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LEADER: L. R. WAGER

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GEOLOGICAL INVESTIGATIONS IN EAST GREENLAND

PART VIII.
THE PETROLOGY OF THE KANGERDLUGSSUAQ
ALKALINE INTRUSION, EAST GREENLAND

BY

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WITH 17 FIGURES AND 11 TABLES IN THE TEXT,
10 PLATES AND 1 MAP

Abstract

The Kangerdlugssuaq alkaline intrusion, of Tertiary age, intrudes the Precambrian metamorphic complex of East Greenland. It was originally overlain by basalts, now removed by erosion, but into which there was considerable stoping, resulting in the incorporation of large basalt xenoliths within the outer part of the intrusion. The syenite mass, 33 km in diameter, has the form of a pile of saucers, centripetally cooled, decreasing in size and silica content upwards and inwards. The lower outer mass is a quartz-nordmarkite which passes gradually with decreasing quartz content into nordmarkite and a quartz- and feldspathoid-free transitional pulaskite. This passes, with the incoming of nepheline and sodalite, into pulaskite and, finally, foyaite. The nordmarkites constitute some 90 per cent of the whole intrusion. The rocks of all the units are cut by a variety of veins and contain pegmatitic segregations.

The chemistry of the main rocks is discussed with the aid of fourteen analyses; nine analyses of the veins, basalt inclusions and country rocks are also included. The normative compositions of the rocks of the intrusion all occur within the thermal valley of the system $Qz - Ne - Ks$ at $P_{H_2O} = 1000$ bars, representing a transition from an over- to an undersaturated liquid. The original magma is calculated as a quartz-poor nordmarkite.

The petrography of the rocks is described, and modal analyses are given. The main mineral in the intrusion is a low-albite – microcline microperthite with a composition of Or_{38} in the nordmarkites, Or_{36} in the transitional pulaskite, Or_{41} in the main pulaskite, and Or_{55} in the foyaite. The nordmarkites and transitional pulaskite contain phenocrysts of low-albite – orthoclase microperthite (Or_{29-28}); these are also present in the basalt xenoliths but have a composition of Or_{18}, and are very rich in lime (up to An_{12}). The perthites are rimmed with sodic plagioclase (An_4) and constitute up to 90 per cent of the nordmarkites and 50 per cent of the foyaite. Quartz is present in the nordmarkites, the main ferromagnesian mineral of which is katophorite. In the pulaskites, aegirine (ca. Ac_{80}) and biotite accompany arfvedsonite, both in part derived from the alteration of the amphibole. In the foyaite, nepheline and sodalite constitute up to 40 per cent of the rock, with consequent reduction in perthite content. Aegirine-augite (Ac_{30}) and melanite are the main ferromagnesian minerals of the foyaite and both amphibole and biotite are absent or present in very small amounts. Iron oxides (ilmenite in the outer, magnetite in the inner rocks), apatite and sphene are the chief accessory minerals, which include in addition some fluorite, analcite, zircon, perovskite, chevkinite and hiortdahlite; astrophyllite, eudialyte, låvenite and catapleiite are present in the veins.

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I. INTRODUCTION

a) Discovery and Exploration

The Kangerdlugssuaq alkaline intrusion (Map 1) is located on the west side of the large fjord of Kangerdlugssuaq, East Greenland (68°20′ N; 32°30′ W). It was discovered in the summer of 1930 by L. R. WAGER during the boat journey from Angmagssalik to Kangerdlugssuaq undertaken by the British Arctic Air Route Expedition led by GINO WATKINS (CHAPMAN, 1934). The intrusion is exposed in the steep mountains which lie to the west of the middle reaches of the fjord, and is dissected by glaciers and partly concealed by snow fields (Plates 1, 2, 3, and 4). The intrusion forms part of the East Greenland Tertiary igneous province (Fig. 1) but is somewhat younger in age than the layered basic complex of Skærgården (WAGER and DEER, 1939), and the gabbro-syenite complex of Kap Edvard Holm (DEER and ABBOTT, 1965).

The preliminary examination in 1930, of those parts of the intrusion close to the fjord coast, disclosed the presence of nepheline syenite and raised hopes that minerals of economic value might be associated with the rocks of the intrusion. Although a further examination of the area, by WAGER in 1932, during the Scoresby Sound Committee's 2nd East Greenland Expedition led by Captain EJNAR MIKKELSEN, did not confirm the earlier expectation it added further to WAGER's conviction that the Kangerdlugssuaq area was one of exceptional petrological interest.

