrast, the alnöite has been strongly carbonatised; here, however, the original texture may be quite well preserved. Lapilli showing each type of replacement often occur side by side. Regardless of the nature of the replacement, the lapilli are typically highly vesicular and porphyritic. The vesicles are often perfectly spherical; most are filled with carbonate.

Two kinds of phenocrysts are represented by pseudomorphs, (i) olivine, easily recognised by its orthorhombic habit with pointedd terminations and traces of irregular alteration cracks, (ii) melilite, characterised by sharp, rectangular elongate sections and squarish cross sections. As a rule, only one or two olivine phenocrysts occur in a lapillus, while melilite phenocrysts are comparatively abundant. These latter tend to be arranged tangentially around the olivine grains, but usually bear no such relationship to the periphery of the fragment. This is clear evidence that the present spherical shape of the lapilli

Fig. 5.49. Photomicrograph of 61710, lapilli tuff, x 40, ordinary light. Note pseudomorphs after euhedral olivine phenocrysts with pointed terminations.

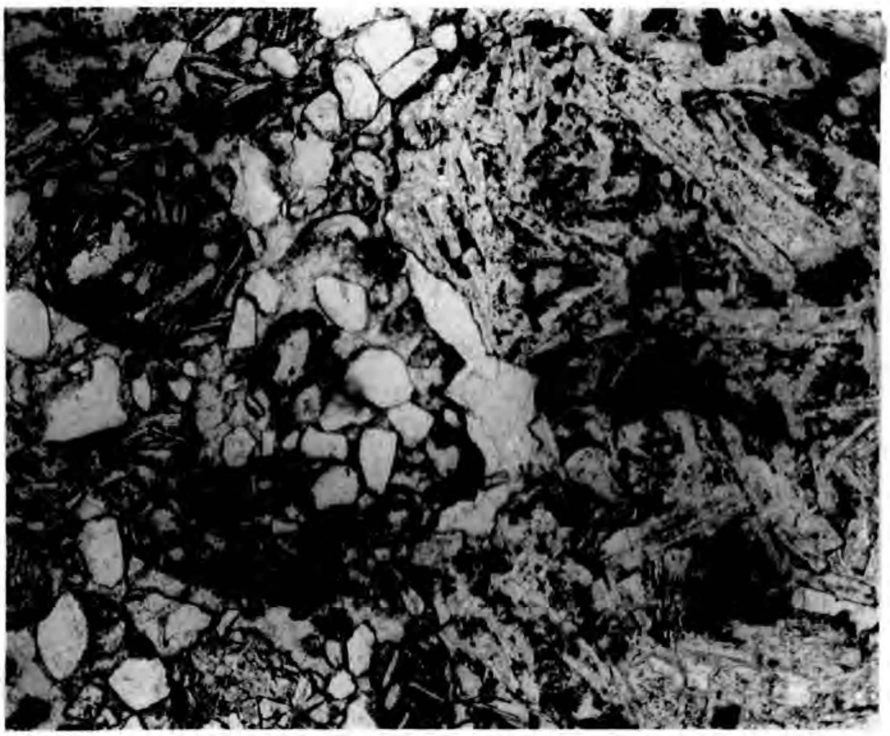


Fig. 5.50. Photomicrograph of 61702, x 40, ordinary light, showing alnöite lapilli (left), sand grains and fragments of olivine basalt in basaltic tuffisite.

has resulted from the attrition of solid fragments rather than surface tension acting on liquid droplets. The majority of the melilite phenocrysts have been replaced by a single crystal of carbonate, but a few contain a chlorite-like mineral of low relief and birefringence with a suggestion of a fibrous structure arranged normal to the elongation. Such grains may also show a trace of a median parting.

Original minerals or their pseudomorphs which can be recognised in the groundmass of the alnöite are melilite, magnetite, perovskite and biotite. Of these minerals, biotite is the most variable in quantity, being entirely absent in most lapilli, a minor constituent of some and in several cases being the dominant mineral. Fine chlorite and sphene are plentiful; the sphene is present both as euhedra and as aggregates of tiny granules outlining pseudomorphs after perovskite (the interior of these pseudomorphs is carbonate). In many cases it is apparent that melilite has formed at least 50% of the groundmass.

The above description is based on examination of specimens 61694, 61710, 61711, 61722 and 61727.

Table 5.9

Analysis of 61710, carbonatised lapilli tuff.

SiO_2	25.5
TiO_2	3.5
Al_2O_3	3.2
Fe_2O_3	12.7
FeO	0.4
MnO	0.3
MgO	12.3
CaO	14.7
Na_2O	trace
K_2O	1.8
P_2O_5	2.0
CO_2	21.6
H_2O	0.9
BaO	0.1
SrO	0.3
ZrO	trace
Total	99.3

Locality: 1 km. from K. G. H. stone on 170° bearing, 100 m. from shore, Qagssiarssuk, South Greenland.

Analyst: B. I. Borgen.

(6) Alnoite Tuff (Specimen 61730)

This rock might with some justification be called a crystal tuff. It is similar in many respects to the more homogeneous parts of the Coarse Calcareous Tuff, with the important addition of some 10% of pseudomorphed, euhedral olivine grains 1 mm. or so in length, which correspond to the phenocrysts of the intrusive alnöites. The margins and cracks of these pseudomorphs are outlined in haematite and contain, variously, carbonate, chlorite and silica. In the rather obscure, haematite stained groundmass, carbonatised melilite laths up to ca. 0.2 mm. in length can be distinguished, together with oxidised magnetite, pseudomorphed perovskite and the abundant sphene which invariably accompanies these. A few grains of apatite occur. The long axes of the elongated grains tend to be orientated parallel to the bedding. The mineral components of this tuff agree closely with those of the associated alnöite bombs and witht the lapilli described above.

TUFFISITE OF THE IRREGULAR INTRUSIONS.

The most common kind of microbreccia in these intrusions is the variety known in the field as "sandy tuffisite". This rock consists essentially of grains of quartz with moderate sphericity, rounding and size-sorting, mostly less than 0.5 mm. in diameter, in a calcareous matrix.

There is no doubt that the quartz grains represent the disintegration product of the country sandstone; the absence of silica overgrowth (usually indicated by "growth" lines) may be indicative of moderate abrasion (which would be anticipated in a fluidized system - cf. Reynolds, 1954) and/or corrosion. The groundmass is of fine grained, turbid carbonate and finely divided opaque material (probably haematite) which gives the rock its characteristic brown or purplish colour. There is clear evidence of both partial and complete replacement of quartz grains by carbonate. Locally, groups of quartz grains are fully pseudomorphed by clear carbonate with polysynthetic twinning. Specimen 61699 is an example of a quartz-rich variety; the grains are quite closely packed and must make up at least 50% of the rock. Replacement of quartz grains by carbonate is particularly well displayed.

While quartz grains remain the most abundant fragmental constituent in these rocks, there is often a considerable admixture of material from other rock types in the area. Basement granite is represented by occasional grains of microcline. These are often well rounded, but internally the twinning testifies to considerable strain and shattering. Tiny fragments of basalt occur locally, some of these are angular, derived from fully crystallised olivine basalt with feldspar laths up to ca. 1 mm. long, while others are rounded, fine grained, lapilli-like and probably of alnöite. The feldspar of the basalt has been altered to albite and the pyroxene has been wholly destroyed. The rounded, anhedral olivine grains have been pseudo-morphed, principally by chlorite, and are most distinctive; they have even been recognised as isolated grains in tuffisite. Carbonatised micro-uncompahgrite occasionally occurs as a clastic constituent although it can only be recognised under favourable circumstances where the lath texture has been emphasised. Carbonatised alnöite is recognised by the pseudomorphs after euhedral olivine. Specimen 61736 is packed with small, angular fragments of a variety of rock types.

Specimen 61704 appears superficially to be a sandstone with moderately rounded quartz grains, a few small fragments of altered olivine basalt, a little epidote and a few zircons. These grains are rather loosely packed in matrix of fine grained alkali feldspar. In plain light the matrix has a very faint pink tinge, under crossed nicols it is an obscure, fine grained crystalline complex in which perthitic structures can occasionally be distinguished at high magnification. Investigation of the powdered rock by X-ray diffraction reveals the presence of a monoclinic potash feldspar phase and albite. The mineral is probably an orthoclase perthite.

The even-grained, rather fine, quartz-rich "sandy tuffisite" varieties pass gradationally into coarser, more calcareous, more heavily altered tuffisites similar to those encountered in the diatremes (described below).

TUFFISITE OF THE THREE DIATREMES SOUTH OF QAGSSIARSSUK.

Rocks from these intrusions are invariably in a highly altered state; moreover, they weather very readily to a coarse sand and fresh material is almost unobtainable. The original clastic constituents have been extensively carbonatised; subsequently, barytes and haematites have been deposited in the interstices. Irregular grains of carbonate 0.5 - 1 mm. in diameter are the most abundant constituents, as a rule. The carbonate is full of tiny red scales, probably haematite derived from the oxidation of ankerite. Obscure, fine grained alteration products occur sporadically, among which chlorite and sphene can be distinguished. It is probable that many of the carbonate grains are replacing lamprophyric material; the texture of the rock, typified by 61733, recalls that of 61616, the lamprophyric tuffisite, to some extent. On the other hand, some of the carbonate grains might represent primary calcareous (carbonatite) microbreccia. Grains of microcline, quartz and heavily altered olivine basalt are present in widely varying amounts. Specimen 61746 is predominantly made up of grains of these materials.

BASALTIC TUFFISITE.

This rock differs from the "sandy tuffisite" in having olivine basalt as an essential major constituent. The rock described is specimen 61702. The matrix is of fine grained, rather turbid carbonate and in it are set grains of quartz up to 0.5 mm. in diameter and rounded to angular fragments of basalt up to several millimetres across. The basalt, which is intensely chloritised, consists of a mesh of plagioclase laths up to 1 mm. in length, with poor size-sorting. Much of the plagioclase is replaced by fine chlorite. The remaining feldspar may be quite clear and fresh in appearance. It has not been albitised, for the refractive index is substantially higher than that of canada balsam and extinction angles indicate an intermediate composition in the plagioclase series. Olivine (now pseudomorphed by chlorite) has been abundant as groundmass granules and as anhedral, rounded phenocrysts. It must have constituted at least 10% of the rock modally. Pyroxene has been wholly obliterated.

In addition to irregularly shaped fragments of olivine basalt, there are numerous well rounded, lapilli-like bodies of altered alnöite, generally less than 1 mm. in diameter (Fig. 5.50). Chloritic pseudomorphs after lath-shaped grains of melilite and euhedral olivine phenocrysts are set in an opaque matrix -- the alteration is comparable with that recorded in the lapilli tuff. In a number of these small pellets, there appears to be a systematic arrangement of the elongated pseudomorphed grains tangential to the margin. A fragment of a carbonatised, highly vesicular rock ca. 2 mm. in diameter, tentatively identified as carbonatised micro-uncompahgrite, is enclosed in a thin envelope of altered alnöite (Fig. 5.51). The enclosing material is identical to that of the small pellets and the

Fig. 5.51. Photomicrograph of 61702, basaltic tuff-isite, x 40, ordinary light, showing fragment of carbonatised uncompahgrite enveloped in alnöite.

Fig. 5.52. Photomicrograph of 61713, red, potassic, leuco-syenite, x 10, crossed polars, to show euhedral form of the alkali feldspar tablets.

elongate grains are disposed tangentially about the core. There can be no doubt that the pellets were originally liquid droplets of alnöite magma.

BLOCK OF RED SYENITE FROM TUFF.

This rock (61713), believed to be derived from the basement granite, is now a highly potassic syenite, devoid of quartz. The principal mineral is alkali feldspar which occurs as rather cloudy rectangular grains up to ca. 4.0 mm. in length (Fig. 5.52) and as small, clear grains of equant shape, ca. 0.5 mm. long. The small grains are of microcline and the large grains are at least partly of microcline. Many of the large grains show a zoning effect -- the margin is of clear feldspar with well developed "tartan" microcline twinning, while the interior is turbid and shows rather faint, but none the less recognisable repetitive twinning, similar to albite twinning.

The interstices between the feldspar grains are occupied by ragged masses of opaque material (haematite) which is arranged with a linear effect reminiscent of the cleavage of mica. It is probable that these structures are pseudomorphic after mafic minerals. They are accompanied by numerous small, rather clear grains of carbonate.

Investigation of the powdered rock by X-ray diffraction revealed the presence of triclinic and monoclinic potash feldspar phases (viz. microcline and orthoclase), present in amounts of the same order. Very careful examination of the diffractometer trace over an extended

2θ range failed to produce any indication of peaks belonging to albite or the plagioclase series. Chemical analysis of the rock for alkalies gave the following result:

	wt.%
Na_2O	0.30
K_2O	11.08

Many of the larger grains consist of two components:

(i) clear microcline with distinct "tartan" twinning.

(ii) cloudy feldspar free from microcline twinning, occasionally showing a rather faint repetitive twinning cf. albite twinning in plagioclase.

The boundary between the two types of feldspar is often quite sharp, but there does not seem to be a refractive index contrast. The distribution of the microcline and the other feldspar in a single grain is sometimes quite irregular, but, as a rule, the microcline tends to occur marginally, often enclosing the cloudy zone. Frequently, the faint repetitive twinning is parallel or nearly parallel to the albite twins of the microcline.

2V was obtained from three of the cloudy grains. Values of $79\frac{1}{2}^{\circ}$ and 81° were found in a grain free from repetitive twinning; a grain with twinning yielded an average 2V of $62\frac{1}{2}^{\circ}$.

The feldspar of this rock presents some very unusual features. The absence of a sodic phase is supported by the low soda value of the analysis; such a small amount can easily be accommodated in any potash feldspar. The cloudy feldspar must be orthoclase; the repetitive twinning of some grains cannot readily be explained unless as polysynthetic carlsbad twinning, which is exceedingly rare and not well documented. The bulk of the soda is probably in the orthoclase, particularly that with the repetitive twinning, to judge by the low 2V.

The microcline appears to be younger than and replacive towards the orthoclase. Some of the orthoclase, in turn, may have replaced earlier plagioclase by expulsion of the lime, followed by most of the soda. The repetitive twinning of the orthoclase, whatever its nature, may be more or less conformable with polysynthetic twinning in a pre-existing plagioclase just as the one set of microcline twins is arranged parallel to the faint twinning in the orthoclase. A few grains of apatite occur within the interstitial opaque material and several euhedral zircons have been distinguished.

INTRUSIVE RED SYENITE (from edge of V1)

This rock, typified by specimen 61717, is closely similar in essentials to 61713 (above). The X-ray diffraction pattern is almost identical and partial chemical analysis similar i.e.

	wt.%
K_2O	13.50
Na_2O	0.50

The ratio $K_2O:Na_2O$ is even higher, however.

Texturally, the feldspar grains are less idiomorphic and grain boundaries are often rather intricate. The orthoclase is largely obscured by a heavy dusting of fine red inclusions, but faint repetitive twinning can be discerned in a few grains. Some of the microcline has a peculiar fine grained internal structure reminiscent of myrmekite. It does not show a refractive index contrast against the host mineral.

Interstitial masses of ragged, porous haematite may pseudomorph mafic minerals; in this instance there is little suggestion of cleavage or other structure which would facilitate identification of an earlier mineral. There is some interstitial carbonate and barytes, numerous small prisms of apatite pierce the feldspar and a single, slightly rounded, cored zircon has been observed.

APATITE SØVITE INCLUSION FROM DIATREME.

This rock type, represented by specimen 61696, is essentially a calcite marble in which apatite and ore occur as accessories (Fig. 5.53). The anhedral calcite grains have an average diameter of ca. 2.5 mm.. The calcite is very clear and shows unusually well developed polysynthetic twinning. The intergranular boundaries are intricate and the grains interlock. Small, rather rounded grains of apatite, many showing signs of moderate corrosion by the carbonate, occur as localised clusters; diameter does not

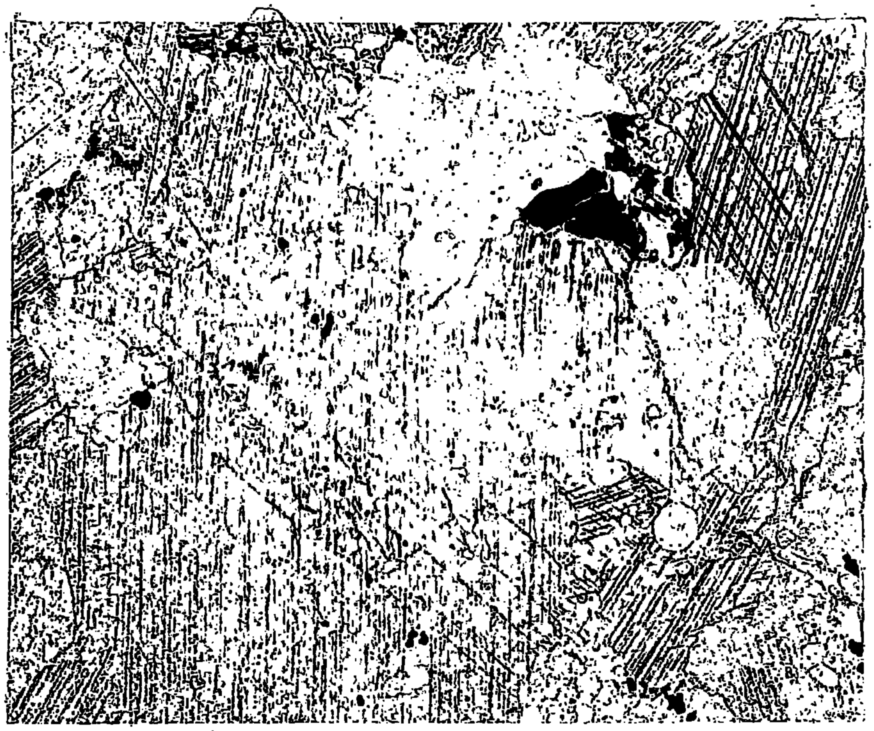


Fig. 5. 53. Photomicrograph of 61696, apatite søvite, x 40, ordinary light.

exceed ca. 0.2 mm. The irregular distribution of the grains precludes an accurate determination of their modal volume; it is unlikely that they constitute more than 1-2% of the rock by volume. An opaque ore, mainly haematite, occurs mainly as anhedral grains up to 1 mm. in diameter, sometimes pierced by apatite. It is thought probable that this mineral was originally magnetite and subsequently oxidised. A number of tiny, pale yellow granules of high relief and birefringence which present square and rhombic sections are probably sphene.