On returning from MIKKELSEN's expedition WAGER began to plan a small scientific expedition that would provide an opportunity for detailed work on the geology and botany of the Kangerdlugssuaq region. To this end he organized and led the British East Greenland Expedition, 1935–36. This expedition spent from July 1935 to August 1936 at a base constructed on the eastern side of the fjord of Kangerdlugssuaq (WAGER, 1937). During this period the initial examination of the Skærgården, Kap Edvard Holm and Kangerdlugssuaq intrusions was undertaken together with the mapping of some 35,000 km² of the mountain region between the Denmark Strait and the Ice Cap to the north and northeast and south and southeast of the fjord. The geological field work was carried out mainly by L. R. WAGER and W. A. DEER with the assistance of Dr. E. C. FOUNTAINE, medical officer and mountaineer,
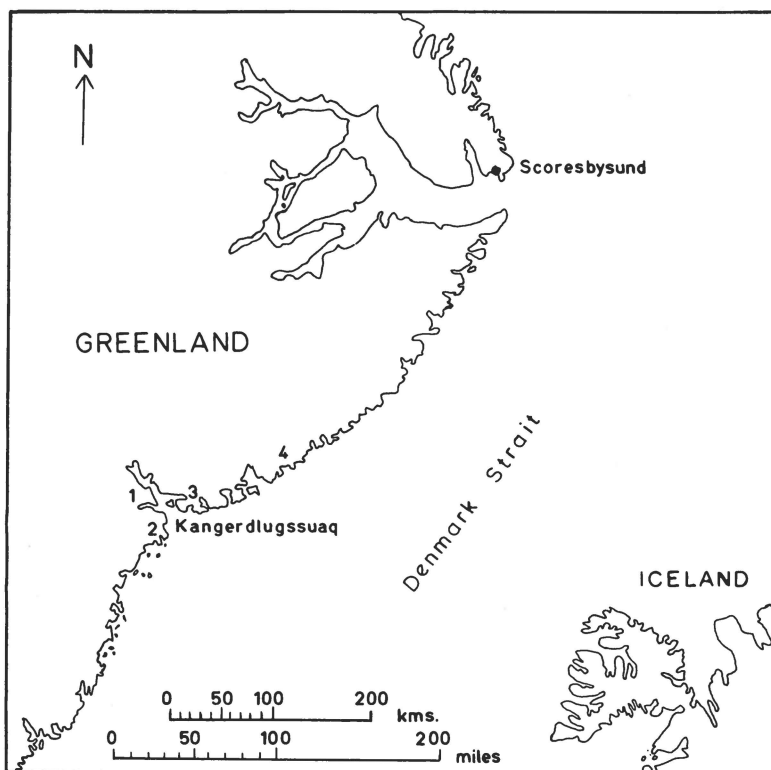
Fig. 1. Small scale map of East Greenland. 1: Kangerdlugssuaq intrusion. 2: Kap Edvard Holm intrusion. 3: Skærgården intrusion. 4: Lilloise Bjerge intrusion.

P. B. CHAMBERS, geological and sledging assistant, and Mrs. L. R. WA-GER. Dr. and Mrs. H. G. WAGER, the other members, were primarily concerned with the botanical aspects of the expedition.

A further expedition was organized by WAGER and DEER who in 1953 led a combined Oxford and Manchester Universities' party, the East Greenland Geological Expedition, to Kangerdlugssuaq, the main object of which was to complete the field work on the three principal intrusions in the area. During this expedition the Oxford members of the expedition which, in addition to WAGER, included Drs. G. M. BROWN (now Professor of Geology at the University of Durham), D. S. WEEDON and C. J. HUGHES, collected further material from the Kangerdlugssuaq alkaline intrusion and completed the mapping of the adjacent Kærven complex. More recently another expedition was planned for the summer of 1966, but before this came to fruition Professor WAGER died on the 20th November 1965. This expedition, the British East Greenland Geological Expedition had, as part of its programme, intended to make a more thorough examination of the veins in the Kangerdlugssuaq

intrusion and particularly those associated with the foyaite. Severe ice conditions in the middle and upper parts of Kangerdlugssuaq fjord during the summer of 1966, however, prevented the completion of this part of the programme.