4. Investigation of the Carbonates of the Intrusive and Extrusive Rocks.

Consultation of the A. S. T. M. Index suggested that it should be possible to distinguish the principal carbonates by X-ray diffraction, using the strongest reflection (211).

Table 5.10

Location of the Strongest Reflection of the Principal Carbonates, (211). 2θ values.

Calcite	-	29.42°	Swanson & Fuyat, 1953.
Ankerite	-	30.80°	Broadhurst & Howie, 1958.
Dolomite	-	30.96°	Harker & Tuttle, 1955.
Siderite	-	32.08°	A. S. T. M. Index, Card 8-133.
Microcline (131)		29.44°-29.50°	Values obtained from country rocks and feldspathic inclusions.
Orthoclase (022 + 041, etc.)		30.80°-30.93°	

The 2θ range embraced by these reflections is sufficiently small to make routine examination for all four convenient. A selection of powdered samples was systematically scanned over this angular range.

The peaks are free from interference by reflections of other minerals occurring in the rocks, with the exception of (131) microcline and (022 + 041, etc.) orthoclase. As a general rule alkali feldspar is not present in quantities sufficient to cause significant displacement of the carbonate peaks.

Siderite was tentatively identified in two specimens only, viz. 61607 and 61608. The calcite (211) reflection was always readily identified, and it invariably occurred close to the expected value.

In the majority of the rocks, the most abundant or only carbonate present is a magnesian or ferro-magnesian variety. 2θ values corresponding quite closely to "dolomite" and "ankerite" of Table 5.11 were recorded and a whole range of intermediate positions was also represented (Table 5.11a).

Examination of Table 5.12 shows a strong concentration of occurrences at 30.86°, a moderate concentration towards the upper angular limit from 30.92°-30.96° and a scatter of single occurrences at intermediate positions. The isolated occurrence at 30.82° is within 0.02° 2θ of the value recorded in the ankerite from Oak Colliery, Oldham (see Table 5.11).

Dolomite, and ankerite with up to ca. 65 - 75% (Fe, Mn) $CO_3.CaCO_3$ are believed to form a continuous series (Smythe & Dunham, 1947). With increasing substitution of Fe^{++} for Mg^{++} the cell dimensions alter and (211) will change position.

Table 5.11.

Specimen number	Wt.% CO_2 (analysis)	Weight Percent (norm)			Mol. Percent of total normative carbonate			$\frac{FeO \times 100}{FeO + MgO}$	(211) deg. 2θ
		$CaCO_3$	$MgCO_3$	$FeCO_3$	$CaCO_3$	$MgCO_3$	$FeCO_3$		
A	47.2	55.8	44.4	0.3	51.2	48.5	0.3	0.6	30.96
61740	36.4	62.8	15.1	1.6	76.4	21.9	1.7	7.2	30.96
61710	21.6	17.6	25.9	0.8	35.8	62.7	1.4	2.2	30.92
61614	28.1	31.7	20.2	9.5	49.6	37.6	12.8	25.5	30.86
			(19.6)	(10.3)		(36.5)	(13.9)	(27.6)	
B	44.7	52.2	27.0	20.6	51.1	31.4	17.4	35.7	30.80
61606	24.5	14.2	25.0	13.6	25.5	53.5	21.0	28.2	30.82
61682	20.8	18.6	24.1	0.0	77.4	22.6	0.0	-	30.87
61685	13.8	11.6	15.0	2.3	36.9	56.7	6.4	10.1	30.78

A — Dolomite, Haley, Ontario (Harker & Tuttle, 1955).
* 61740 — Carbonatised uncompahgrite lava.
* 61710 — Lapilli Tuff.
* 61614 — Ankerite veins in breccia.
B — Ankerite, Oak Colliery, Oldham, Lancs. (Broadhurst & Howie, 1958)
* 61606 — Carbonatised nodular uncompahgrite.
* 61682 — Carbonatised alnöite with magnetite phenocrysts.
* 61685 — Carbonatised monchiquite.

* The complete analyses and localities of these specimens are given elsewhere in this chapter.

Table 5.11a

X-ray Data from Carbonates in Carbonatised Rocks.

Specimen No.	Mode of occurrence	2θ D-A	C D-A
61606	Sheet of nodular uncompahgrite	30.82	0:1
61607	" " " " (fig. 5.2)	30.86	1:5
*61614	Ankerite veins in feldspathised granite breccia (fig. 5.12)	30.86	1:5
61624	Uncompahgrite sheet cutting lamprophyric neck.	30.86	0:1
* 61682	Sheet of mica monchiquite	30.87	0:1
*61685	" " mönchiquite	30.84	0:1
61686	Carbonatised uncompahgrite lava	30.93	2:1
61691	" " "	30.89	1:1
61708	" " "	30.95	1:5
61718	" " "	30.92	3:2
61732	" " "	30.95	0:1
*61740	" " "	30.96	9:1
61697	"Tilestone"	30.94	1:10
61698	Calcareous tuff	30.86	1:6
61712	" "	30.86	9:1
61719	" "	30.86	2:1
61731	" "	30.86	1:10
61735	Folded, banded carbonate-quartz rock (fig. 5.22)	30.88	1:4
*61710	Lapilli tuff	30.92	1:5
61720	Martite tuff	30.95	1:10
61739	Neck of uncompahgrite	30.93	0:1
61744	Dike " "	30.89	0:1
61747	Sill " "	30.92	1:10
61696A	Vent tuffisite	30.90	2:3
61696B	Søvite inclusion in vent tuffisite.	30.90	9:1
61700	Carbonatised alnöite in irregular tuffisite intrusion.	-	1:0

Table 5.12

Position of (211) in Fe - Mg Carbonates, in 22 specimens showing Incidence of Occurrences at 2θ values 30.78° to 30.96.

30.80	- - - - - - - ANKERITE $\frac{FeO \times 100}{FeO + MgO} = 35.7$ ("B", Table 5.11)
30.81	-
30.82	X
30.83	-
30.84	X
30.85	-
30.86	X X X X X X X ANKERITE $\frac{FeO \times 100}{FeO + MgO} = 25.5$ (27.6) (Specimen 61614)
30.87	X
30.88	X
30.89	X X
30.90	X X
30.91	-
30.92	X X X
30.93	X X
30.94	X
30.95	X X X
30.96	X - - - - - - DOLOMITE ("A", Table 5.11)

An attempt was made to estimate the Fe^{++}:Mg^{++} ratio of the Fe - Mg carbonate of the analysed rocks and to correlate this with the position of (211). A partial norm was calculated for each rock; the following steps are relevant:

(i) Unite MnO with FeO and SrO and BaO with CaO.

(ii) Allocate CaO (and SiO_2) to TiO_2 to form sphene; petrographic examination of the rocks indicates that most of the titania is contained in this mineral rather than in ilmenite or perovskite.

(iii) Allocate CaO to P_2O_5 to form apatite.

(iv) Remaining CaO is combined with CO_2 to form $CaCO_3$.

(v) MgO is combined with CO_2 to form $MgCO_3$.

(vi) Remaining CO_2 is combined with FeO to form $FeCO_3$.

In analyses of pure members of the ankerite-dolomite series (e.g., A and B in Table 5.11), the molecular proportions of $CaCO_3$ and (Mg, Fe) CO_3 are constant within limits of a few percent, with $CaCO_3$ usually present in slight excess of the requirement of the formula Ca (Mg, Fe) $(CO_3)_2$, (Smythe and Dunham, 1947).

In the analysed rocks under consideration, the only non-carbonate minerals in which Ca^{++} can occur in significant quantity are apatite and sphene, and optical examination confirms the presence of these minerals in nearly every case. Neither chlorite nor mica can accommodate Ca^{++} in any significant quantity - - 1% by weight is the usual limit. Accordingly, once CaO for the formation of sphene and apatite has been allocated in the norm, the molecular quantity of the remaining CaO should at least be equal to the sum of the molecular amounts of MgO and FeO involved in steps (v) and (vi) above. Excess CaO, as in 61740, corresponds to free calcite.

If surplus MgO, or MgO and FeO, remains after all the CO_2 has been combined with divalent oxides for the formation of normative carbonate, it must be present in the rock in non-carbonate minerals of which chlorite and dark mica (and magnetite in the case of 61682) are the most probable. The proportions of Mg^{++} and Fe^{++} in chlorite and dark mica can vary over extremely wide limits and, since the composition of these minerals is unknown, the partition of MgO and FeO between carbonate and chlorite, etc., must also remain open to question.

In view of the above considerations, 61606, 61682 and 61685 are unsuitable for the calculation of the Fe^{++}: Mg^{++} ratio of the Fe - Mg carbonate contained in the rocks.

Apart from abundant associated silica in the form of chalcedony and a little chlorite, the vein ankerite, 61614, is nearly a monomineralic rock.

Table 5.13

Chemical Analysis of Vein Ankerite, 61614

	wt.%
SiO_2	28.3
TiO_2	0.2
Al_2O_3	2.6
Fe_2O_3	3.3
FeO	5.9
MnO	0.5
MgO	9.6
CaO	17.9
Na_2O	0.0
K_2O	2.0
P_2O_5	0.1
CO_2	28.1
H_2O	0.7
BaO	0.0
SrO	0.2
Total	99.9

Locality: 260 m. altitude, 3.5 km. west of Qagssiarssuk, South Greenland.

Analyst: B. I. Borgen.

The following normative minerals have been calculated, employing the steps outlined above and including a theoretical chlorite R_6^{++} Si_4O_{10} $(OH)_8$ with Fe^{++} as R^{++} in the first instance:

Table 5.14

Normative Minerals - Wt. Percent.

Sphene	0.3
Apatite	0.3
Calcite	31.7
Magnesite	20.2 (19.6)
Siderite	9.5 (10.3)
Orthoclase	12.2
Chlorite	0.7 (0.6)
Quartz	20.5
Haematite	3.3
Alumina	0.3
Water	0.6
TOTAL	99.6 (99.7)

The alternative values given for the percentage weights of some of the standard minerals of Table 5.14 (in parenthesis) correspond to substitution of Mg^{++} for R^{++} in the theoretical chlorite formula.

The normative mineralogy appears to correspond closely with the mode of the rock. The surplus alumina is presumably accommodated in the chlorite and the water in chalcedony.

Examination of the molecular percentages of the normative carbonates in Table 5.14 reveals that the composition of the chlorite can affect these but little, the two extreme compositions corresponding to a difference of only 1.1% $FeCO_3$. The signficance of this small difference is dominated by the magnitude of experimental errors and errors involved in the various theoretical assumptions.

In 61710, the normative carbonate has the following molecular composition: $CaCO_3$ 35.8%; $MgCO_3$ 62.7%; $FeCO_3$ 1.4%. The amount of $MgCO_3$ is nearly double that of $CaCO_3$, and since magnesite is absent from the rock, the analysis must be suspect. The very low ferrous iron content of the rock (0.4%) makes it seem certain that modal Fe-Mg carbonate lies fairly close to the magnesian end of the dolomite-ankerite series.

61640 is a rock of very simple mineralogy and the FeO:MgO ratio of the normative carbonate probably agrees closely with that of the modal Fe-Mg carbonate.

The location of (211) depends upon several factors, in particular:

(i) Experimental precision of the X-ray method; in the present case this varies between ± 0.01 and 0.02° 2θ.

(ii) The extent of substitution of Fe^{++} for Mg^{++} in the formula $CaMg(CO_3)_2$.

(iii) Other substitutions in the formula, e.g. the introduction of Mn^{++}.

Of these, (iii) is undoubtedly the most important, and the angular position of the (211) peak is within reasonable limits an indication of the relative amount of iron in the Fe-Mg carbonates of the area. In the present case there is insufficient analytical data available to justify the construction of a working curve of iron content plotted against the angular position of (211), however, the following generalisations are probably valid.

The Fe^{++} content of the Fe-Mg carbonates, expressed as $\frac{FeO \times 100}{FeO + MgO}$ varies from a low value, e.g. ca. 7% or less in 61640, up to about 35% in 61606 and 61685.

There is a concentration of occurrences at 25.5 - 27.5%, and again near the dolomitic end. Even allowing for the possible sources of error listed above, there would appear to be a number of Fe-Mg carbonates with $\frac{FeO \times 100}{FeO + MgO}$ values intermediate between 7% and 25%.

The concentration of occurrences at 25.5 - 27.5% may be on account of the simple molecular proportions of the divalent ions at this composition, corresponding quite closely to the formula $Ca_4(Mg_3Fe)(CO_3)_8$.

Tennant and Berger (1957) describe an X-ray method for the determination of the relative proportions of the carbonate phases in dolomite-calcite rocks. A rapid, semi-quantitative variation of this method was developed for the investigation of two-carbonate rocks of the Qagssiarssuk area.

A set of standards was prepared, consisting of pure calcite (iceland spar) and ankerite (specimen 61614) in the following proportions by weight:

	Ankerite	Calcite
1	90	10
2	75	25
3	50	50
4	25	75
5	10	90

X-ray diffraction traces of these mixtures were obtained and the proportions of the carbonate minerals in the suite under investigation found by visual comparison of their X-ray diffraction traces against those of the five standard mixtures.

The results are no more than semi-quantitative, but quite adequate for the purpose of the investigation, viz: to show whether there is a systematic distribution of the two minerals - - in particular, whether there is a radial distribution pattern which would indicate a focus of carbonatisation and possibly show whether the calcitic or the dolomitic carbonatisation was the earlier.

It is at once evident from the data obtained that the material examined is inadequate to yield a full explanation of the distribution of the carbonate minerals. This is due more to the limited area of high level calcareous rocks preserved than to inadequacy of sampling. However, critical consideration of the data brings out the following significant points:

(i) The carbonatised intrusives from the Basement and the minor intrusions of uncompahgrite from the Qagssiarssuk Triangle are very poor in free calcite.

(ii) The most highly ferroan ankerites occur in the Basement.

(iii) The most calcitic rocks appear mainly to be confined to the northernmost outcrops of the Calcareous Unit. (It may be noted that in the two-carbonate rocks there does not seem to be any systematic relationship between the iron content of the ankerites and the relative abundance of co-existing free calcite).

It would appear that at some depth (i.e. in the Basement), there is usually a single carbonate phase, a ferroan ankerite. In the Qagssiarssuk Triangle, where rocks of a higher level are exposed, the uncompahgrite neck, dike and sill (which are probably all associated) are ankeritic. The effusive carbonate rocks of the Triangle (and possibly of some of the diatremes) show various proportions of calcite and ankerite. There is a clear concentration of calcitic rocks toward the northern limit of the calcareous strata.

The manner in which the carbonatised uncompahgrite stock dominates the Qagssiarssuk Triangle suggests the possibility that it may have been a main conduit, (cf. Kerimasi and Hanang, James 1956), and concievably a focus of carbonatisation. If such were the case, the calcitic rocks at the north of the Calcareous Unit would be relics of an earlier phase of calcitisation, just beyond the limit of a later aureole of dolomitisation centred about the stock.

5. Trace Element Studies.

It is well established that carbonatites and associated ultramafic silicate rocks are typically characterised by enrichment in certain minor elements, in particular Ti, P, Ba, Sr, Zr, Nb, Y, Ce, La and the rare earths; moreover, the trace element assemblage characteristic of carbonatites contrasts markedly with that of sedimentary limestones. (cf. Hizagy, 1954, Pecora, 1956, and Campbell Smith, 1956).

A selection of the principal ultramafic-silicate and carbonate rock types from the Qagssiarssuk area was analysed for 8 trace elements by a semi-quantitative X-ray method (see Appendix III). The choice of elements (Ni, Cu, Zn, Rb, Sr, Zr, Nb, and Pb) was to some extent limited by instrumentation. Results for Ba, quoted below, are taken from analyses by B. I. Borgen; this element also was determined by X-ray spectrography. The results of the analytical work leave no doubt that these rocks have affinities with carbonatite and other unusual rock types (see Table 5.16).

The trace element pattern of the original ultramafic magmas of the Qagssiarssuk area have been modified in many cases by subsequent carbonatisation. Garson, (1962, p. 194) refers to the "dilution" of the original trace element concentrations in an alnöite by carbonatisation. While carbonatisation may cause depletion of some of the original elements of the rock, the carbonatising fluid may be enriched in other elements which become concentrated in the host rock.

Rock number 61634, the altered mica pyroxenite, has a composition somewhat resembling ugandite (see Table 5.16); the distribution of the concentrations of the minor elements is closely similar to that of the potassic ultramafic rocks of Western Uganda (Hizagy, 1954) and has close affinities with kimberlite. A lamprophyric (camptonite) dike from the Narssaq area, belonging to a swarm younger than the alkaline intrusive complex, shows a similar trace element pattern. This agreement, considered together with the remarkable persistence of the trace element pattern from one ultramafic rock type to another in Uganda (cf. Hizagy, op. cit.), makes it seem likely that the carbonatised Qaggsiarssuk rocks originally had trace element concentrations closely similar to those of the mica-pyroxenite.

Table 5.15

Concentrations of trace elements in rocks from Qagssiarssuk.

Spec. No.	61634	50853	61606	61682	61685	61614	61710	61740
Ni	210	125	265	250	415	100	385	35
Cu	55	75	65	50	115	130	45	40
Zn	190	105	450	200	215	175	185	155
Rb	330	220	30	55	85	90	115	x
Sr	2050	3400	9500	5000	1600	1850	3120	4300
Zr	1100	780	560	500	600	200	780	320
Nb	85	100	50	40	60	5	85	475
Ba	6000	2000	13000	4000	5000	x	1000	1000

Amounts are in parts per million. Analytical method: X-ray fluorescence. Ba determined by B. I. Borgen, other elements by J. W. Stewart. 50853 is a camptonite from Nungmiut, near Narssaq. The other rocks are from the country around Qagssiarssuk and their analyses appear elsewhere in this chapter.

Due allowance must of course be made for the variation of elements such as Rb, whose distribution closely follows that of a particular mineral or minerals.

The vein ankerite, 61614, represents the extreme case of ankeritic carbonatisation. The three carbonatised lamprophyres, 61606, 61682 and 61685 have trace element concentrations consistent with the modification of an original pattern cf, 61634 by material with a composition cf. 61614. The vein ankerite is low in Zr and Nb and the values for these elements in the lamprophyres are reduced, compared with the pyroxenite.