b) General Geology

The geology of the East Greenland coastal region between Angmagssalik and Kap Dalton has been outlined in a series of six papers. The first (WAGER, 1934) gives a general account of the coastal geology and records the discovery of six plutonic centres at Kap Gustav Holm, Kialinek, Nûgâlik, Igdlutarajik, Kangerdlugssuaq and Lilloise Bjerge respectively. The second paper (WAGER, 1935) deals with the geology of Kap Dalton, the third (WAGER and DEER, 1938) with the East Greenland dyke swarm and coastal flexure, and the fourth with the petrology of the Skærgården intrusion. The fifth paper (WAGER, 1947) is concerned with the stratigraphy and tectonics of Knud Rasmussens Land and the Kangerdlugssuaq region; and the sixth (WAGER, 1965) is a preli-

Table I. *Analyses of Country Rocks*

	A	B	C
SiO_2...................	68.17	47.89	47.61
TiO_2	0.63	1.74	1.58
Al_2O_3.................	16.13	14.36	10.92
Fe_2O_3	0.58	1.63	3.80
FeO	2.09	10.14	7.25
MnO	0.05	0.19	0.19
MgO	1.82	7.28	13.49
CaO	2.07	10.51	8.07
Na_2O	4.40	3.01	2.74
K_2O	3.22	0.22	0.10
H_2O^+.................	0.40	2.76	3.62
H_2O^-.................	0.16	0.10	0.58
CO_2	–	0.19	0.02
P_2O_5	0.31	0.18	0.17
Total	100.03	100.20	100.22

Norms

	A	B	C
q	22.88	–	–
or.....................	19.03	1.11	0.56
ab	37.23	25.15	23.06
an	8.25	25.30	17.24
cor	2.39	–	–
di	–	20.53	17.44
hy	6.94	7.96	17.10
ol	–	10.70	11.69
mt	0.84	2.32	5.57
il	1.20	3.34	3.04
ap	0.73	0.34	0.34
cc....................	–	0.40	–

A. Grey Gneiss, E. G. 1867. Average material, Mellemø, Skærgården (WAGER and DEER, 1939). Anal. W. A. DEER.

B. Basalt. E. G. 383. Altered variolitic basalt. Middle of 18 ft. flow, south point of Hængefjeldet, Kangerdlugssuaq (WAGER, 1934). Anal. H. F. HARWOOD.

C. Basalt. E. G. 1519. Altered olivine basalt. Below the sills at the extreme end of the south side, Mikis Fjord (WAGER, 1934). Anal. H. F. HARWOOD. (Total includes NiO, 0.06; Cl, 0.02).

minary account of the field relations, petrology and origin of the Kangerdlugssuaq intrusion.

The country rock of the whole region is a basement complex of metamorphic rocks. In his earliest account of the area, WAGER (1934) considered that the complex was Precambrian in age. More recently WAGER and HAMILTON (1964) gave the age (K/A) of a hornblende from

the basement gneiss as 2720 m.y. and of biotite (Rb/Sr) as 1600–1800 m.y. The dominant rock type of the metamorphic complex is a banded grey acid gneiss, a detailed discussion of which is given by WAGER and DEER (1939). An analysis of the typical acid gneiss is given in Table I. Feldspar comprises about 64 per cent of the rock, with an andesine plagioclase, 49 per cent, well in excess of orthoclase, 15 per cent; quartz forms approximately 28 per cent of the rock, and biotite and hornblende together some 8 per cent. The biotite is largely chloritized and is greatly in excess of the hornblende; accessory minerals are iron oxide, sphene and apatite. Plagioclase amphibolites and a few garnet-sillimanite gneisses, schists and metabasic masses constitute about one tenth of the metamorphic complex. The Kangerdlugssuaq Sedimentary series (WAGER, 1934; 1947) rests unconformably on the metamorphic complex. This is a thin series of shallow water sediments of late Cretaceous to early Eocene age which occur to the east of Kangerdlugssuaq in the area north of J. C. Jacobsen, Ryberg and Nansen Fjords, and are not found in the region of the Kangerdlugssuaq intrusion.

The rocks of the metamorphic complex and the Kangerdlugssuaq Sedimentary series are overlain by a thick series of early Tertiary plateau basalts, which in J. C. Jacobsen Fjord are some 7.5 km in thickness (WAGER, 1947). The basalts, apart from the area in which the Sedimentary Series is exposed, form a complete cover northeast of the Skærgården intrusion, but to the southwest they have been largely removed by erosion. Small areas are preserved to the west of Kap Edvard Holm, where thick gabbro sills are intruded into the basalts, and a small outcrop of basalt is preserved on the southeast coast of Amdrup Pynt (Plate 2). Basalt also occurs at Trekantnunatakker, to the northwest of the Kangerdlugssuaq intrusion. As basalt xenoliths occur in both the syenite of the Kangerdlugssuaq intrusion and the gabbros and syenites of the Kap Edvard Holm complex (DEER and ABBOTT, 1965), it is probable that the basalts were originally much more extensive on the west side of the fjord of Kangerdlugssuaq. The extrusion of the basalt was followed by a period of plutonic activity which gave rise to the layered gabbros of the Skærgården and Kap Edvard Holm intrusions.