The uncompahgrite lava, 61740 has been so completely carbonatised that it seems certain that the present concentrations of the trace elements reflect the composition of the carbonatising fluid rather than that of the original uncompahgrite. Ni, probably located in ferromagnesian minerals in the other rocks, and Rb, elsewhere located in mica or feldspar, are extremely low. The high Nb is accordingly tentatively related to the calcitic carbonatisation.

Ni Most of the values are within the range usual for basic igneous rocks and the element is probably mainly concentrated in ferromagnesian minerals.

Cu, Zn These elements show typical values for basic igneous rocks, as a rule.

Pb Lead is rather high and may be present as sulphide.

61606, which has rather high Zn and Pb, is finely pyritous.

Rb Values are closely related to the presence of the potash bearing minerals mica (e.g. 61634) and potash feldspar (e.g. 61614). 61640, almost free of such minerals, has a very low value.

Sr Strontium is abundant in all the specimens. There is no sign of important concentration or depletion of the element in any particular rock type and it is likely that the quantity in the original silicate magma and the amount liable to be introduced during carbonatisation were similar.

Zr Zirconium is probably concentrated in sphene (cf. Hizagy, op. cit., p. 51); the mineral has been most readily identified in 61634 and 61710, the rocks with the highest concentrations of the element. Original values of ca. 1000 p.p.m. may have been diluted by Zr-poor carbonatising fluids.

Nb The distribution of this element has already been discussed. While sphene is probably capable of accommodating the element in the quantities present (Winchell, 1951, p. 525), there is poor correlation between the amounts of sphene and niobium present in the various specimens. The high Nb value in 61740 is outstanding, emphasising the chemical identity of this rock with carbonatite.

Ba This element has been abundant in the original ultramafic magmas and in very low concentration in the carbonatising fluids. Ba is much more abundant than Sr in the pyroxenite while the ratio is greatly reduced or reversed in the other rocks. It appears logical to ascribe this change to carbonatisation processes. Barium may be present in carbonate and/or sulphate.

Large crystals of baryto-celestite from minor mineral deposits (Fig. 5.36) have refractive indices characteristic of a Ba rich variety ($\beta = 1.632$, $\gamma = 1.640$). Specimens 61710 and 61740 contain interstitial baryto-celestite, but have low Ba: Sr ratios. Assuming that the analytical values are correct, we are left with the following alternativels:

(i) the sulphate is a strontian variety

(ii) strontium is concentrated in the carbonate in preference to barium.

Table 5.16 Trace elements of mica-pyroxenite and carbonatised uncompahgrite with comparative data.

		Ni	Cu	Zn	Rb	Sr	Zr	Nb	Ba	Pb
1	61634, mica pyroxenite, Qaqssiarssuk	210	55	190	330	2050	1100	85	6000	75
2	50853, camptonite, Nungmiut, Narssaq	125	75	105	220	3400	780	100	2000	110
3	Sphene-rich biotite-pyroxenite, Uganda	2	50		170	1000	1200		1200	< 10
4	Average katungite, Uganda	185	85		220	6685	1000		3370	< 10
5	Average ankaratrite, Uganda	93	68		170	6900	550		2900	x
6	Kimberlite, Basutoland		100		100	> 1000	450	200	2600	10
7	Average ultrabasic rock	2000	10	50	0.2	1	45	16	0.4	1
8	Average basic igneous rock	130	87	105	30	465	140	19	330	6
9	61740, carbonatised uncompahgrite, Qagss.	35	40	155	x	4300	320	475	1000	115
10	Average carbonatite	8	2.5			2900	83	1600	2500	
11	Carbonate dike, Premier Mine, S.Africa	200	45		x	1000	90		290	< 10
12	Carbonatite (i), Oldoinyo Dili	x			x	2500	200	800	3500	
13	Carbonatite (ii), Oldoinyo Dili	x			x	2500	450	225	3500	
14	Average carbonate sediment	20	4	20	3	610	19	0.3	10	9

x = below level of detection. Further particulars on next page.

Particulars about analytical data in Table 5.16.

1. 61634, altered mica-pyroxenite, Qagssiarssuk area.
2. 50853, camptonite dike, Nungmiut, Narssaq area.
3. Sphene-rich biotite pyroxenite. Ejected block, K4, Katwe Crater, S. W. Uganda. (Hizagy, 1954).
4. Average katungite, S. W. Uganda, (Hizagy, 1954).
5. Average ankaratrite, S. W. Uganda, (Hizagy, 1954).
6. Micaceous hardebank, analysis No. 343, Robert Dike, Basutoland (Dawson, 1962).
7. Average ultrabasic rocks (Turkenian and Wedepohl, 1961)
8. Average basaltic rocks (Turkenian and Wedepohl, 1961)
9. 61740, carbonatised uncompahgrite lava, Qagssiarssuk.
10. Average carbonatite (D. P. Gold, 1963)
11. Carbonate dike, Premier Mine, South Africa (Hizagy, 1954).
12. Carbonatite, analysis J. G. 2349, Oldoinyo Dili, Tanganyika (Bowden, 1962).
13. Carbonatite, analysis J. G. 2536, Oldoinyo Dili, Tanganyika (Bowden, 1962).
14. Average carbonate sediment (Turkenian and Wedepohl, 1961).

1, 2 and 9, analyst J. W. Stewart.

3, 4, 5 & 11, analyst R. A. Hizagy.

6 analysts Miss J. M. Rooke and Mrs. P. E. Fisher.

12 and 13 analyst P. Bowden.

(c) Notes on the Geology of the Country West of the Qagssiarssuk Triangle.

The structure and stratigraphy of the upper part of the Ilímaussaq Peninsula is very poorly known. The chief reason is the absence of distinctive horizons in the broad area of sandstone which stretches across the Peninsula from Nûgârssuk to Tasiusaq.

The broad peninsula which projects northwards into Tasiusaq is of sandstone containing two interbedded volcanic horizons. The more northerly of these was visited during reconnaissance in 1960, when a close resemblance to Volcanic Horizon (1) at Igaliko (Chapter IV) was remarked. The horizon is composite, with a total thickness of ca. 5 m.. The lower layer is of a compact reddish rock which is probably olivine basalt (perhaps affected by potash-feldspathisation). The upper layer is of a greenish, fine grained compact basalt containing very sparse, glassy feldspar phenocrysts of blocky form. This rock is analogous to the sills of olivine-free basalt at Sitdlisit (Chapter I) and Igaliko (Chapter IV). H. Scharbert (in litt.) has observed structures in the horizon (presumably in the lower layer) resembling possible cooling-cracks in the olivine basalt of Qagssiarssuk shore.

The southerly horizon is of greenish, compact, aphyric basalt and Scharbert (op.cit.) implies that it may be a sill.

(d) Notes on Minor Upfaulted Areas between Nûgârssuk and the Qagssiarssuk Triangle.

(i) At the inner corner of a small bay about 1 km. south-east of the most southerly part of the Triangle, a small area of soft red and yellow sediment is seen to underlie cavernous red sandstone on the south-eastern side of a 60° fault. To the north-west, the rock is a pale, compact sandstone of the type found in the Lower Sandstone Unit and elsewhere. The base of the coloured shaly rock is not exposed and a minimum thickness of 10 m. is indicated. This rock closely resembles beds developed near the top of the Calcareous [illegible] Unit and is believed to be of the same origin, viz. pyroclastic, possibly of subaquaeous deposition. The cavernous red sandstone appears to be identical with the basal development of the Upper Sandstone Unit in the Qagssiarssuk Triangle.

If this is indeed an outcrop of the same horizon as that exposed on the north face of Angmassiviup Qáqâ, there would be a relative upthrow of the order of 600 m., partly or wholly caused by the 60° fault.

(ii) Immediately north of where the important east-west fault reaches the coast on the northern side of Nûgârssuk, the basal unconformity of the Gardar Continental Series has been brought up by a 50° fault. The granite outcrops just above sea level and is heavily weathered; moreover, it has been undercut by marine erosion and is inaccessible. The granite may contain some thin sheets of 'carbonatite', though this is not absolutely certain. The lowest part of the sedimentary sequence is probably an arkose formed by in situ weathering of the granite; no conglomerate is present. The overlying sandstone lacks distinctive characteristics.

No trace has been found of interstratified volcanic beds recorded in earlier mapping.

(e) Geological History.

Much of the north-west boundary of the Qagssiarssuk Triangle is known to be faulted, with downthrow to the south-west. The probable thickness and lithology of the concealed strata may be inferred by comparison with other areas. In the Mâjût - Ilímaussaq area (ChapterI) and at Igaliko (Chapter IV) Gardar sandstones and basaltic lavas with an aggregate thickness of the order of 500 m. were laid down prior to the first manifestation of the ultramafic - carbonatite vulcanism. Assuming that the ultramafic effusives of the Calcareous Unit do not greatly predate the related rocks in the other areas, it seems likely that a comparable succession of sandstones and basalts underlies the Qagssiarssuk Triangle.

Nearer at hand, the strata of the peninsula which projects northwards into Tasiusaq (see above) and the basalt of Qagssiarssuk shore may be stratigraphically equivalent to parts of the concealed succession.

The total absence of Gardar Continental Series material from the pipe-breccias of the Basement reinforces the suggestion of a substantial difference in erosion level on either side of the 60° fault. A very common feature of volcanic pipe-breccias is the occurrence of fragments which can be correlated with stratigraphical horizons many hundreds of metres above (cf. Wagner, 1914, pp. 21-24, Gates, 1959, p. 799, Upton, 1962, pp. 39-41).

Early in the Gardar Period, after a succession of sandstones and lavas some hundreds of metres thick had been laid down in the Qagssiarssuk area, a reservoir of lamprophyric magma highly charged with volatiles (particularly CO_2 and H_2O) became available at moderate depth in the region around Tunugdliarfik. Locally, diatremes began to make their way towards the surface. Various mechanisms of advance are discussed by Gates (1959). Diatreme drilling was particularly active in the Qagssiarssuk and Narssarssuaq areas. The isolated areas of gneiss breccia in the Basement may represent brecciation ahead of diatremes, (cf. Gates, 1959, p. 812).

Eventually, at some point, the pressure at the head of the diatreme exceeded the hydrostatic pressure of the superincumbent rocks sufficiently for a fissure to open along some line of weakness, connecting the diatreme with the surface.

If the magma column were preceded by a cell filled with volatiles under extreme pressure (cf. Gates, op. loc.) the opening of the fissure would result in the sudden expansion of the volatile material, manifested by an explosion at depth. Such an explosion might be responsible for the development of the set of low angle fissures in the country rock which are now occupied by ultramafic sheet intrusions. The classical example of such fissuring is at Alnö, where sets of concentric conical fractures occur. Von Eckermann relates these sets to a succession of explosions in carbonatite magmas at various depths (Von Eckermann, 1948). The regional disposition of the fissures at Qagssiarssuk is unknown.

The sudden expansion of the gaseous magma into the fissures led to the disintegration of the magma into spherical drops (cf. Rust, 1937, p. 68). Subsequent attrition during passage along the fractures may account for the general absence of arrangement of elongate minerals parallel to the periphery of the nodules (ctr. Rust, op. cit.). The large nodules of the lamprophyric breccia (up to 5 cm. in diameter) have most probably formed from plastic or solidified lamprophyre. Similar nodules have been described in a 1 ft. dike of monchiquite in Ayrshire (Eyles, et al., 1949). Of this occurrence the authors write ... "The exposures indicate intrusion of monchiquite along a dike-fissure with explosive violence, followed by brecciation and calcite veining".

The angular form of the gneiss inclusions in the lamprophyric sheets and the irregular nature of the lateral contact surfaces, including the occurrence of screens and blocks almost, but not wholly, detached from the wall-rock, would seem to be at variance with the conception of explosive introduction of the magma. Moreover, there is an absence of pyrometamorphic effects which might be expected in the country rock on exposure to this ultrabasic magma for any length of time. (By contrast, the granitic blocks in the pyroxenite are well rounded, presumably by corrosion). Dawson, (1962 (a) p. 558, dealing with closely similar problems concerning the emplacement of kimberlite, invokes fluidisation as a mechanism of intrusion capable of explaining the lack of pyrometasomatism in the country rock, the survival of fragile wall-rock appendages and the high degree of metasomatic alteration of the inclusions.

It is possible that the limited metamorphic effects and lack of erosion of the wall-rock may simply reflect rapid cooling of the magma. In many dikes, great volumes of magma pass through, maintaining a high temperature at the contact for prolonged periods. In such cases the wall-rock is well smoothed and may show evidence of thermal metamorphism. The fissures of the present discussion are of very limited lateral extent - they formed cul de sacs for magma as opposed to channels. Heat loss to the country rock would have been at a maximum; expansion of the gases would also have contributed to rapid cooling. The lack of a through-current would explain the abundance of angular fragments and appendages. The latter could have become partially detached, (e.g. as a result of differential thermal expansion) when the main fissure had already filled. The specific gravity of the granite is undoubtedly lower than that of lamprophyre, so the distribution of the fragments is probably related to the late movements of partly cooled, viscous magma.

With the passage of fragment-laden gases, the original opening to the surface became eroded and enlarged. Most of the diatremes in the Basement are small in area and in many cases their location on fissures can hardly be disputed. Those of the Qagssiarssuk Triangle are mostly of much greater area and have a sub-circular cross-section. This apparent widening with decreasing depth recalls the structure of many kimberlite pipes (cf. Wagner, 1914, pp. 5-15) and is further evidence that the exposures of the Basement country and those of the Triangle are at substantially different erosion levels.

The angular nature of the granite blocks in the intrusive breccias indicate that they have not long been subjected to attrition. The excellent linear arrangement of inclusions illustrated in Fig. 5.11 is local evidence of gas flow with energy sufficient to induce alignment but inadequate to cause entrainment, which inevitably would have been followed by collapse and disorientation. All of the pipes in the Basement (with the exception of the pyroxenite necks) contain lamprophyre and/or a breccia consisting of lamprophyric and country rock material in various combinations.

In the Basement north of Qagssiarssuk, the lamprophyric magma was followed by uncompahgrite which penetrated many of the earlier lamprophyre sheets, cut a few of the diatremes and also formed separate sheet intrusions. Possibly another explosion at depth formed a further set of fissures.

Nodular uncompahgrite may have formed where the melilitic magma penetrated fissures or pipes filled with nodules of lamprophyre, sweeping them into suspension.

The Calcareous Unit of the Qagssiarssuk Triangle is believed to represent the eroded remnant of a volcanic cone or a group of adjacent cones. The effusive products are predominantly pyroclastic, as is frequently the case where ultramafic magmas are involved (cf. King and Sutherland, 1960, pp. 306-307). The pyroclastic material comprises contributions from the lamprophyric and uncompahgrite magmas, from the various country rocks and possibly from a concealed body of massive carbonatite. The importance of the latter component is open to question. Many of the fine calcareous tuffs may represent carbonatite ash (cf. Dawson, 1962 (b) pp. 358-359; Downie and Wilkinson, 1962, p. 415); on the other hand, pyroclastic material of almost any composition would be exceedingly susceptible to carbonatisation on account of the small grain size.

Possible pyroclastic derivatives from an underlying body of carbonatite magma are:

(i) the martite tuff
(ii) the block of apatite søvite.

In mineralogical composition, the martite tuff finds numerous parallels in carbonatite bodies of many regions. Octahedral magnetite or martite (often with stepped crystal faces) and apatite are probably the most common accessory minerals in carbonatites. Records of pyroclastics of similar composition are rare, but in the Feira District, Sothern Rhodesia, D. K. Bailey has recorded carbonatitic tuffs, containing martite octahedra in circumstances where their genetic relationship to intrusive carbonatite is indisputable. (Bailey, 1960, pp. 55-58).

In the pyroclastic beds of Mfwanganu Island, Western Kenya, Whitworth has observed blocks of carbonatite (Whitworth 1961, pp. 168-169) probably derived from the Rangwa volcanic complex (op. cit., p. 178). One such block, in the collection of this Department, is of coarse, white søvite with numerous octahedra of iron ore, and grains of accessory apatite and mica. The size, habit and incidence of the ore grains is such that the rock closely resembles the martite tuff from Qagssiarssuk macroscopically, if colour is disregarded.

The apatite søvite inclusion (61696) was collected from a tuffisite pipe; similar blocks were observed in the bedded pyroclastics of the Calcareous Unit. In appearance, the rock is a typical plutonic søvite, and apart from its low content of iron ore and lack of mica it is very similar to the block from Kenya.

The alnöite lapilli are essentially similar to those found in the sheet intrusions north of Qagssiarssuk and probably formed at depth. (cf. Holmes, 1956, p. 142).

The lava flows of the Qagssiarssuk Triangle are of one rock type only, viz: a highly carbonatised uncompahgrite. The uncompahgrite necks may represent the conduits which fed these flows.

Evidence of various high level sub-volcanic structures is abundant in the Triangle. Some of the tuffisite diatremes apparently failed to penetrate wholly to the surface; others, such as V_1 and V_2, have outward-flaring margins and contain well stratified, occasionally cross-bedded tuffs which are probably crater deposits which have been subjected to surface sedimentation mechanisms. The sandstone unit which succeeds the Calcareous Unit does not appear to be breached by diatremes and the period of explosive activity was followed by one of volcanic quiescence in this area. The dome structure in the sandstone indicates a minor, localised renewal of upward pressure at some later stage.

The diatremes and associated sills of the Basement country are almost certainly contemporaneous with those of the Triangle. The rock types found in both areas agree closely and are regarded as being comagmatic.

One of the youngest rock types associated with the Qagssiarssuk volcanics is the coarse red syenite which intrudes V_1. This rock is regarded as rheomorphic, potash-feldspathised Basement rock. After consolidation, it was brecciated and penetrated by veins of ankerite.

The barytes and fluorite mineralisation may represent the latest event of the volcanic activity. At Chilwa, the hydrothermal introduction of fluorite was part of "the final manifestation of a waning carbonatitic activity" (Garson and Campbell Smith, 1958, p. 82) and of African alkaline intrusions King and Sutherland write ... "Fluorspar and barytes are concentrated in the carbonatite, evidently by late stage processes". (King and Sutherland, 1960, p. 513).

(f) PETROGENESIS

Concealed Intrusion of Carbonatite.