The first plutonic phase was followed by a major tectonic event which produced a relative vertical movement of the coastal mountain belt of East Greenland, and resulted in the development of a major flexure of the crust. Where the flexure is intense it is associated with a dyke swarm which follows the convex part of the flexure. There is no direct evidence that the Kangerdlugssuaq intrusion was emplaced before the crustal warping and dyke swarm developed. To the south of the Kangerdlugssuaq intrusion, however, syenites of the Kap Edvard

Holm complex were emplaced subsequently to the dyke swarm injection as, unlike the adjacent gabbros, the syenites are not intruded by the swarm. Moreover some of these syenites, *e. g.* the fayalite syenite of Kap Deichman, are similar in composition to the Kærven fayalite syenite which is itself earlier than the Kangerdlugssuaq alkaline intrusion but younger than the banded gabbros of Kærven.

The age of the Kangerdlugssuaq intrusion has been determined as 52 ($\pm$2) m.y., which places it in the Lower Eocene (Wager and Brown, 1968).

II. THE FORM OF THE INTRUSION

The surface form of the Kangerdlugssuaq intrusion is roughly circular, with steeply outward dipping or vertical contacts with the rocks of the metamorphic complex (Map 1). It is the largest Tertiary plutonic complex in the region and has a diameter of some 33 km. In outcrop the intrusion consists of a succession of ring-like units which in three dimensions have a saucer-shaped form (Fig. 2). These increase in size downwards, and range in composition from an outer nordmarkite, richer in quartz along the outer margin, through a transitional pulaskite containing neither quartz nor feldspathoids, and a main pulaskite containing
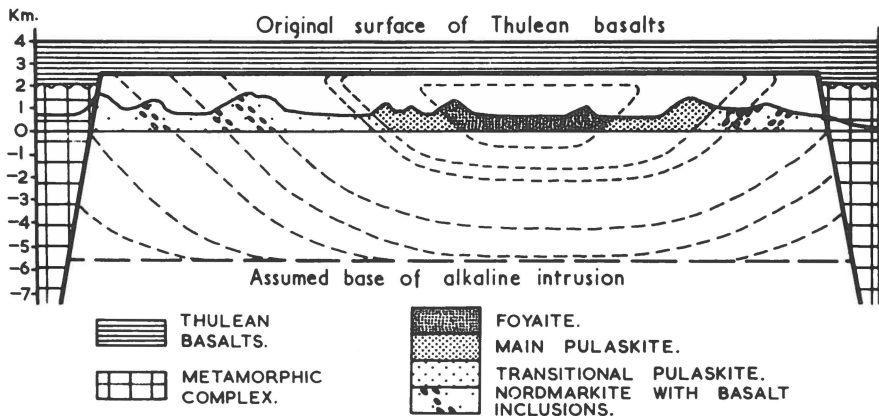
Fig. 2. Section across the intrusion (from WAGER, 1965).

up to 5 per cent feldspathoids, to a central core of foyaite, rich in nepheline and sodalite. The change in the modal composition of the rocks is gradual, and there are no sharp contacts between the various rock types nor other evidence to indicate that the intrusion was formed by successive injections of magmas of different composition. The disposition of the individual units is not symmetrical, thus the width of the nordmarkite ring varies from 11 km along the western margin to 2 km in the east where the intrusion is adjacent to the Kærven complex. In the southeast the intrusion has been partially displaced by the later Snout complex, and the width of the nordmarkite in this area is estimated to have been originally 5 km in width rather than the present $1^1/_4$ km, and