Many carbonatite bodies were at one time thought to be enclaves of sedimentary limestone or intrusions of rheomorphosed sedimentary limestone (cf. Brøgger, 1921, Shand, 1932). With the detailed mapping of greater numbers of these complexes, many of them situated in deeply eroded basement rocks, it has become clear that any connection with sedimentary limestone is generally fortuitous and somewhat exceptional. There can be no question that limestone of sedimentary origin is absent from the pre-Gardar basement for a great distance around Qagssiarssuk.

At the present time, it is probable that a majority of geologists believe that most major carbonatite intrusions have been emplaced in a magmatic form, rather than by replacive processes (cf. King and Sutherland, 1960, p. 712. Garson, 1962, p. 196, de Kun, 1962).

For many years, one of the principal arguments against the existence of a carbonate melt was the high melting point of calcite viz. 1339°C. at 1025 atm. of CO_2, according to Smyth and Adams (1923). More recent work by Wyllie and Tuttle has shown that the presence of abundant H_2O can reduce the melting point of calcite enormously (Wyllie and Tuttle, 1960). A mixture with the composition 68 CaO, 19 CO_2, and 13 H_2O (wt.%), at 1,000 bars total pressure, is completely melted at 683°C. Eitel has shown that addition of alkali carbonates to $CaCO_3$ also causes a lowering of the melting point (Eitel, 1954). It is possible that other components of the melts, e.g. P_2O_5 and fluorine, lower the melting point still further.

The nature of the ultramafic silicate rock suite, the widespread potash-feldspathisation and the intense carbonatisation, with its highly significant trace element pattern, makes it certain that a carbonatite body has been emplaced at no great depth below the present erosion surface, in the Qagssiarssuk region.

The martite tuff and apatite søvite blocks are regarded as actual samples of this concealed intrusion; the apatite which they contain indicates that P_2O_5 was a significant component of the carbonatite magma and fluorite mineralisation in the area suggests that fluorine was also present. The potash responsible for the potash-feldspathisation of the country rocks may have been present in the melt as potassium carbonate at an earlier stage.

Potash Feldspathisation.

The emplacement of carbonatite is characteristically accompanied by metasomatic transformation of the country rocks. The alteration, in which desilication and introduction of alkalies are prominent, is known as fenitisation. At the outer limit of fenitisation, the process is represented by the development of sodic pyroxene or sodic amphibole in cracks and veins and around quartz grains. Nearer the intrusion, the country rocks may be transformed into a metasomatic syenite or even nepheline syenite. There is no indication whatever of this type of fenitisation at Qagssiarssuk; neither sodic pyroxene nor sodic amphibole has been recorded.

At some African carbonatite complexes a process known as feldspathisation is developed in association with fenitisation, e.g. at Chilwa Island (Garson and Campbell Smith, 1958) and Tundulu (Garson, 1962). Chemically, the most outstanding feature of feldspathisation is the introduction of abundant K_2O and, where the process is fully developed, an almost pure potash-feldspar rock is produced.

Garson and Campbell Smith compare the chemical changes which occur in fenitisation and feldspathisation as follows:

	Increase	Decrease
Fenitisation	$K_2O, Na_2O, FeO, P_2O_5, Al_2O_3$	SiO_2
Feldspathisation	K_2O, Al_2O_3, H_2O(?), S(?)	Na_2O, FeO, Fe_2O_3

(Garson and Campbell Smith, 1958, p. 30)

These authors regard feldspathisation as a late process imposed upon the fenites, possibly the ultimate stage of fenitisation.

At a number of carbonatite localities potash-feldspathisation is found unaccompanied by fenitisation. Examples occur in the Rufunsu district, Northern Rhodesia (Bailey, 1960), S. W. Tanganyika (James, 1958; Miller and Brown, 1963) and in the country around Qagssiarssuk. In most of the African localities the intrusions are eroded to a considerable depth and the effects of potash-feldspathisation are confined to basement rocks. At Rufunsu, however, Bailey reports felds-pathisation of sandstone and conglomerates (Bailey, 1960, p.41). In the vicinity of Qagssiarssuk, where more extensive supra-crustal rocks are preserved, sandstone and olivine basalt are feldspathised, in addition to basement granite. (The feldspathised olivine basalt occurs in the Igaliko area, Chapter IV).

At some of the African carbonatite localities, the feldspathised country rocks are believed to have been locally mobilised and intruded as dikes (e.g. Garson, 1962, p.198). In the Qagssiarssuk area, the red, potassic leucosyenite in the vent V_1 is believed to have originated in this manner. The syenitic sill of the Musartût Unit (Chapter I) is sufficiently similar to suggest a like origin. The higher soda content of the latter rock suggests that mobilisation was initiated before the potash-feldspathisation process had been carried to completion.

Brecciation and plastic-flow.

Many carbonatite bodies are surrounded by an aureole of strongly crushed or shattered country rock -- the thermal shock-zone of Von Eckermann (1948) or the contact breccia of Garson and Campbell Smith (1958). Von Eckermann describes granulation of quartz in the country rock. The exfoliation ellipsoids and accompanying breccias developed adjacent to the carbonatised minor intrusions north of Qagssiarssuk are regarded as a comparable phenomenon. Mortar structure is developed in the rock fabric.

Von Eckermann considers this brecciation to be due mainly to dynamical strain set up by heat flowing out from the intrusion. Other sources of dynamic strain which may have affected the country rocks at Qagssiarssuk are:

(i) Volume increase in the ultramafic intrusion caused by carbonatisation.

(ii) Volume increase in the country rock caused by feldspathisation.

(iii) Solid intrusion or plastic flow of the carbonatised intrusives.

There is no data available to substantiate the suggestions of volume increase. There is, however, some evidence of a limited amount of plastic flow. This is indicated by the fractured apatite prisms (Fig. 5.41) and the flattened form of the alnöite nodules in the carbonatised sheet intrusions of nodular uncompahgrite (Fig. 5.4). Both the matrix and the nodules in this rock type contain substantial amounts of carbonate and might be expected to show the plastic deformation effects characteristic of carbonate rocks. Obviously, the plastic deformation could be induced by a volume increase in the intrusion or in the wall rock.

The Ultramafic Rock Types.

The association of ultramafic rock types with carbonatite has been recorded in numerous instances. Lamprophyric dikes are frequently found, including the varieties mica-peridotite, alnöite, and monchiquite, e.g. at Alnö (Von Eckermann, 1948, 1958), Oka, (Stansfield, 1923), Turja (Kranck, 1929), Chilwa (Garson and Campbell Smith, 1958).

Pyroxenite occurs in the vicinity of some carbonatite complexes, e.g. at Iron Hill (Larsen, 1942) Palabora, (Russell, Hiemstra and Groeneveld, 1955) and centres in Tanganyika (James, 1958).

Uncompahgrite and rocks with a comparable high melilite content are very uncommon and apparently restricted to localities where carbonatite is present, viz.: Iron Hill, Turja, Oka, and the Rangwa complex in Kenya (McCall, 1958).

Rocks of all the above types occur at Qagssiarssuk.

The lamprophyres.

The varieties mica-peridotite, alnöite, mica-monchiquite and monchiquite are regarded as members of a gradational suite. They are distinguished from one another by varying proportions of olivine, biotite, pyroxene and melilite. In rocks of these types, close chemical similarity is frequently masked by contrasting mineralogy. This is well shown by Flett (1933, pp. 182-183) who provides analyses of monchiquite, nepheline-monchiquite and biotite-monchiquite which are closely similar and quotes average analyses of nepheline basalts, ankaratrites and alnöites which are also in close agreement.

Bowen's account of the alnöitic rocks from Isle Cadieux, and the related laboratory investigation of melts of comparable, though simplified composition, indicates some of the reactions involved in the development of such a lamprophyric suite (Bowen, 1922). The potassic ultramafic lavas of Western Uganda have many features in common with the Qagssiarssuk rocks. Holmes states that compositional variability is a characteristic of the W. Uganda province (Holmes, 1950, p. 778); elsewhere, he notes a roughly complementary relationship between augite and melilite in rocks of similar type (1956, p. 151).

The amount of mica in the Qagssiarssuk rocks is very variable and in some instances there are signs that it is of very late-magmatic or post-magmatic crystallisation. For example, euhedral biotite has been observed within carbonated pseudomorphs after olivine and forming a shell around a nodule of carbonatised alnöite (Fig. 5.43). Bowen (op. cit.) invokes a late-stage alkaline liquid to account for the biotite in the Isle Cadieux alnöite. At Qagssiarssuk, the availability of a potash-rich fluid is indicated by the feldspathisation of the country granites.

In the greater Qagssiarssuk region, monchiquite has the most extensive occurrence in space and time of the members of the lamprophyre suite. Typically, the rock does not contain melilite or biotite.

The uncompahgrite.

The classic uncompahgrite from Iron Hill, Uncompahgre Quadrangle, described by Larsen, contains ca. 68% melilite, (Larsen, 1942). The rock is a coarse grained plutonic variety. The okaite of the Monteregion province contains a similar proportion of melilite (Stansfield, 1923) and the turjaite of Kola contains 41.7% of melilite in a calculated mode. Katungite may contain 40% of melilite (Holmes, 1950, p. 781). At Rangwa, uncompahgrite and turjaite have been described (McCall, 1958).

So far as is known, effusive uncompahgrite has never before been recorded; however, the subvolcanic nature of the Rangwa complex is well substantiated (McCall, 1958, 1963) and McCall describes dikes at the adjacent Ruri complex which have been exceedingly rich in melilite and probably closely similar to the melilite rock of Qagssiarssuk (cf. McCall, 1963).

Among the hypabyssal intrusives of Alnö, some of the types classified as kimberlites and ouachitites are very rich in melilite, (Von Eckermann, 1948, 1958). This is much more apparent from photomicrographs of the Alnö rocks than from text descriptions (cf. Von Eckermann, 1958, Plate VII Fig. 2, Plate VIII Fig. 2 and Plate X Fig. 1). It is probable that a number of the rocks classified as alvikite by Von Eckermann are in fact carbonatised uncompahgrite (cf. op. cit. p.49). McCall (op. cit.) follows Von Eckermann in referring to such dikes as alvikite.

At Turja, Kranck considers it likely that the melilite of the turjaite "originated under the influence of residual solutions (or melts) rich in lime which had penetrated into a partly consolidated pyroxene-bearing rock belonging to the ijolite stem or the lamprophyres." (1929, p. 90).

Larsen demonstrates that the rock types of Iron Hill can be explained "by postulating an original basaltic magma modified first by assimilation of marble and then by crystal differentiation." He shows that 33⅓ parts of the bases of limestone (27 parts CaO, 4⅓ parts MgO and 2 parts SiO_2), added to 100 parts of Daly's average plateau basalt, would give a rock of composition similar to that of uncompahgrite. The apatite and magnetite of Larsen's "marble" indicate that the latter is an igneous or carbonatitic limestone.

The hypothesis is proposed that the uncompahgrite of Qagssiarssuk is derived from the lamprophyres, probably the monchiquite, by intense desilication caused by a reaction with carbonatite. The rock is quite distinct from the lamprophyres in mineralogy and there is an absence of types transitional between the uncompahgrite and the most melilite rich of the lamprophyres. A considerable bulk of the uncompahgrite magma must have been available, to account for the sills, flows and necks of the rock. It is likely, therefore, that the reaction which produced the uncompahgrite magma operated on a considerable scale and that sizeable quantities of lamprophyre were wholly converted to uncompahgrite before the latter was erupted.

Calcitic Carbonatisation.

It is believed that the lamprophyre and uncompahgrite magmas of the Qagssiarssuk region were very rich in normative $CaCO_3$ and that the resulting rocks were subjected to a strong late-magmatic carbonatisation. The monchiquites of Nunasarnaq and Sitdlisit, (which are most remote from Qagssiarssuk and, presumably, the carbonatitic intrusive centre as well) contain abundant calcite and virtually no dolomite.

In an earlier section of this chapter, it was shown that there is evidence to suggest that in the Qagssiarssuk area, an early phase of calcitic carbonatisation of the ultramafic rocks was succeeded by an ankeritic carbonatisation and that only at the highest levels were the calcitic rocks partially preserved.

While it seems probable that the lamprophyres were subjected to an autometasomatic calcitic carbonatisation, the same explanation can hardly apply to the uncompahgrite flows. In the case of these, the compositional change is so complete that the disposal of the expelled materials (principally silica; also possibly alumina, magnesia, etc.) presents a formidable problem. Alternative explanations are (i) that the uncompahgrite was already carbonatised prior to extrusion and (ii) that the flows were carbonatised after extrusion. The latter alternative is also subject to the silica disposal problem. In other areas, e.g. Rufunsu (Bailey, 1962) and Chilwa (Garson and Campbell Smith, 1958, pp. 82-83), a late silicification may be complementary to carbonatisation of silicate rocks, but at Qagssiarssuk quartz veins appear to be absent from the flows and pyroclastics of the Calcareous Unit.

Carbonatite flows.

McCall (1963) states that the highly carbonatised melilite rich dikes of North Ruri "must surely have been intruded as carbonatite (alvikite), not as alnöite". He believes that certain of these dikes "represent an alnöitic magma which has been at least partly crystallised and then metasomatically transformed by a pulsation of carbonate on its upward passage, and solidified as alvikite". The Qagssiarssuk flows represent the extrusive equivalent of such a magma. (Saether, 1957, pp. 103 and 109, produces evidence to show that melilite may persist into peri-magmatic or possibly hydrothermal conditions). Other "carbonatite" flows recorded in Africa may have a similar origin.

Examination of thin sections of the recent carbonatite flows from Oldoinyo Lengai (Dawson, 1962 b, DuBois et al., 1963, Dawson 1962c) has revealed the presence of numerous structures which have been interpreted as pseudomorphs after at least two different silicate minerals. Pseudomorphs of the first group are well rounded, show traces of a well developed cleavage and are thought to have been originally mica or possibly serpentinised olivine; pseudomorphs of the second kind are lath-shaped and thought to be replacive after melilite. (The slides were made available to the author by courtesy of Mr. T. Deans of the Overseas Geological

Surveys Office).

Table 5.17

	I	II	III	IV	V
SiO_2	4.4	5.62	1.01	7.29	3.99
TiO_2	2.4	0.53	0.06	0.86	0.06
Al_2O_3	0.7	1.29	0.23	1.04	0.57
Fe_2O_3	4.1	2.84	0.64	2.23	3.36
FeO	0.5	1.94	3.19	1.58	tr.
MnO	0.5	0.46	1.12	0.35	1.40
MgO	7.2	1.46	0.88	3.74	1.35
CaO	40.1	46.88	49.02	45.71	48.54
Na_2O	0.2	0.40	0.14		0.21
K_2O	0.1	0.64	0.13		0.13
P_2O_5	2.7	1.96	0.69	0.67	0.07
CO_2	36.4	33.02	41.66	34.88	40.22
H_2O	0.1	1.57	0.40	1.78	0.09
BaO	0.1	0.75	0.60		
SrO	0.4	0.39	0.01		
SO_2		0.48			
F			0.18		
S			0.49	0.20	
SO_3		0.48			
Total	99.9	99.91	100.44	100.33	99.99

I Carbonatised uncompahgrite flow, 61740, Qagssiarssuk. Analyst: B. I. Borgen.

II Carbonated lava, C. 5509, Bomb from Kalyango Volcano, Fort Portal volcanic field, Uganda.
Analyst: W. H. Herdsman. (Holmes, 1956).

III Alvikite dike, analysis No. 120, Alnö.
Analyst: R. Blix. (Von Eckermann, 1948).

IV Carbonate dike, Premier Mine, (No. 3125).
Analyst: Miss H. E. Vassar (Daly, 1925).

V Søvite, Tundulu, Nyasaland.
Analyst: Miss J. R. Baldwin (Garson, 1962).

Similar extreme carbonatisation of ultramafic flows is recorded from the Fort Portal area in Uganda (Holmes and Harwood, 1932; Von Knorring and DuBois, 1961) and at Kerimasi (see Bowden, 1962) and Igwisi (Sampson, 1956, Fozzard, 1958) in Tanganyika.

The carbonated lavas of Oldoinyo Lengai, Fort Portal and (?) Kerimasi have been widely accepted as examples of extrusive carbonatite. Judged by the same criteria the carbonatised uncompahgrite flows of Qagssiarssuk might equally be described as extrusive carbonatite. Certainly the chemical composition could hardly be more typically carbonatitic. (See Tables 5.16 and 5.17).

Ankeritic carbonatisation.

While it is believed that the lamprophyre and uncompahgrite magmas contained abundant normative calcite, it is not improbable that the concealed carbonatite contributed to the calcitic carbonatisation of these rocks. The later, ankeritic carbonatisation and the barytes and fluorite mineralisations are ascribed to volatile fluids expelled from the concealed body. In other carbonatite complexes, e.g. Fen (Saether, 1957), Chilwa, Tundulu and Rufunsu, earlier calcitic carbonatite is partly replaced by ankerite at a later stage. This is the sequence to be expected under conditions of falling temperature (cf. Saether, 1950, p. 123).

The lamprophyre and uncompahgrite magmas, the calcitic carbonatitic fluid (if such existed separately) and the ankeritic fluid, would all appear to be potential sources of the K_2O and Al_2O_3 which caused the potash feldspathisation. The relative importance of the three sources as donors of these oxides is uncertain. In the Igaliko area, potash-feldspathisation of olivine basalt is not accompanied by carbonatisation; this indicates the independent existence of a hydrothermal potash solution.

Comparison with W. Uganda.

Compositionally, the mica-pyroxenite pegmatoid is a glimmerite. The occurrence of this rock type recalls the hypothesis of Holmes regarding the genesis of katungite and its associates (Holmes, 1950) (vid. Table 5.). Thin sections of katungite from Katunga crater (kindly provided by Mr. R. Freeman of this Department) were compared with lamprophyres from Qagssiarssuk. The texture of the Qagssiarssuk alnöites, typified by 61627 (Fig. 5.39), in so far as it is preserved, agrees closely with the Uganda rock.

The minerals which have been positively or provisionally identified in the lamprophyres are wholly characteristic of the W. Uganda suite, (op. cit., pp. 776-778).