in calculating the area and volume of the intrusion, and in relating specimens to their positions within it, the estimated original value has been used. The transitional pulaskite varies in width from $2^1/_4$ km in the southeast to $^1/_2$ km in the west; similarly, the main pulaskite varies from 5 km in the east to a little over 1 km in the southwest.
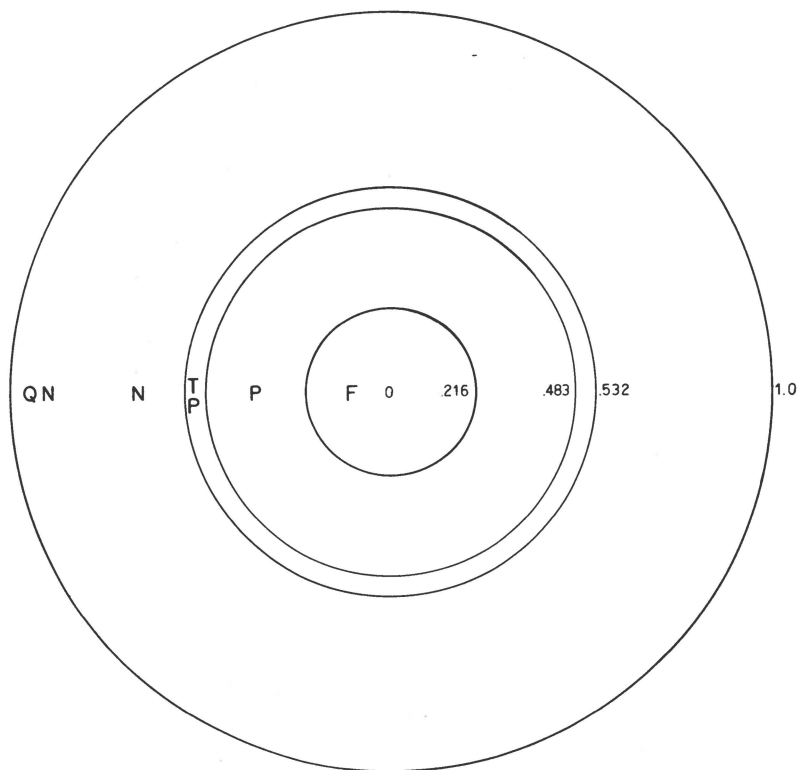
Fig. 3. Diagrammatic representation of the intrusion. The figures give the distance, on a scale of 0 to 1, from the centre to the outer margin of each rock type.

In order to facilitate relating the positions of specimens within the intrusion, their distance from the centre has been measured. In view of the asymmetry of all but the central foyaite unit, this measurement is of little value unless the position within a ring is expressed in terms of the proportion of its distance from the inner margin relative to the total width of the ring at that point. Thus, the measured distance from the centre of, for example, a nordmarkite on the northeast outer margin, in contact with the Kærven complex, is the equivalent of the distance on the west side of approximately a third of the way from the inner margin of the nordmarkite. The proportional method of measurement has been used throughout and the relative distance from the centre is

expressed in all diagrams on an arbitrary scale of 0 to 1, taking 0 as the centre of the foyaite. This plan has been idealized by measuring the areal extent of each ring and converting it into a symmetrical ring and the positions of the boundaries are shown in terms of the 0 to 1 scale (in Fig. 3). Following WAGER's earlier work (1965), no division has been made of the outer ring into quartz-nordmarkite and nordmarkite, and where the prefixes QN and N are used the former refers to the outer and the latter to the inner halves of the ring.

Clusters of basalt inclusions, varying in size from small fragments to blocks measuring hundreds of metres across, are found especially in the outer half of the nordmarkite, and to a much lesser extent in the transitional pulaskite. No such inclusions are found in the two inner pulaskite and foyaite rings. Many of the inclusions are concentrated in zones in which they exceed in volume the enclosing syenite (Plate 5); the zones dip inwards towards the centre of the intrusion at angles of 40–50°. These inclusions provide evidence of the presence of a thick basalt cover at the time of intrusion, and of the stoping mechanism of the magmatic emplacement. Another directional feature of the intrusion is particularly well displayed in the pulaskites north of Søndre Syenit-gletscher; here the tabular feldspars, which constitute the bulk of the rock, exhibit a pronounced parallelism which dips inwards at 30–60°. Sporadic segregations of ferromagnesian minerals into layers with a similar inclination are also found in some of the pulaskites. Elsewhere, as in the north and southwest of the pulaskite ring, a less well-marked parallelism of the tabular feldspars occurs, and is similarly present in some areas of the nordmarkite.

In order to develop the inwardly dipping structures described above, the accumulation of crystals must have proceeded centripetally, upwards and inwards, from the bottom and outer margins. The presence of basalt inclusions in the rocks of the outer rings, in addition to providing evidence of roof stoping also indicates that the products of crystallization did not accumulate to any substantial degree adjacent to the roof of the intrusion. Further evidence of the accumulation of the crystal phases at the bottom and outer margins of the intrusion is shown by the compositional relationships of the aplite and pegmatite veins, which throughout the intrusion are always found cutting a more saturated or oversaturated rock type, indicating that the saturated rocks were solidified at a time when the undersaturated magma was still active.