Table 5.18

	I	II	III
SiO_2	37.5	37.31	42.14
TiO_2	6.2	3.33	3.38
Al_2O_3	6.2	8.81	8.73
Fe_2O_3	5.9	8.42	4.72
FeO	12.0	2.60	5.63
MnO	0.2	0.19	0.18
MgO	13.1	11.02	16.59
CaO	7.2	16.23	8.98
Na_2O	0.2	1.66	2.00
K_2O	4.9	4.46	3.98
P_2O_5	1.0	1.33	0.48
CO_2	2.7	2.36	0.31
H_2O	1.6	2.27	1.99
BaO	0.6		0.22
SrO	0.2		0.14
Total	99.5	99.99	100.07

I Mica-pyroxenite (pyroxene-glimmerite) 61634, Qagssiarssuk.
Analyst: B. I. Borgen.

II Melanite ouachitite, Turja.
Analyst: E. H. Kranck (Kranck, 1929).

III Ugandite (with xenocrysts of biotite), G.44. Katwe crater, Uganda.
Analyst: H. F. Harwood. (Holmes, 1956).

In view of the high potash associated with the ultramafic rocks of Qagssiarssuk, there is a distinct possibility that the lamprophyric suite was originally closely analogous to rock types such as katungite and ugandite, even to the extent of containing minerals such as kalsilite and potassic glass. The successive episodes of carbonatisation would inevitably have destroyed these minerals and, since they are not characterised by euhedral form, recognisable pseudomorphs would not occur.

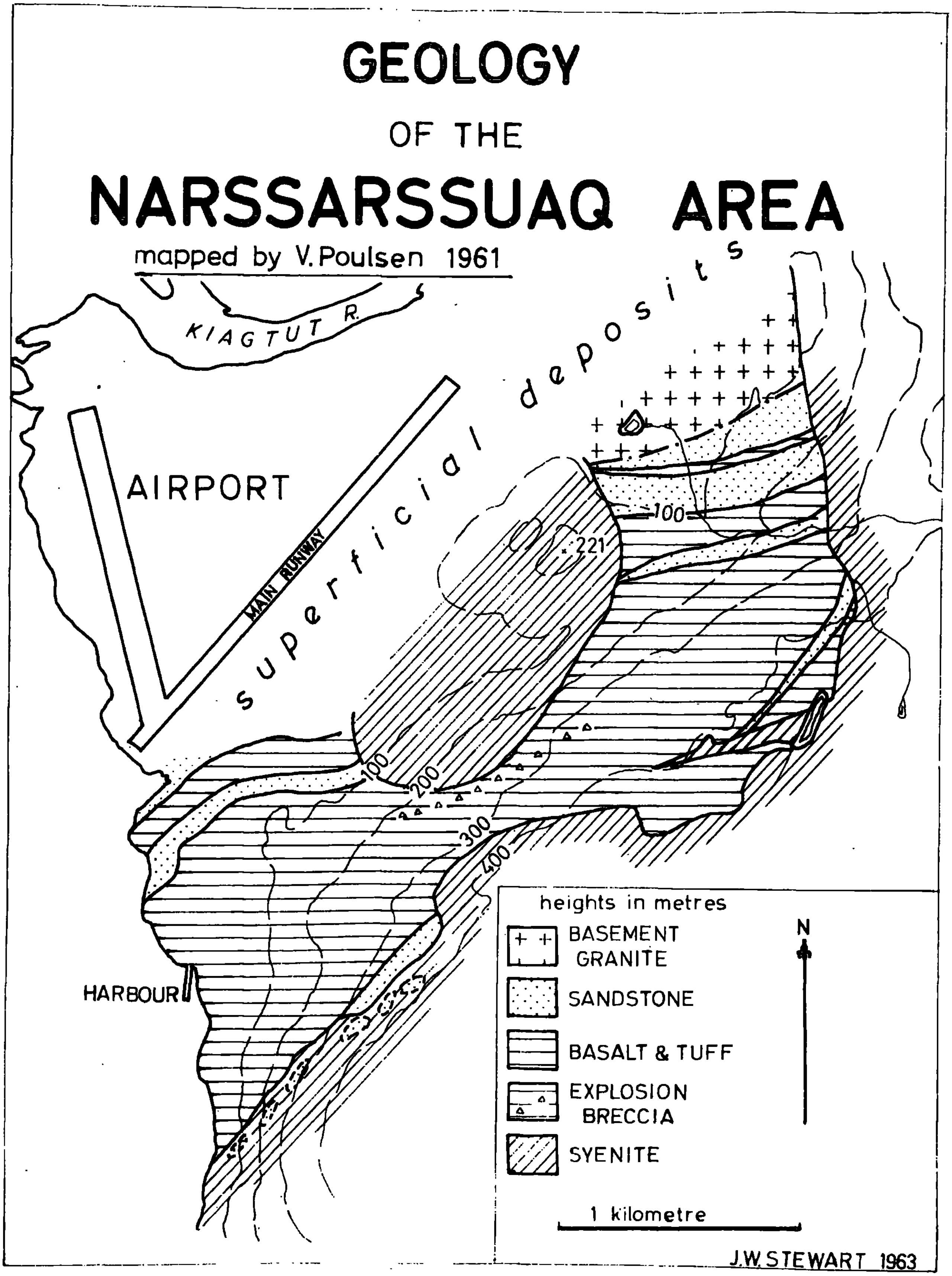

GEOLOGY
OF THE
NARSSARSSUAQ AREA
mapped by V. Poulsen 1961
KIAGTUT R.
superficial deposits
AIRPORT
MAIN RUNWAY
100
221
100
200
300
400
HARBOUR
heights in metres
N
BASEMENT GRANITE
SANDSTONE
BASALT & TUFF
EXPLOSION BRECCIA
SYENITE
1 kilometre
J.W. STEWART 1963

Fig. 6.2.

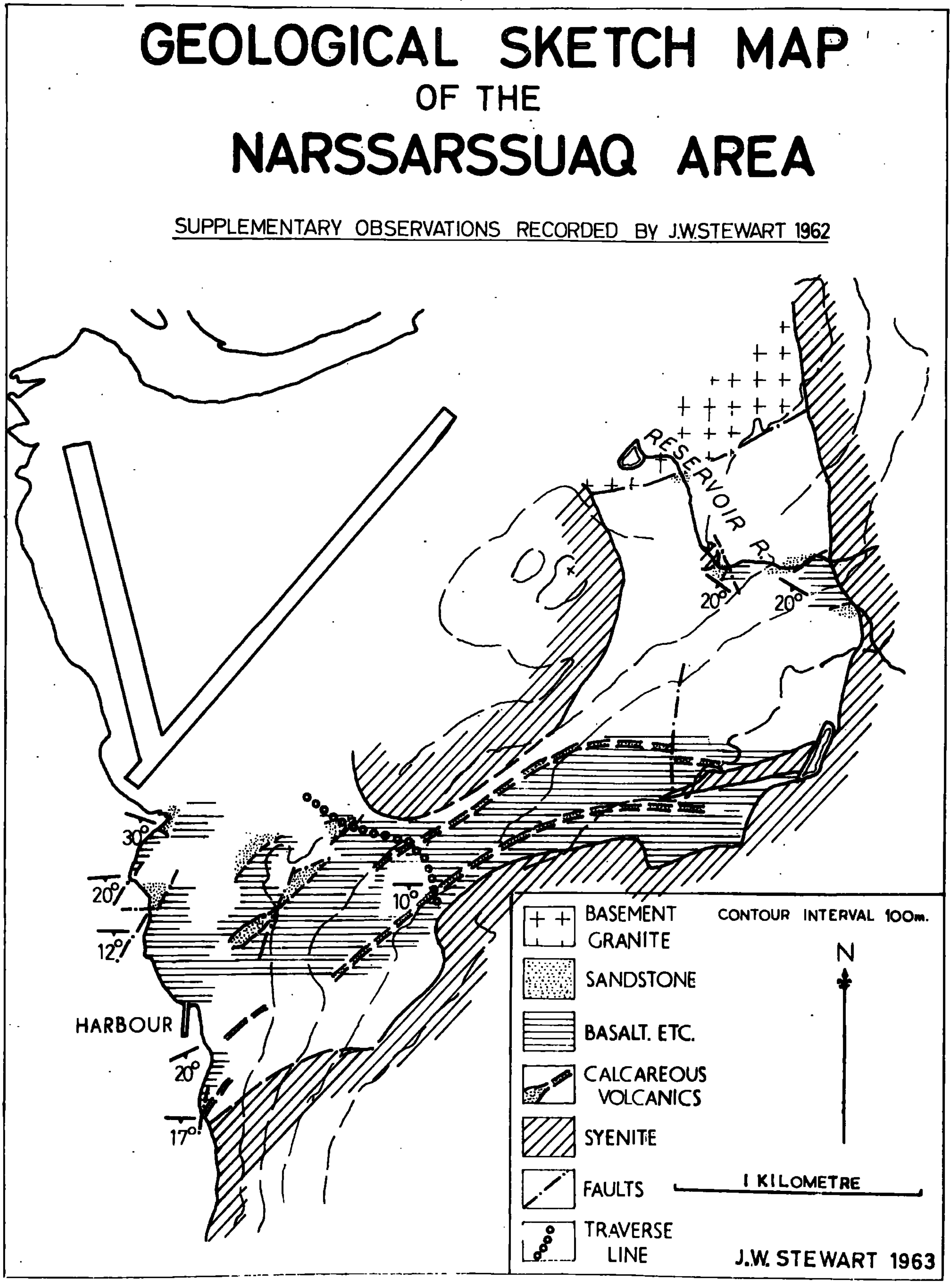

GEOLOGICAL SKETCH MAP
OF THE
NARSSARSSUAQ AREA
SUPPLEMENTARY OBSERVATIONS RECORDED BY J.W.STEWART 1962
RESERVOIR R.
HARBOUR
30°
20°
12°
20°
17°
10°
20°
20°
BASEMENT GRANITE
SANDSTONE
BASALT. ETC.
CALCAREOUS VOLCANICS
SYENITE
FAULTS
TRAVERSE LINE
CONTOUR INTERVAL 100m.
N
1 KILOMETRE
J.W. STEWART 1963

Fig.6.3.

CHAPTER VI. THE NARSSARSSUAQ AREA.

(a) GEOLOGY.

About three square kilometres of stratified Gardar sediments and volcanics outcrop immediately south-east of Narssarssuaq Airport. The strata strike approximately east-west, dip regularly to the south at an angle of 20° and outcrop on the north-west-facing slope which stretches from the gravel flats of the Kiagtut River estuary up to the margin of the Igaliko Nepheline Syenite Complex where the ground begins to level off at about 400 m.. Much of the slope is very steep or precipitous and south of the Harbour the land plunges almost vertically into the waters of the fjord.

The greater part of the area is mantled by soil or scree, both of which support a prolific growth of vegetation, in particular willow scrub, which is often head-high or considerably taller, seriously impeding movement and observation. These willow bushes seem to grow regardless of relief and persist with remarkable tenacity on the steepest gradients.

The amount of outcrop is very restricted indeed and continuous exposure over more than a few tens of metres is rare, away from the coast and Reservoir River sections. In both these places the strip of exposure is exceedingly narrow and liable to occasional interruption.

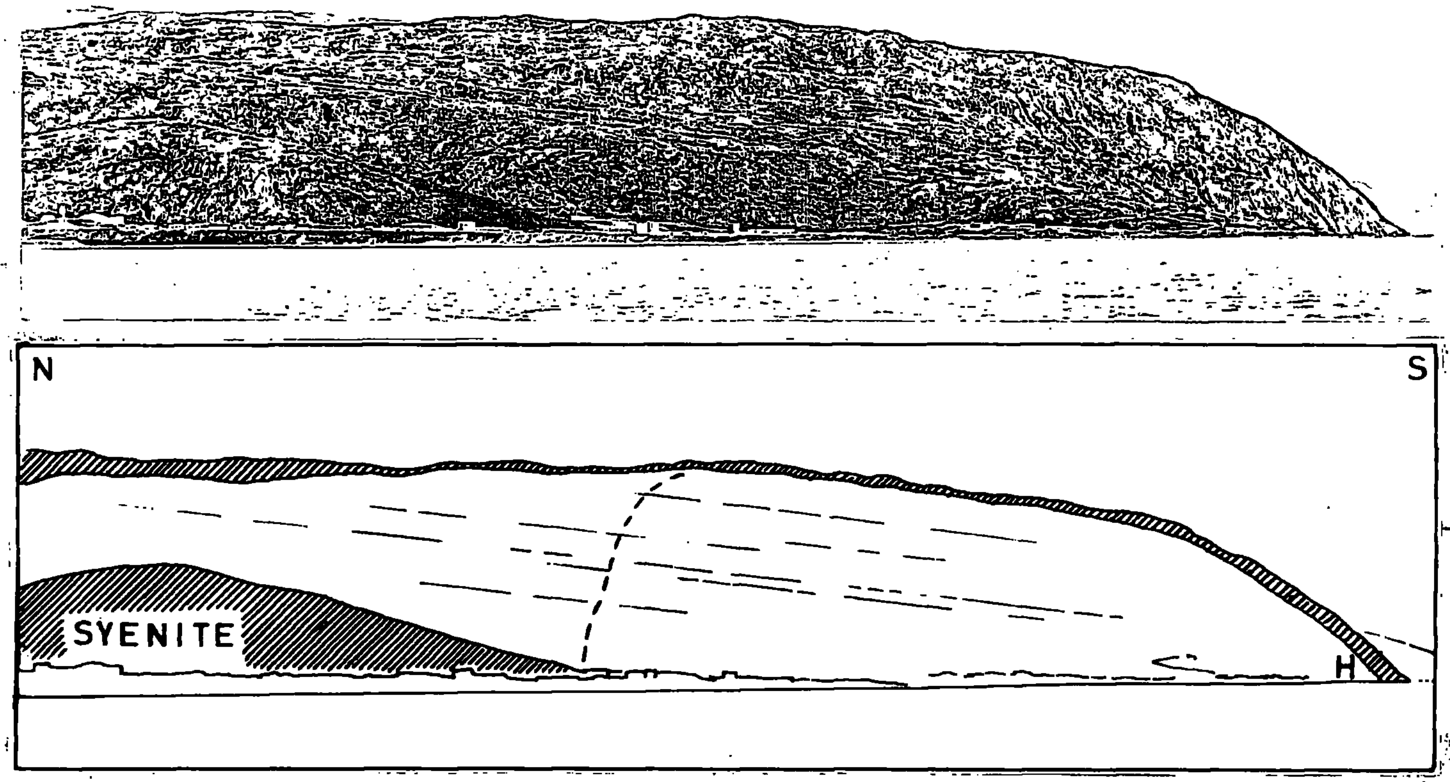


Fig.6.1. Narssarssuaq from the west. Note regular stratification of the sediments and volcanics. Harbour is at H. Dotted line shows location of measured section in Table 6.1.

Table 6.1

Stratigraphical Succession on Hillside above Narssarssuaq.

For Location see Fig. 6.3

Because of various considerations of relief, vegetation and available exposure, the Measured Section was taken almost directly uphill, i.e. in a south-east direction, at a considerable angle to the strike of the strata. The thicknesses of the major layers (e.g. thick sequences of basalt) are recorded simply as the difference in altitude between base and top; there is no doubt that this value may depart considerably from true thickness on occasion.

In the case of thinner beds, with thicknesses of up to about 5 m., true thicknesses are recorded; these were estimated visually. It is possible that minor stratigraphical layers have been missed out.

TOP

Metres	
	The contact with the intrusive syenites at ca. 350m. is not exposed.
330-350	Compact metabasalt.
325½-330	Calcareous tuff, locally agglomeratic, with marked cross-bedding (Fig. 6.4). At the top there is a 5 - 10 cm. thick layer of fine greenish rock

containing large, round quartz grains. This may be comparable to the "tilestone" of other areas. Total 4½ m..

324½-325½	Fine grained, green quartzite, 1 m..
323-324½	Calcareous tuff. 1½m..
320-323	Strongly cloven metabasalt. 3m..
281-320	Compact metabasalt.
280-281	Finely banded green and purple chert-like rock with a 5cm. layer of pale grey limestone 30cm. up from the base. $90^{\circ}/10^{\circ}$S. 1m..
263-281	Basalt with occasional vesicles.
260-263	Coarse, calcareous lapilli tuff, locally agglomeratic. 3m..
250-260	Black, vesicular metabasalt. The basal part is pale pink and has a knife-sharp contact with the underlying black basalt.
240-250	Metabasalt with occasional small vesicles. Partings at 10cm. intervals.
235-240	Massive, pale grey basalt. 10cm. partings in upper part.
225-235	Bedded sandstone, poorly exposed.

100-235 Basalt.

70-100 Quartzite.

ca. 20-70 Basalt. Possibly faulted against overlying quartzite.

below ca. 20 Reference to the shore section suggests that the basalt may be underlain by sandstone.

BASE

At about 250m. there is a break in the slope and a rather wide, level shelf is developed. The following group of rocks outcrops at essentially constant altitude:

TOP

(vi) Dense black basalt, base not exposed. ca. 2m..

(v) Fine grained, pale green rock, containing large, round quartz grains. (cf. "tilestone" ?). 30 cms.

(iv) Calcareous tuff. 30cms.

(iii) Fine, green rock with large, round quartz grains, becoming shaly toward the top. 30 cms..

(ii) Calcareous tuff. 20 cms..

(i) Sill of dark red microsyenite, with dark blue, finely spherulitic, chilled upper contact. At least 2m..

BASE

- - - - - - - - -

Table 6.2.

Stratigraphical Succession in the Reservoir River, Narssarssuaq.

The contact of the basement granite against Gardar sandstone is exposed in the stream bed at about 70 m.. Although the rock surface is rather deeply weathered, the position of the contact plane can be located to within a few centimetres; it strikes roughly east-west and appears to be steep. No basal sedimentary facies is developed; on the other hand, there is no definite sign of crushing or mylonitisation at the contact. Although the general impression indicates that the boundary is faulted, this is not absolutely certain.

TOP

Metres	
Above 350	At about 350m. the basalt is overlain by quartzite. The thickness of this sedimentary layer is uncertain, since relationships are confused by the intrusive alkaline rocks. It is probable that the sedimentary

layer was only a few metres thick and was succeeded by further basalt.

220-350	Basalt. At 220m. the basalt/quartzite contact is very well exposed. Its disposition is 120°/ 20°S. A short way above this, the main contact of the syenite is reached in the principal east - west stream. A left bank tributary was followed southwards.
180-220	Quartzite, considerably shattered and intruded by syenite.
142-180	Basalt.
140-ca. 142	Quartzite.
120-140	Basalt. At ca. 120m., immediately below a waterfall, basalt is exposed overlying quartzite with a contact plane disposed 125°/ 20°S. Apart from this single outcrop, the quartzite is not exposed and its thickness is unknown.
100-120	Intrusive, fine, red syenite.
70-100	Not exposed.