In addition to the lack of sharp contacts between the various compositional units, field observation during the mapping of the intrusion, particularly in the mountains southeast of Kælvegletscheren, also indicated that the gradational contacts themselves have an inward dip. This concept of successive sloping surfaces on which the basalt inclu-

sions came to rest, and on which the parallelism of the platy feldspars
was developed, is illustrated diagramatically in Fig. 2. From the esti-
mated heights given in the caption to the figure the actual and relative
volumes of the main units were calculated by Wager (1965).

	Wager (1965)	Revised percentages
Nordmarkite...............	5700 km³ (88 %)	90.6 %
Transitional pulaskite.......	250 km³ (3.9 %)	3.5 %
Pulaskite.................	430 km³ (6.7 %)	5.3 %
Foyaite	90 km³ (1.4 %)	0.6 %

These values are given above, together with the results of revised esti-
mates. In calculating the revised estimates the saucer-shaped masses,
representing the four main rock types, are assumed to be spherical
segments and the following formula was used to obtain the new values:

$$V = {}^1/_6 \pi h (h^2 + 3a^2)$$

in which: V = volume
h = height of the spherical segment
a = radius of the spherical segment.

To convert the outcrops into symmetrical rings, as described earlier,
the outline of the intrusion was traced on to stiff paper, and the rings
cut out and weighed; the weights, representing relative areal extent,
were then used to redraw the rings symmetrically. To obtain h in the
above formula, an average dip of 50° was applied to the width of the
rings; the thickness thus obtained gives the height h.

Both calculations give an average composition for the intrusion of
a quartz-poor nordmarkite, and the revised average composition is now
taken as the composition of the initial magma. This estimate makes no
allowance for the veins and pegmatites which are considered to have
an almost negligible affect on the composition; for any gains or losses
of constituents which may have taken place during solidification (Wager,
1965); nor for the basalt inclusions.

If this three-dimensional concept of the intrusion and of the postu-
lated theory of centripetal cooling are accepted, the intrusion is a re-
markably symmetrical and simple structure pluton. The possibility that
the intrusion represents a layered series and the problems of its petro-
genesis will be discussed in a later paper.

III. PETROGRAPHY

In the following sections, the petrography of the four main rock types is described, together with notes on the veins and pegmatitic segregations found within each rock type, and also the basalt inclusions in the nordmarkites. The detailed mineralogical data have been omitted and will be presented subsequently.

a) Quartz-nordmarkite and nordmarkite

The nordmarkites are grey or fawn in colour and are fairly coarse-grained rocks. Perthitic alkali feldspar, in crystals of up to 10 mm in length, forms, on average, 84 per cent of the quartz-nordmarkite and 90 per cent of the nordmarkite. Modes and analyses of some typical quartz-nordmarkites and nordmarkites are given in tables II and III respectively. The locations of the analysed rocks are shown in Fig. 4. The bulk of the feldspar is a low-albite—orthoclase or low-albite—microcline microperthite (mesoperthite); the rocks also usually contain large dark grey crystals, up to 20 mm in length, of microperthite (Plate 6, Fig. 1). The latter were described as cryptoperthite porphyroblasts by WAGER (1965) and considered by him to be derived from the metasomatism of inclusions of the grey gneiss from the metamorphic complex; they are here described as phenocrysts, and these low-albite—orthoclase microperthites are included in the total modal figure for alkali feldspar. They are not always easily distinguished, are sometimes zoned, and are distributed in proportions varying from a few per cent in some rocks to others in which they constitute 65 per cent of the alkali feldspars; locally they are absent. On account of their composition and structure they are now regarded as phenocrysts, and the term fine microperthite is used to describe them; for the 'groundmass' feldspar the term coarse microperthite is used. The average compositions of the two alkali feldspars are Or_{29} and Or_{38} respectively; the coarse groundmass microperthites in the later rocks are more potassic, their compositional range and that of the phenocrysts always being distinct. The coarse microperthites occur as subhedral or euhedral crystals, among which the fine microperthite phenocrysts are irregularly distributed (Plate 6,