BASE

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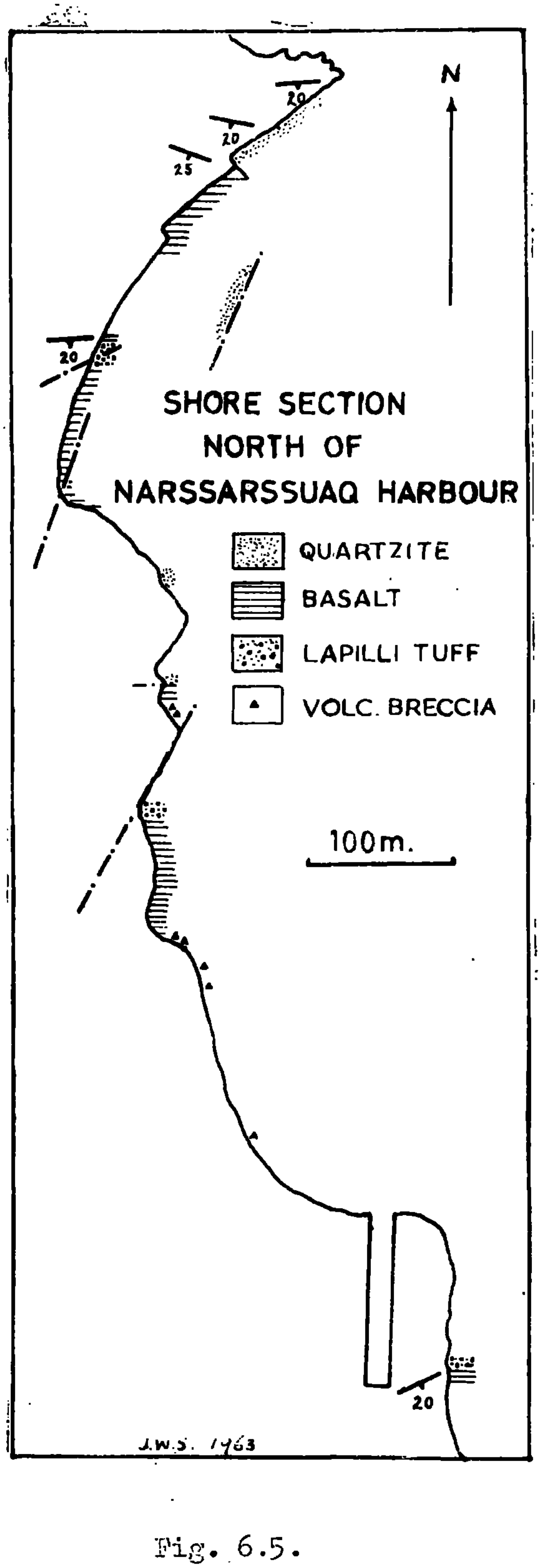

N
SHORE SECTION
NORTH OF
NARSSARSSUAQ HARBOUR
QUARTZITE
BASALT
LAPILLI TUFF
VOLC. BRECCIA
100m.
20
20
25
20
20
J.W.S. 1963

Fig. 6.5.

Fig. 6.4. Cross-bedded calcareous tuff.

Fig. 6.6. Scoriaceous top of basalt flow.

Coast Section North of Narssarssuaq Harbour.

(See Fig. 6.5)

The lowest rock of the sequence which is exposed outcrops 800 m. north of the harbour. It is a well laminated white sandstone with occasional ripple marks. The bedding and lamination strike 100° and dip southward at an angle of 20°. The bed is exposed for about 50 m. along the shore. The uppermost few metres are recrystallised to saccharoidal quart zite.

The succeeding rock is a black basalt, which is chilled against the quartzite at a contact disposed 110°/30°S. The first flow is 5m. thick; of this, the lowest 30cm. is quite massive, but above, the rock becomes increasingly porous. The top 1m. is coarsely scoriaceous. The next flow, although only 2-3m. thick, dips at a very low angle and outcrops for some 50m. along the coast. It is very prous and the top part is notably scoriaceous (Fig. 6.6). The base of a third flow is chilled into this. There is a break in exposure for 40m., beyond which a massive basalt is briefly exposed, overlain by lapilli beds; details of these are as follows:

TOP

(v) Coarse lapilli with abundant large grains of quartz. 50cm.

(iv) Alternating layers of fine sediment and lapilli. 1m.

(iii) Coarse lapilli. ca. 1m.

(ii) Fine sediment. 50cm.

(i) Cross-bedded, fine lapilli tuff. 1m.

BASE

- - - - - - - -

This section is cut by a 65^{o} fault with ca. ½m. downthrow to the S.E. The tuffs are overlain by a basalt layer. The bottom few centimetres are quite porous, upward the flow becomes compact.

Beyond another break in exposure of about 40m., quartzite is exposed for ca. 100m.. A reading $93^{o}/12^{o}$S was taken on the bedding. To the south, the quartzite is faulted against basalt. A crush zone about 1½m. wide is formed, consisting of angular fragments of quartzite in a dark, obscure, quartz-impregnated matrix. The trend of this crush is not wholly certain; it is probably roughly east-west.

The only exposure over the next 100m. or so consists of two small outcrops of volcanic breccia, probably belonging to a diatreme. Beyond a conspicuous mylonite zone, striking 30^{o}, bedded lapilli and fine sediment are developed, followed by dense basalt. The pyroclastics are closely similar to those described above.

Between this point and the Harbour there is scarcely any exposure, but the road cutting, and various small quarries near

Fig. 6.7. Section of basalt flows and bedded calcareous pyroclastics south of Narssarssuaq Harbour. Note irregular segregations of carbonate in basalt at top of picture.

the shore show a succession of basalt flows.

Shore Section South of Narssarssuaq Harbour.

The most southerly outcrops of sedimentary and volcanic strata in the area occur about 400m. south of the harbour mouth and must be approached by boat. Next to the contact with the syenites, the stratified rocks are strongly metamorphosed. The calcareous rock types are devoid of original structures and have been transformed to serpentine marble.

A little way to the north of the contact a section of stratified rocks is very well displayed (Fig. 6.7), although only the lowest 4 - 5m. is accessible to close inspection. The succession is as follows:

TOP

(viii) A compact basalt of unknown thickness. The lowest 1m. is porous, and toward the base approximately 50% of the rock by volume is made up of irregular bodies of carbonate. It is thought that primary amygdaloidal material in the lava has been concentrated and to some extent redistributed by the effects of heat and/or pressure. This lowest part may represent a separate thin flow.

(vii) Pale grey limestone with thin dark partings. 7 - 8cms.

(vi) Calcareous lapilli tuff. Contains numerous platy cleavage fragments, up to 10 cm. long, of limestone and of the underlying banded rock, orientated roughly parallel to the bedding. This layer has the appearance of a reworked sedimentary horizon. 14 cms.

(v) Fine grained green and purple rock with very regular, fine banding. The bottom 5 cm. is unbedded . 50 cms.

(iv) Pale limestone with thin dark partings. 6 cms.

(iii) Fine, banded rock. 2 cms.

(ii) Pale, fine limestone. 2-3 cms.

(i) Porous basalt. A maximum of ca. 2½ m. is exposed.

BASE

\- - - - - - - -

Metamorphism

All the volcanic and sedimentary rocks have been subjected to metamorphism by the Igaliko Nepheline Syenite Complex. A resumé of the alteration effects displayed by each of the principal rock types follows, based on field observations.

(i) Sandstone is converted to quartzite, with a varying degree of recrystallisation. The fine, banded, siliceous tuff or sediment becomes chert-like.

Near the contact with the plutonic rocks the sandstone is metasomatised and partly assimilated by the intrusive syenite with the production of alkali granite which veins both parent rocks.

(ii) Basalt throughout the area is dense, black, fine-grained and tough. The amygdular minerals are recrystallised. A cleavage is sometimes developed parallel to the top and bottom of t he flows. Closer to the intrusive contact the rock is often crossed by a network of fine veins of some unknown material which is more resistant to weathering than the host rock, and extensive brecciation is sometimes seen. The most strongly affected basalts may undergo a colour change, becoming pink or a pale creamy colour. Hornfels, such as is developed at Iganek, has not been recorded here.

(iii) The calcareous pyroclastics have undergone a varying amount of recrystallisation. Structures often survive a surprisingly high degree of metamorphism, although their presence may only be demonstrable in outcrop where emphasised by the effects of differential weathering.

Adjacent to the contact, calcareous material, whether pyroclastic or amygdular, is recrystallised as a coarse, saccharoidal rock, commonly dark grey, but occasionally with pale, yellow - green streaks indicative of a serpentine marble.

Structure

Viewed from the west, the stratification of the Gardar succession appears to be very regular (Fig. 6.1). There is no sign of dislocation; however, faulting in the dip direction would not necessarily be apparent from this side.

The geological map of the area (Fig. 6.2) should be regarded as schematic, for the sandstone/basalt boundaries are largely intuitive extrapolations based on a very limited number of outcrops. It is often uncertain whether boundaries are successional or faulted. Observations made in the Reservoir River section, in particular the disposition of two well-exposed basalt/quartzite contacts, make it quite clear that the strata hereabouts conform reasonably closely to the general dip and strike of the area. The most northerly basalt/quartzite boundaries shown in Fig. 6.2 must therefore be considered erroneous.

(b) PETROGRAPHY

Only six thin sections are available, three of basalt and three of calcareous rocks.

Basalt. All three specimens are from the low ground north of the Harbour.

44471 is a rather coarse type with an undirected fabric of rather broad feldspar laths 1 - 2 mm. long, which have been altered to a fine aggregate of chlorite and sericite. Interstitial pyroxene has been pseudomorphed by a pale green amphibole. About 10 - 15% olivine is indicated by pseudomorphs formed of chlorite and ore. The olivine grains have been irregular in size, shape and distribution. The largest were ca. 1mm. in diameter.

44477 is of a very fine-grained variety of basalt which was probably entirely lacking in olivine. The plagioclase laths are ca. 0.2 mm. in length and the pyroxene has been ophitic. Alteration has been similar to that of 44471.

44475 resembles 44477, but is highly vesicular and more strongly altered. Most of the groundmass has been converted to fine-grained chlorite, sericite, iron ore and sphene. The vesicles, which are very numerous, contain clear carbonate, pierced by occasional large, well-formed grains of sphene and occasionally accompanied by a clear feldspar of low relief, probably albite. Around the periphery, there are sheaves of chlorite fibres and occasional grains of epidote.

Marble. 44472 was collected at the Harbour and 44478 from the contact with the intrusives at 400 m.. Both specimens have a similar coarse, saccharoidal texture and consist principally of carbonate. Many of the other minerals have a rounded habit and poikiloblastic relationships are common. In addition to clear carbonate, 44472 contains iron ore and an olivine with a very large 2V, while in 44478 the carbonate is accompanied by partly serpentinised olivine, garnet, ore and a colourless mica, probably phlogopite.

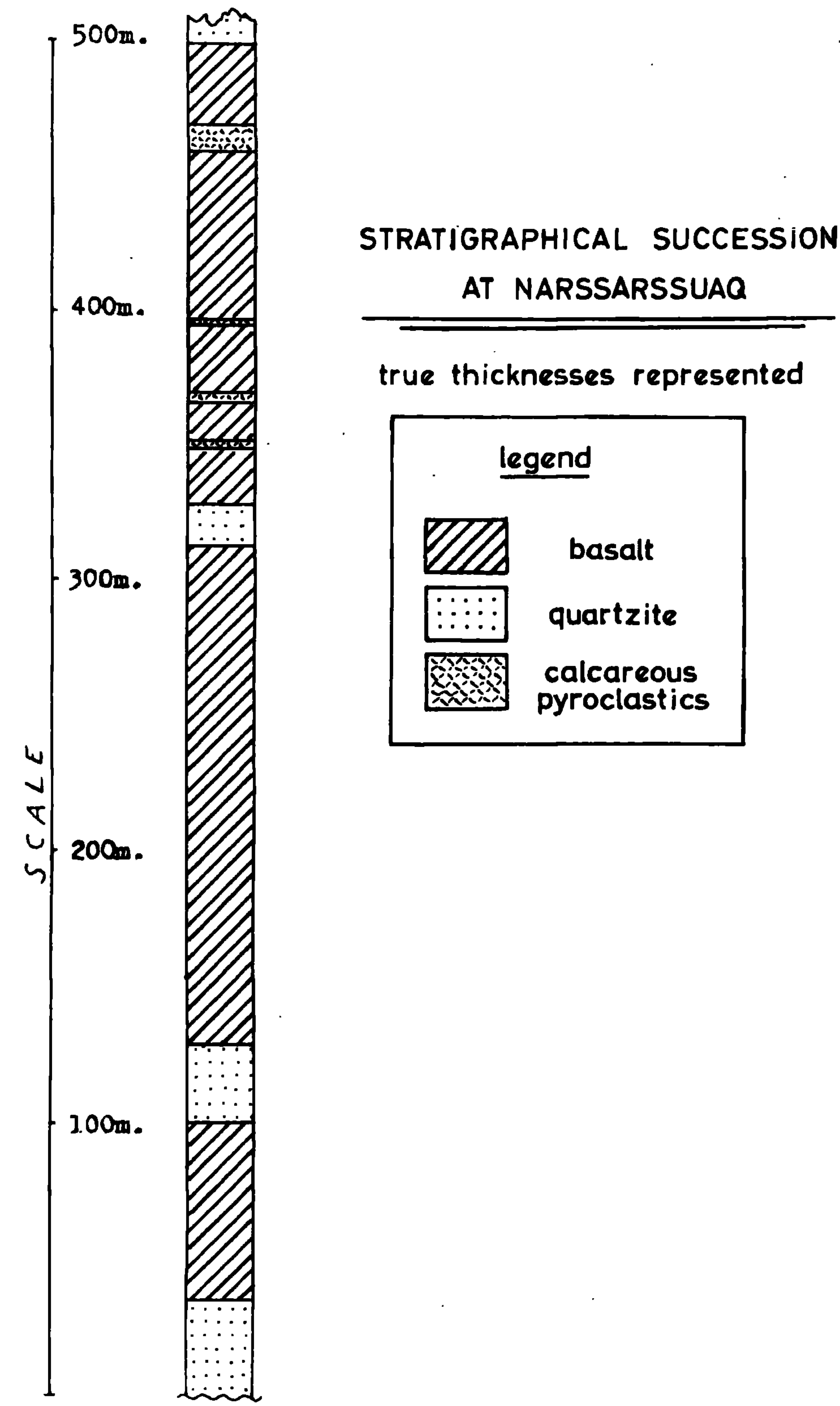
Calcareous Tuff. 44473 was collected above 300m. in the north-eastern part of the area. It is only partly recrystallised, but the original nature of the rock is much obscured. The ground-mass consists of clear, anhedral grains of carbonate, occasional corroded prisms of apatite and some grains of ore which may represent corroded octahedra, in a base of fine chlorite. The inclusions, most of which are well rounded, range from 1 - 5mm. in diameter. Most are of a fine-grained aggregate of chlorite and carbonate with a sprinkling of fine ore grains; analogy with the lapilli tuffs of Qagssiarssuk suggests that these may possibly represent altered monchiquite. A few are of feldspathic rock, consisting of groups of ragged laths of untwinned feldspar of low refractive index, up to 1mm. in length, probably representing lapilli of highly altered basalt.

(c) GEOLOGICAL HISTORY

The total thickness of the stratified volcanic rocks at Narssarssuaq is 400m., constituting more than four fifths of the known succession. Three periods of eruption are represented, each preceded and followed by periods of volcanic quiescence during which water-laid sandstone was deposited; no conglomerate beds have been seen. The sandstones appear to be free of volcanic material and no structures have been observed in the lavas which would indicate that their extrusion was ever other than terrestrial.

The two earlier volcanic sequences contain lapilli beds which indicate occasional phases of explosive vulcanism. The pyroclastics are of basaltic material, presumably derived from the same magma as the flows. In the uppermost volcanic sequence, explosive products occur at four horizons, at least. The pyroclastic material is highly calcareous and may indicate periodic incursions of another magma connected with the lamprophyre-carbonatite association.

All the lavas are basaltic and essentially aphyric.



STRATIGRAPHICAL SUCCESSION
AT NARSSARSSUAQ
true thicknesses represented
legend
basalt
quartzite
calcareous pyroclastics
500m.
400m.
300m.
200m.
100m.
SCALE

Fig.6.8.

VII. OTHER OCCURRENCES OF GARDAR STRATA.

(Refer to Fig. C. in the Introduction)

1. Occurrences in the Tunugdliarfik - Sermilik region.

(i) At Agpat, on the southern shore of Tunugdliarfik, a small area of sandstone a few hundred metres in length occurs at the margin of the Ilímaussaq Intrusive Complex. The bedding is inclined at 25° toward the south-west. So far as is known, marker horizons are absent and the stratigraphical position of the block, with relation to the Gardar Continental Series is uncertain. (Ussing, 1912, p. 71).

(ii) Near the head of Kangerdluarsuk, fragments of sandstone up to 100 m. in length are included in augite syenite near the margin of the Ilímaussaq Intrusive Complex. (cf. Ussing, 1912, pp. 51-52).

(iii) Recently, fairly extensive remnants of Gardar sandstones and pyroclastics have been found adjoining the Igaliko Intrusive Complex some kilometres east of narssarssuaq. (C. H. Emeleus, pers. comm.).

(iv) On the island Igdlutalik, south-east of Narssaq, angular fragments of quartzite have been recorded in a diatreme which pierces the Basement granite (Upton, 1962, p. 39). So far, this is the only instance where sedimentary material has been observed in a diatreme below the level of the Gardar basal unconformity.

(v) In the Tugtutôq central complex, Upton describes the occurrence of quartzite and basalt as "intrusion-brecciated roofing material" in syenites and alkali granites. (Upton, op. cit. p. 46). Examination of a few of the basalt fragments indicates affinity with flows of the '"star" basalt' type found of the Ilímaussaq Peninsula.

(vi) In the Basement granite on the island Qeqertarssuaq, 15 km. east-north-east of Narssaq, Scharbert records a 1.5 m.-thick fissure-filling of wind-blown sand, which may be of Gardar age. (Scharbert, 1963).