Table II. *Modal analyses of quartz-nordmarkites and nordmarkites*

Specimen number	Distance from centre	Number of points counted	Perthitic alkali feldspar	Sodic plagioclase	Quartz	Alkali amphibole	Alkali pyroxene	Biotite	Accessories
			Quartz-nordmarkites						
2784.....	.996	2401	78.3	2.1	14.1	4.7	0.1	−	0.7
1399.....	.996	4126	78.6	8.0	7.1	5.4	0.1	−	0.8
1397.....	.992	1589	87.5	2.3	4.0	4.7	tr.	0.3	1.2
2012.....	.992	2048	89.2	1.0	4.7	3.1	1.0	0.2	0.8
2044.....	.947	2307	87.7	2.9	4.8	2.6	0.6	0.6	0.8
2084.....	.677	2547	87.8	0.4	6.0	3.9	−	0.4	1.5
2779.....	.670	2514	80.9	0.1	12.3	4.2	1.2	0.1	1.2
Average mode			84.3	2.4	7.6	4.1	0.4	0.2	1.0
			Nordmarkites						
1294.....	.650	1768	92.6	2.5	0.5	2.9	−	0.2	1.3
2094.....	.647	1380	87.9	1.1	4.9	4.4	0.9	0.1	0.7
2690.....	.616	2246	90.4	3.7	0.2	3.9	1.0	0.1	0.7
Average mode			90.3	2.4	1.9	3.7	0.6	0.2	0.9

Fig. 2). An irregular border or rim of sodic plagioclase (An_4) usually borders the coarse microperthites, which frequently show simple or multiple Carlsbad twinning.

The main ferromagnesian mineral is a sodic amphibole, katophorite, which occurs in clusters of subhedral crystals, ringed with crystals of ilmenite, sphene, and apatite. The amphibole is pleochroic from greyish-yellow to greyish-green or greyish-blue. It is sometimes zoned, shows anomalous interference colours, and frequently contains small inclusions of the accessory minerals; less commonly the amphibole encloses lines of exsolved iron oxide, 'peppered' along lamellar {100} twin planes. Small inclusions of a similar amphibole, acicular aegirine and biotite occur in some of the phenocrysts of fine microperthite; the coarse microperthites, on the other hand, are generally clear of inclusions. The rocks usually carry a little sodic pyroxene, an aegirine, pleochroic from yellow to dark green, which forms subhedral crystals adjacent to the amphibole. When biotite is present it is frequently intergrown with the amphibole and accessory minerals.

In most of the nordmarkites the ferromagnesian minerals occur in small clusters in which amphibole, pyroxene, biotite, ilmenite, haematite, sphene and apatite form in small 'clotted' masses. Some of the clusters appear to consist mainly of altered amphibole crystals, a relationship which is consistent with the general textural evidence that where re-

Table III. *Quartz-Nordmarkites and Nordmarkites—Analyses*

	1	2	3	4	5	6
Distance from centre	.996	.996	.992	.677	.670	.616
SiO_2	67.98	66.14	64.96	64.81	66.78	64.62
TiO_2	0.55	0.61	0.94	0.80	0.66	0.65
Al_2O_3	15.87	16.49	16.75	17.02	16.19	17.91
Fe_2O_3	1.06	1.85	0.96	1.36	1.48	1.54
FeO	2.29	1.81	2.16	2.05	1.84	1.12
MnO	0.07	0.19	0.16	0.09	0.11	0.10
MgO	0.36	0.48	0.66	0.79	0.50	0.45
CaO	0.35	0.62	0.81	1.28	0.89	0.90
Na_2O	6.02	6.11	6.87	6.06	6.07	7.16
K_2O	4.98	5.32	5.18	4.79	5.11	5.60
H_2O^+	0.16	0.15	0.43	0.11	0.15	0.19
H_2O^-	0.11	0.12	0.04	0.09	0.08	0.01
P_2O_5	0.17	0.18	0.19	0.24	0.16	0.09
Total	99.97	100.07	100.11	99.49	100.02	100.34
Norms						
q	11.93	8.19	2.81	7.31	9.46	–
or	29.43	31.44	30.62	28.31	30.20	33.10
ab	50.94	51.70	57.32	51.27	51.36	60.55
an	0.63	1.86	–	4.78	1.84	0.20
ne	–	–	–	–	–	0.01
cor	0.35	–	–	0.12	–	–
ac	–	–	0.71	–	–	–
di	–	0.03	2.32	–	1.26	2.42
wo	–	–	–	–	–	0.24
hy	3.45	2.32	2.60	3.45	1.89	–
mt	1.54	2.68	1.04	1.97	2.15	2.05
hm	–	–	–	–	–	0.13
il	1.04	1.16	1.78	1.52	1.25	1.23
ap	0.40	0.43	0.45	0.57	0.38	0.21