2. <u>Occurrences outside the Tunugdliarfik - Sermilik region.</u>

(i) Moltke describes erratic blocks of diabase, red sandstone and porphyry in moraine associated with the more westerly of the two glaciers which reach down from the Inland Ice to the innermost part of Sermilik. He comments on the similarity these rocks bear to the strata of the Ilímaussaq region and

and suggests that Gardar strata may underlie the Inland Ice. (Moltke, 1896, pp. 104-105). The locality is ca. 40 km. north of Narssaq.

(ii) The Nunarssuit Intrusive Complex, ca. 100 km. west of Narssaq, contains abundant meta-volcanic and metasedimentary material as large xenoliths. (Harry and Pulvertaft, 1963). Although the authors favour a pre-Gardar source for this material (op. cit. p. 81), the petrographic description is strongly suggestive of "star" basalt of the Ilímaussaq Peninsula, while the epidote nodules recall the epidote mineralisation found in the Gardar volcanics adjacent to the Ilímaussaq Intrusive Complex (cf. op. cit. pp. 78-81).

(iii) Wegmann (1938, p. 60) refers to two further areas where Gardar strata may be concealed by the Inland Ice. The first is in "the feeding ground of the Sermitsialik Glacier", the second "below the glacier of Kobbermine Bay". These localities lie ca. 50 km. and ca. 90 km. west of Narssaq, respectively. Wegmann's inference is based on the discovery of volcanic and sedimentary rocks among glacial erratics. Investigations by members of the Survey in these areas in recent years indicate that the material is more probably derived from pre-

Gardar formations (cf. Harry and Pulvertaft, 1963, pp. 15 and 16).

VIII. SYNTHESIS AND CONCLUSIONS.

Stratigraphic Correlation.

For purposes of comparison, the stratigraphic succession of the Ilímaussaq Peninsula between Mâjût and Ilímaussaq is taken to be the standard succession for the Gardar Continental Series.

The succession of the hillside south of Igaliko is obviously the stratigraphic equivalent of the Mâjût Sandstone Unit together with the lower part of the Musartût Unit of the Ilímaussaq Peninsula. This is best shown by the nature of the sediments, which include arkosic beds, conglomerate horizons and even a rock similar to "Igaliko sandstone". The succession at Igaliko is somewhat condensed, compared to that north of Tunugdliarfik. Correlation of individual effusive basalt sheets cannot be satisfactorily effected. On the Ilímaussaq Peninsula, the lowest effusive basalt is ca. 800 m. above the base of Gardar while the lowest basalt flow at Igaliko is only ca. 260 m. above the basal unconformity. The basaltic sills are petrographically identical with those of the Ilímaussaq Peninsula and may originally have been in continuity with these.

In the Qagssiarsaq - Tasiusaq area, basalt flows and sills are tentatively correlated with those of the Musartût Unit. The composite volcanic horizon on the peninsula jutting into Tasiusaq closely resembles composite horizons at Igaliko. The "tilestone" at the base of the Calcareous Unit in the Qagssiarssuk Triangle, a rock of highly individual characteristics, is essentially identical to the "tilestone" of the Musartût Unit.

The stratigraphy of the Narssarssuaq area is radically different from that of the other areas. The greater part of the 500 m. succession consists of extrusive basalts, with intercalations of carbonatitic pyroclastics in the upper part. The absence of "star" basalt weighs heavily against correlation with the Ipiutaq or Ilímaussaq Volcanic Units. The carbonatitic tuff has close affinities with the pyroclastics of the Qagssiarssuk area. The Narssarssuaq succession is provisionally correlated with the upper part of the Musartût Unit above Musartût where, in a period represented by ca. 330 m. of strata, at least four thick flows of basalt were erupted and calcareous pyroclastic material ("tilestone") deposited on at least one occasion (possibly on two occasions - cf. Table 1.2).

In the country to the south and west, at Narssaq and Nunasarnaussaq, the stratigraphy of the lower part of the Gardar Series is quite different from that of the Musartût and Igaliko vicinities. At Nunasarnaussaq, the strata underlying the Ipiutaq basalts are condensed to 400 m.; this contrasts with the succession on the main part of the

Ilímaussaq Peninsula where the Mâjût Sandstone Unit, the Musartût Unit and the Naujarssuit Sandstone Unit have an aggregate thickness of the order of 1500 m.. No correlation with individual horizons within these Units can be made.

In sub-area 6 of the Narssaq area, the 300 m. of lower Gardar strata which is preserved resembles the succession of Nunasarnaussaq. A group of alternating thin layers of sandstone and tuff is common to both areas; repeated thin dark horizons in the sandstone of Iganek (north of Igaliko) may represent tuffs of similar age.

It is evident that the thicknesses of the various lithological members of the Gardar succession vary greatly from one area to another. It is also apparent that the stratification in all of the areas is generally very regular. This is well typified by the cliff section above Sermilik (cf. Fig. 1.1). Apparently, the sediments and lava flows were usually laid down on a sub-horizontal surface. Inevitably, minor lateral changes in the succession would occur - - this is shown by the wedging out of the basalt flows in the Nunasarnaq Sandstone Unit. It is likely that pyroclastic cones of ultramafic composition rose above the level Gardar landscape, but only a single example of such a cone has been found (in the Qagssiarssuk Triangle).

To account for the contrasting stratigraphical successions of adjacent areas, it is postulated that the several main areas of Gardar strata are on different fault blocks which subsided, relative to one another, at different rates, during Gardar times. Apparently, the main fault block of the Ilímaussaq Peninsula sank rather rapidly relative to the Igaliko and Nunasarnaussaq blocks. The succession of the Ilímaussaq Peninsula is now strongly downfaulted relative to the strata south of Tunugdliarfik; the base of the Gardar at Mâjût is downfaulted ca. 1400 m. (assuming that the plane strikes east-west and dips south at 10°).

The sites of some of the principal faults involved are now occupied by younger intrusives and by the fjords. It is probable that a 50-60° fault along Tunugdliarfik, with downthrow to the north-west, was active in early Gardar times, prior to the development of the phase of 60° fracturing which marked the main period of dike intrusion in the region.

The important reduction in the succession of the Ilímaussaq Volcanic Unit in sub-area 5 of the Narssaq area, compared with the sequence north and east of the Ilímaussaq Intrusive Complex (cf. Chapter II), may be due to early movements on the 90° fault which cuts across the Narssaq Intrusive Complex.

Faulting.

The regional fault system has yet to be worked out fully and at present only a few preliminary observations of a general nature can be made.

The three main fault directions of the Ilímaussaq Peninsula and the nearby areas are 80°-90°, 50°-60° and 115°. There are strong indications that some of the faults were active over an extended period.

In the Qagssiarssuk - Tasiusaq Area, Gardar strata are enclosed by faults representing all of these directions. The provisional sequence of faulting is as follows:

(i) The development of early 90° faults, forming a graben.

(ii) 60° faulting. The fault at Qagssiarssuk has downthrow to the S.E., the one north of Nûgârssuk has downthrow to the N.W.. The big 60° gabbro dike is not affected by (i).

(iii) The formation of a graben between 115° faults with lateral movement (probably sinistral).

On the main part of the Peninsula, stretching south and west to the intrusive complexes, faulting is restricted to minor, vertical movements of the order of a few tens of metres on 50° - 60° planes.

Faulting in the vicinity of the intrusive complexes is partly related to the emplacement of the plutons; however, two major faults of regional importance also occur, viz.:

(i) The concealed fault with an upthrow of ca. 2 km. to the south, which separates sub-areas (5) and

(6). The strike of this fault must lie between east-west and south-east - north-west.

(ii) The 90° fault which crosses Narssaq Fjeld. This fault was probably active during early Gardar times, with downthrow to the north (see above). Movement at a later stage is indicated by a broad shatter zone which crosses the Narssaq Intrusive Complex. Poor exposure makes the eastward limit of the shatter zone uncertain. There are indications that the Narssaq Intrusive Complex has suffered sinistral displacement by the fault while the western boundary of the Ilímaussaq Intrusive Complex appears to have been affected by a sinistral translation movement of ca. 3 km..

The Gardar strata of the Igaliko Area are bounded to the south by an 80° fault. Observations by Poulsen (1961) indicate movement at two periods, viz.:

(i) sinistral translation with a vertical component. This movement induced drag folding seen in the strata of the narrow fault-block immediately to the north.

(ii) sinistral translation of ca. 800 m. (shown by displacement of a "Big Feldspar" dike). The vertical component is unknown.

The total downthrow of this boundary fault is not known, but it must have exceeded 800 m. in the eastern part of the area.

A 65° fault crosses Iganek, causing a relative upthrow of about 300 m. on the northern side.

Faulting on the Ilímaussaq Peninsula and in adjacent areas appears to have developed in three main phases:

(i) There was a period of early east-west faulting with some sinistral movement.

(ii) Important 60° faults were active along the sites of the present fjords from earliest Gardar times (cf. Upton, 1962, pp. 8 and 9). The Ilímaussaq Peninsula lies in a graben defined by faults along Sermilik and Tunugdliarfik.

(iii) Prior to the emplacement of the alkaline plutons, tension at right angles to the 60° directions led to intense fissuring in the Ilímaussaq Peninsula and Tugtutôq; the fissures were intruded by swarms of dikes. There was very little vertical or translational movement on the 60° fractures of this age. These may be regarded as dilational fractures, possibly induced by arching of the upper crust related to the pressure of the underlying magma.

(iv) Late faulting in 80°-115° directions, including reactivation of early east-west faults. Sinistral translation is usual.

A number of important 115° and 90° faults can be traced for long distances in S.W. Greenland. Most show sinistral displacement, often of several kilometres. Some of these had already been active in pre-Gardar times. The Laksenaes fault, which crosses the Grønnedal - Íka complex, causes a total sinistral displacement of 6 km., made up of three successive movements. Only the latest of these (3 km.) took place in Gardar times (Henriksen, 1960).

Upton, (1962, p. 9) states that on Tugtutôq, east-west faults with sinistral displacement underwent their main movements before the intrusion of the E.N.E. - W.S.W. dike-swarm was initiated.

Regional Tectonic Setting.

The Gardar sediments and volcanics of the Ilímaussaq region formed in an epeirogenic tectonic environment. This is supported by the following facts:

(i) The region has a rigid, consolidated basement of crystalline rocks.

(ii) The region is characterised by block faulting. No thrusting is known.

(iii) Although inclined at various low angles, the strata are virtually free from folding.

(iv) The sediments are exclusively continental deposits. There is no shale, sedimentary limestone nor any evidence of marine ingression.

(v) The volcanic rocks are basic, ultramafic and alkaline varieties. Intermediate types (e.g. andesite) are absent.

(vi) The associated intrusive rocks (syenites, nepheline syenites, kimberlites and carbonatites) are usually confined to epeirogenic areas (cf. Backlund, 1932).

Pre-Gardar tectonegenesis and regional metamorphism resulted in the transformation of the upper crust into a rigid cratonic block which adjusted to external stress by fracture (cf. Wegmann, 1938, Harry and Pulvertaft, 1963). There has been a high incidence of Gardar faulting in the region and differential vertical and horizontal movements have been relatively great.

The main areas of Gardar strata are largely confined within faulted boundaries. In practically every case the basal plane of the Gardar Series is downfaulted relative to the present erosion levels of the surrounding Basement country. Many of the boundary faults were active before and during Gardar times.

The nature of the pre-Gardar erosion surface is eloquently described by Wegmann (1938, pp. 61-62). During a prolonged period of erosion the land was worn to a state of extreme topographic maturity. A system of faults (some of which were already in existence), became active with the onset of crustal widening which heralded the Gardar Period. Adjacent blocks were raised or depressed in adjustment to the regional stress pattern. The elevated blocks became sources of sedimentary material, which was maintained by repeated reactivation of the faults.

The limits of the sedimentary basin in this region are imperfectly known; in some directions, at least, it extended beyond the present limits of the strata. There may have been a system of interconnected basins of great extent.

In the vicinity of the most northerly 115° fault, north of Tasiusaq, Poulsen (1958 and 1961) has recorded very coarse arkosic material which may be reworked fault-breccia. The abundance of arkosic material in the Mâjût Sandstone Unit of the Ilímaussaq Peninsula and at equivalent horizons in the Igaliko area, indicates deposition soon after derivation, implying proximity to the boundary of the sedimentary basin. Elsewhere, the sediments are almost exclusively of pure quartz sandstone and it seems probable that when this material was deposited the source of supply was more remote.

The basalt-alkaline vulcanism.

As a rule, the extrusion of the basaltic and alkaline lavas was unaccompanied by explosive activity. While this may be partly accounted for by the dry desert conditions and consequent lack of ground water, it also indicates that the volatile content of the lavas cannot have been excessive; in particular, the volatile content of these magmas must have been low compared with that of the lamprophyric magmas.

It is not known for certain whether the lavas were erupted through fissures of from volcanoes of central type. On the Ilímaussaq Peninsula and in the country to the south, there is a complete absence of dikes of a composition comparable to that of the effusive basalts. In these areas dike intrusion was distinctly later than the building of the sedimentary and lava sequence. If fissures existed, they must have been confined to the sites of the present fjords. The giant dikes of Tugtutôq (Upton, 1962) were in continuity with the gabbro of Narssaq which was emplaced in the Gardar Continental Series when the total thickness of the latter was in excess of 3 km.. The thick gabbro dike in the upper part of the Ilímaussaq Peninsula is of similar composition and was probably intruded at the same time.

It seems most probable that the lavas were extruded from one or more shield volcanoes. The central alkaline complexes of Ilímaussaq, Tugtutôq and Igaliko may have been emplaced in the sites of the former basaltic necks. The extremely regular stratification of the basaltic lavas, particularly in the Ilímaussaq Volcanic Unit, indicates high fluidity of the magma. The lava cones must have had a very low profile.

The composition of the olivine basalt remained quite constant for a prolonged period and may have survived several phases of local volcanic quiescence. The chemical composition, characterised by high alumina and relatively low alkaline earths, is similar to that found in a number of major and minor intrusives of early and mid-Gardar age (see Table VII). It seems that a basic magma of this composition was characteristic of the Gardar Province.

In the lava sequence of the Ilímaussaq Peninsula, olivine basalt was eventually succeeded by trachyte and rhomb-porphyry. The initial investigation of the latter varieties indicates an abrupt change of the magma type from basic to alkaline, rather than a gradual transition through mugearite and trachy-andesite (ctr. Tomkeieff, 1937). A comparable change in magma type is manifested in the minor and major intrusives of South Greenland, in the former case from basic "Big Feldspar" dikes to dikes of syenitic composition (cf. Upton, 1962) and in the latter from gabbro to augite syenite (cf. Ussing, 1912; Upton, 1962, Harry and Pulvertaft, 1963).

The reverse, i.e. a change of magma type from alkaline to basic, also occurs, almost at the top of the lava sequence. Again, comparable examples can be provided from the intrusive rocks. In the Narssaq area, the sequence of magma types is as follows:

(vii) Alkaline Intrusive Complex.

(vi) Big Feldspar Dikes (Basic).

(v) Alkaline Dikes.

(iv) Gabbroic Sills.

(iii) Basic Lavas.

(ii) Alkaline Lavas.

(i) Basic Lavas.

Intrusion of (vi) and (v) was virtually contemporaneous and composite intrusions of the two magmas are quite common (cf. Upton, 1962, pp. 32-35). At Kûgnât, a ring-dike of gabbro was injected into the alkaline intrusive complex at a late stage (Upton, 1960).

The abrupt change in magma type from basic to alkaline finds a parallel in the Oslo Permian Province (Barth, 1954), but contrasts with Scottish Carboniferous-Permian Province where alkaline lavas and lavas transitional between basic and alkaline in composition have a frequency distribution compatible with derivation from a basic parent magma by fractional crystallisation (Tomkeieff, 1937).

The Lamprophyre-Carbonatite Vulcanism.

Volcanic diatremes with associated intrusive sheets of ultramafic rocks have occurred on a regional scale in many parts of the world at different periods. The tectonic environment seems always to have been epeirogenic. Well known examples of this kind of intrusion are to be found in South Africa, (DuToit, 1954), the Schwabische Alb (Branca, 1894), Scotland (Tyrrell, 1928), Missouri (Rust, 1937) and Arizona (Williams, 1936). A comparable development of ultramafic diatremes on a regional scale occurred in the country between the head of Tunugdliarfik and the outer islands south-west of Tugtutôq during Gardar times. The greatest concentration of diatremes is in the country immediately north of Narssarssuaq and Qagssiarssuk, where, in an area of ca. 100 sq. km., the average incidence of the intrusions is of the order of one per square kilometre. The magma associated with the pipes was a monchiquitic or alnöitic variety in most cases.

In the other regions referred to above, composition is frequently similar, although feldspathoid-bearing types are also quite common. The rocks are often highly carbonated and in some instances there are indications of associated carbonatite. Tyrrell records a block of carbonatite from the Black Rock vent in Ayrshire (Tyrrell, 1955, p. 415).

Stratigraphic correlation in a preceding section of this chapter indicates that the pyroclastic deposits of the areas around Ilímaussaq were probably more or less synchronous and were laid down during the deposition of the upper part of the Musartût Unit. It is known that the diatremes around Qagssiarssuk were active at this time.

Following this phase of intense explosive activity, there is little record of ultramafic vulcanism in the succession. The thin, red, shaly horizon intercalated in the Naujarssuit Sandstone Unit may be a fine calcareous tuff and the flow of monchquite near the top of the Nunasarnaq Sandstone Unit shows that the magma was still available and virtually unchanged in composition.

Three tuffisite diatremes pierce the gabbro intrusion close to Narssaq. Although extremely altered, the rock is identified as a lamprophyric variety.

Provenance of the Magmas.

The Basaltic Magma. The persistence of the basaltic magma of the Gardar Province in time and space points to a source of great lateral extent, in which processes of differentiation were not active; the existence of a basaltic substratum in the region seems to be indicated. The ultimate source of the basalt was a basaltic crustal layer, or the upper part of the earth's mantle (cf. Turner and Verhoogen, 1960, p. 233). There is no record of peridotite nodules in the Gardar lavas.

The Ultramafic Magmas. There is now widespread agreement that the ultimate source of carbonatite is an ultramafic magma, rich in volatiles and enriched in P, Ti and various trace elements, although opinions differ as to the importance of alkalies in this magma (vid. Campbell Smith, 1956; King and Sutherland, 1960). It is also generally agreed that this ultramafic magma is derived from the earth's mantle and that its penetration into the crust is mainly confined to areas of block-faulting and rifting.

The relationships of the ultramafic-silicate and carbonatite rocks of Qagssiarssuk to each other are not wholly clear, but their provenance can be quite well accounted for in terms of the hypothesis of Holmes (1950). Holmes allows that the liquid carbonatite fundamental to the development of the potassic, ultramafic silicate rocks of W. Uganda may originally have been associated with peridotite (op. cit., p. 790).

There is some justification for regarding the monchiquite of the Ilímaussaq region as a magma of parental status. Conceivably, prolonged differentiation of a body of this magma at depth could lead to a segregation of carbonatite in the upper part. Further differentiation, hybridisation, contamination and metasomatic processes could then account for the varied suite of rock types. Von Eckermann (1961) outlines such a process, applied to the Alnö complex.

<u>The Alkaline Magma</u>. The alkaline lavas and dikes of the Ilímaussaq region are undoubtedly genetically related to the alkaline intrusive complexes. A very close resemblance has been noted between the rhomb-porphyry flows, the

porphyritic syenite dikes and a porphyritic marginal facies of one of the syenites of the Narssaq Intrusive Complex. (Author's unpublished results).

Conclusion.

While it is not possible to correlate periods of volcanic activity in the earlier Gardar of the Ilímaussaq region with particular phases of fault movement, it is none the less likely that a close relationship exists between tectonism and vulcanicity.

Occurrences of olivine basalt magma and magmas of lamprophyric and carbonatitic affinities in epeirogenic regions seem generally to be separated in time and space. An exception occurs in the Rungwe volcanic province of southern Tanganyika, where Harkin suggests that contamination of olivine basalt magma by a concealed carbonatite complex is responsible for a suite of highly alkaline basic lavas. (Harkin, 1960).

In the Ilímaussaq region, magmas of the two contrasting types were available for a prolonged period and at times were erupted almost simultaneously. Despite the closest association in space and time, the two magmas appear to have remained quite independent of one another.

The results of the present work, taken with the recent description of a carbonatite-alkaline intrusive complex at Grønnedal-Íka (Emeleus, 1964), suggest that it is time that the origin of the South Greenland intrusive complexes was reappraised in terms of a possible genetic connection with carbonatite. Further comparisons of the Gardar Province with the alkaline provinces of southern and eastern Africa could profitably be made.

Appendix I

X-ray investigation of alkali feldspars.

Preparation of sample. A few ccs. of material were crushed to finer than 120 mesh/inch in a "Spex" mixer-mill and thoroughly washed in dilute HCl to remove carbonate. The powder was then dried and packed into cavity mounts.

Instrumentation. The instrument used was a Philips X-ray diffractometer with generator PW 1010 and goniometer PW 1050. CuKα radiation was used and the tube was run at 40 kV, 20 mA. A discriminator and linear amplifier were also employed.

Procedure. Following preliminary reconnaissance diffractometer traces at $\frac{1}{2}^{o}$/minute scanning speed, the 29°-32° 2θ portion was selected as most informative and rescanned systematically for each specimen at conditions of maximum resolution, viz: scanning speed $\frac{1}{8}^{o}$/minute; slits 1°:$^{1}/_{10}$: 1°: rate meter 2; time constant 8 X 1; chart speed 400 mm. per hour.

For qualitative work the sample was oscillated from 29° to 32° and back again. Where measurements were required two oscillations were made.

Recognition of Phases.

The feldspar of these rocks occurs as three principal phases, present in various quantities and combinations:

(i) Plagioclase (mainly albite) .... triclinic.

(ii) Microcline .... triclinic.

(iii) Orthoclase .... monoclinic.

The peaks were indexed against well-documented examples of triclinic sodic feldspar and monoclinic and triclinic potash feldspar, viz: Microcline: Goldsmith and Laves, 1954 (converted for CuK_α radiation) Sanidine (artificial): Donnay and Donnay, 1952. Low Albite (Amelia): Smith 1956.

Where more than one phase co-exists in the feldspar of the rock, some of the reflections may be so close together that the peaks on the diffractometer trace interfere with one another. This is particularly the case in the central part of the range where strong reflections tend to be concentrated. The (131) peak of microcline, the (131) of orthoclase and the (131) and (02$\bar{2}$) of albite tend to be relatively free of interference and are most suitable for identification. Where orthoclase and microcline are both present, one in very limited quantity, the small (131) peak tends to coalesce with the large (131) peak of the more abundant constituent.

An approximate assessment of the relative abundance of co-existing phases might be made by comparison with a series of rocks in which the characteristic peak intensities are correlated with modal estimates from thin sections. The limited material available in the present case precludes any systematic development of this technique and only the extremes of relative abundance are recognised.

Measurement of Obliquity.

Determination of the obliquity of the microcline is complicated by the presence of a considerable quantity of the albitic phase. The (130) - ($1\bar{3}0$) and (131) - ($1\bar{3}1$) doublets usually employed for this measurement are partly obscured by albite peaks. Although the ($1\bar{3}1$) microcline peak is strongly affected by the ($1\bar{3}1$) albite peak, the (131) microcline peak is often free from interference. While the separation of the (131) - ($1\bar{3}1$) doublet is unobtainable, an alternative measure of obliquity can be found by measuring the movement of the (131) microcline peak relative to some fixed datum position. Parsons (1963), investigating the microcline of perthitic feldspars from Loch Ailsh, found that the position of the ($02\bar{2}$) albite peak was essentially constant in about eighty specimens; it appears to be equally stable in the specimens considered in the present study. Parsons also shows that the movement of each of the peaks of the microcline doublet bears a simple linear relationship to the change in obliquity. In the present instance, the highest obliquity will be found in the microcline with the greatest (131) microcline --($02\bar{2}$) albite separation, this property is referred to as Δ^x in the present work. The maximum (131) microcline --($02\bar{2}$) albite separation found in these rocks is 1.07°. It is interesting to note that the maximum separation found in the Loch Ailsh rocks (op. cit.) is 1.08° and that the mineral in question is believed to be close to "maximum" microcline.

A.1

List of specimens investigated in study of potash feldspathisation

Specimen No.	Locality	Mode of Occurrence
61870	8 km. north of Narssarssuaq	Exfoliation shell in granite
61608	Qordlortoq R. at 80 m.	Inclusion in sheet of nodular uncompahgrite (Fig. 5.2)
61631	Umiussat	Inclusion in nodular lampophyric breccia.
61632	"	Country rock adjacent to above intrusion.
61614	3.5 km. west of Qagssiarssuk	Isolated area of brecciated feldspathised granite.
61615	Large diatreme north of Qagssiarssuk.	Large foliated gneiss block, brecciated, ankerite-veined.
61616	" " " "	Small inclusion in tuffisite.
61617	" " " "	Wall rock, intensely brecciated.

APPENDIX II

X-ray investigation of the carbonates.

Preparation and instrumentation are the same as in Appendix I, except that the acid-wash is omitted. Instrument settings were the same with the following exceptions: scanning speed $\frac{1}{4}^{\circ}$/minute, rate-meter 2.

Earlier routine X-ray diffraction traces showed that many of the rocks contained some quartz. Since quartz was chosen as a suitable internal standard, a little finely crushed quartz was added to the quartz-free specimens, prior to mounting. The specimens were oscillated twice beteen 26° and 32° and the location of the carbonate peaks found by measurement from the quartz (101) peak which appears at 26.66° 2θ.

APPENDIX III

X-ray analysis for trace elements.

The method used was similar to that described by Hirst in a recent paper (Hirst and Dunham, 1963). A Philips vacuum X-ray spectrograph was employed with a topaz analysing crystal. The instrument was used with air-path and scintillation counter since the elements under consideration have high to medium atomic number.

Specimen 61682 was used as a matrix for the standards, since preliminary chart recordings showed that it contained relatively low amounts of the trace elements concerned. Precision was checked by running a series of replicates for each element in one of the samples and reproduceability was found to be satisfactory. Since comparable material with known trace element concentrations was not available, the absolute accuracy of the method could not be checked. However, this method has been used extensively in this Department and its limitations are fairly well known. The accuraay of 61682 is probably very high; that of the other analysed specimens will be more or less accurate, depending on the extent to which the major element composition differs from that of 61682.

61740 is essentially a limestone and its major element constitution contrasts markedly with that of 61682. Mr. C. Rowley of this Department, who was determining trace elements of sedimentary limestone by the same method, kindly included 61740 in his schedule. The results, taken from working curves based on standards prepared from a calcitic sedimentary limestone, were comparable to those obtained by the author.

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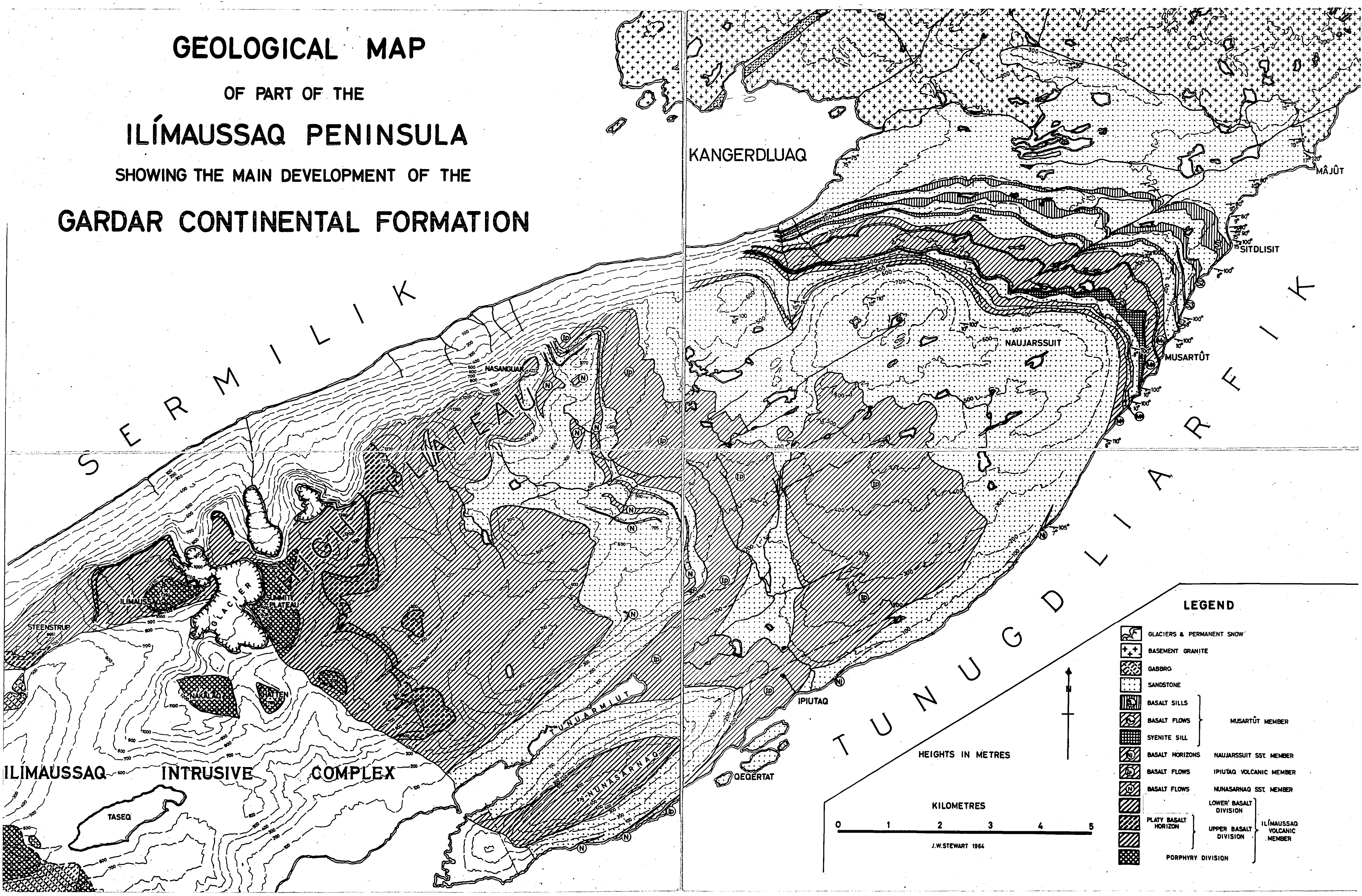
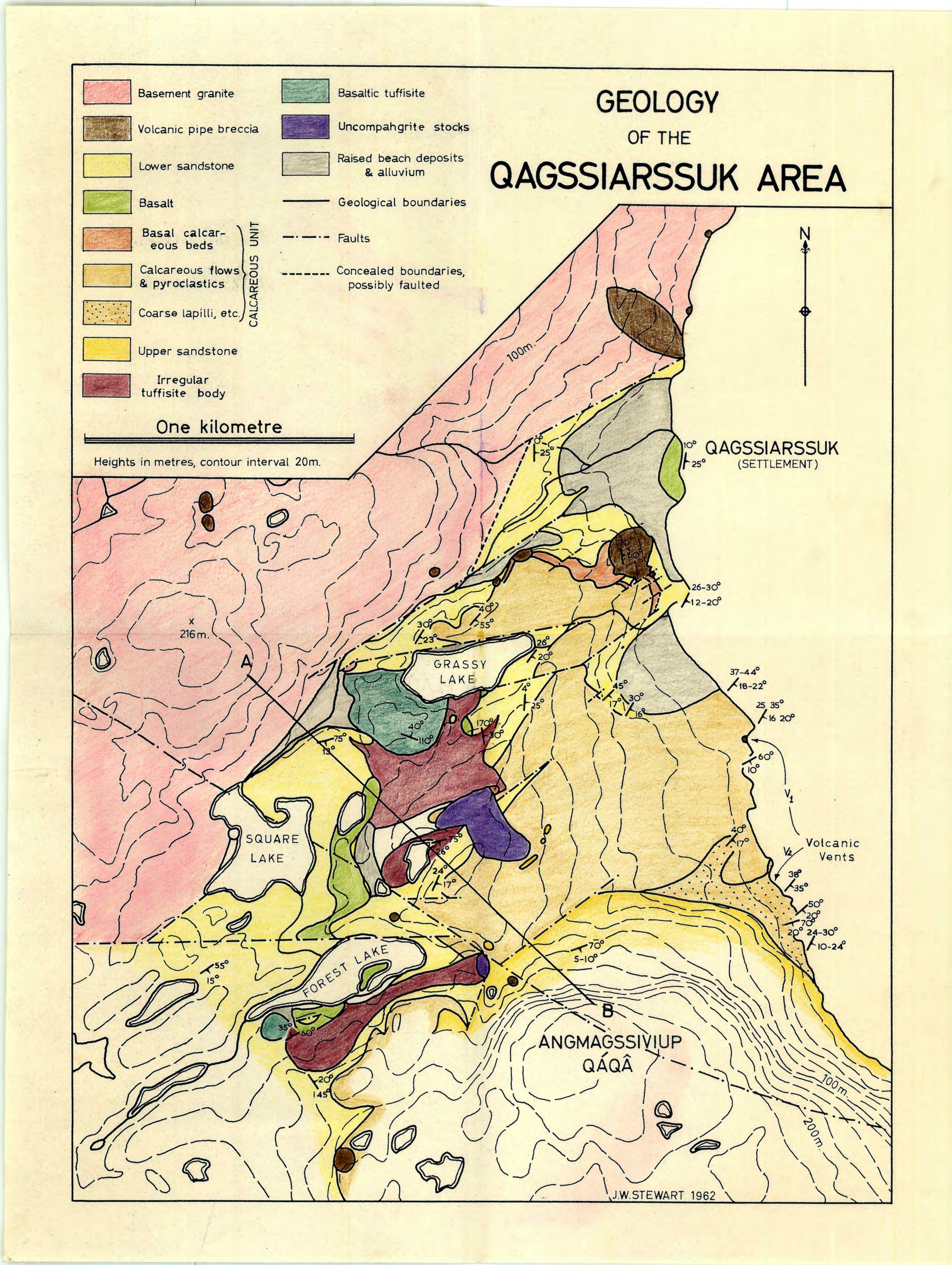


GEOLOGICAL MAP
OF PART OF THE
ILÍMAUSSAQ PENINSULA
SHOWING THE MAIN DEVELOPMENT OF THE
GARDAR CONTINENTAL FORMATION
SERMILIK
KANGERDLUAQ
TUNUGDLIARFIK
MÅJÛT
SITDLISIT
MUSARTÛT
NAUJARSSUIT
NASANGUAQ
IPIUTAQ
QEQERTAT
TUNUARMIUT
NUNASARNAQ
TASEQ
STEENSTRUP
NAKALAQ
HATTEN
GLACIER
ILÍMAUSSAQ INTRUSIVE COMPLEX
HEIGHTS IN METRES
KILOMETRES
0 1 2 3 4 5
J.W.STEWART 1964
LEGEND
GLACIERS & PERMANENT SNOW
BASEMENT GRANITE
GABBRO
SANDSTONE
BASALT SILLS
BASALT FLOWS
SYENITE SILL
MUSARTÛT MEMBER
BASALT HORIZONS
NAUJARSSUIT SST. MEMBER
BASALT FLOWS
IPIUTAQ VOLCANIC MEMBER
BASALT FLOWS
NUNASARNAQ SST. MEMBER
LOWER BASALT DIVISION
PLATY BASALT HORIZON
UPPER BASALT DIVISION
ILÍMAUSSAQ VOLCANIC MEMBER
PORPHYRY DIVISION


GEOLOGY
OF THE
QAGSSIARSSUK AREA
Basement granite
Volcanic pipe breccia
Lower sandstone
Basalt
Basal calcar-eous beds
Calcareous flows & pyroclastics
Coarse lapilli, etc.
CALCAREOUS UNIT
Upper sandstone
Irregular tuffisite body
Basaltic tuffisite
Uncompahgrite stocks
Raised beach deposits & alluvium
Geological boundaries
Faults
Concealed boundaries, possibly faulted
One kilometre
Heights in metres, contour interval 20m.
N
100m.
QAGSSIARSSUK
(SETTLEMENT)
x
216m.
A
GRASSY
LAKE
SQUARE
LAKE
FOREST LAKE
Volcanic
Vents
B
ANGMAGSSIVIUP
QÁQÂ
100m.
200m.
J.W.STEWART 1962