1. Quartz-nordmarkite, E. G. 2784, small nunatak southwest of Hovedvejsnunatakker. Anal. W. A. DEER and D. R. C. KEMPE.

2. Quartz-nordmarkite, E. G. 1399, coast northwest of snout of Kælvegletscheren. Anal. W. A. DEER.

3. Quartz-nordmarkite, E. G. 1397, immediately northwest of E. G. 1399. Anal. J. H. SCOON.

4. Nordmarkite, E. G. 2084, small nunatak southwest of Trebjørnebjaerget. Anal. W. A. DEER and D. R. C. KEMPE.

5. Nordmarkite, E. G. 2779, Fangetårnet. Anal. W. A. DEER.

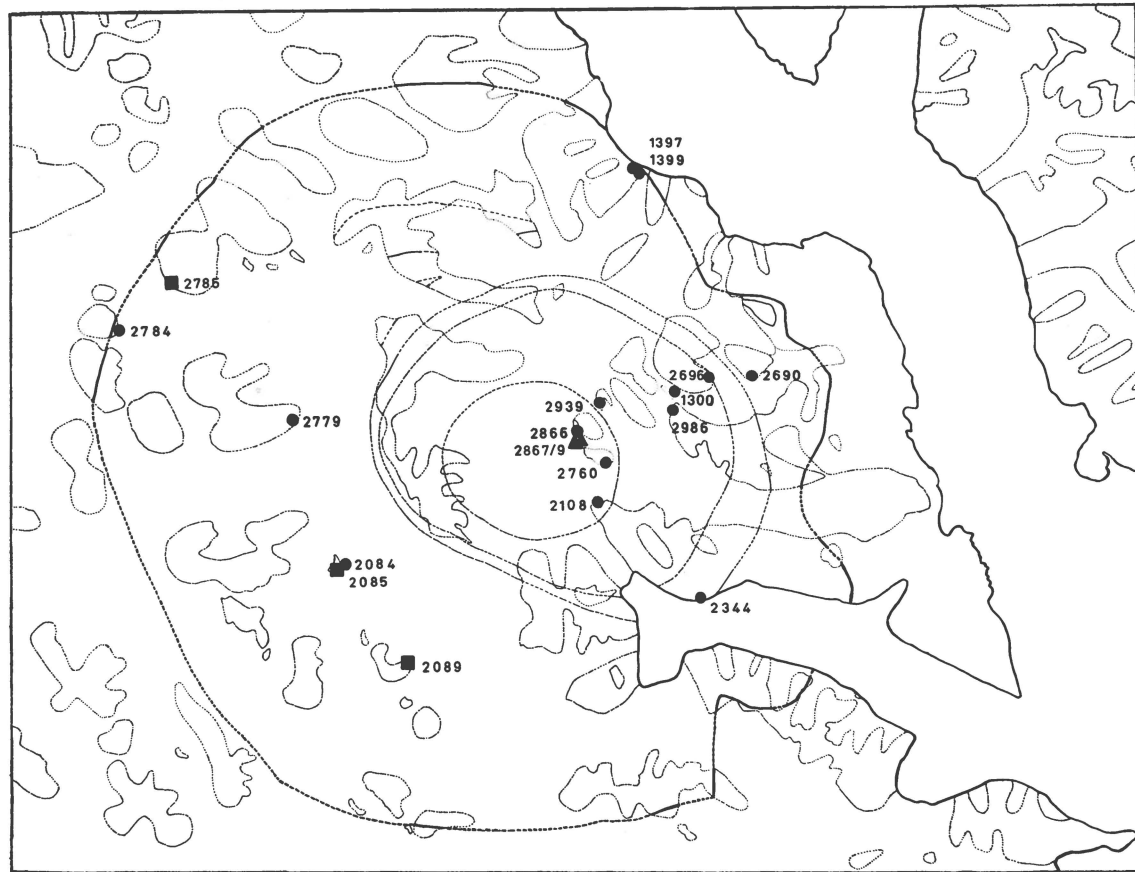6. Nordmarkite, E. G. 2690, nunatak north of Nordre Syenitgletscher. Anal. J. H. SCOON.

Fig. 4. Locality map of analysed rocks (main rocks, circles; veins, triangles; basalt inclusions, squares).

placement has occurred it is amphibole→pyroxene (and biotite). The conversion of ilmenite to sphene has also been observed in several rocks.

Quartz generally has an interstitial relationship with the feldspars and on the textural evidence was the last mineral to crystallize. It decreases in quantity from the outer quartz-nordmarkite border and is absent at the inner limit of the nordmarkite.

The common accessory minerals are accompanied rarely by small crystals of fluorite, perovskite, pyrite, haematite, chevkinite, zircon, astrophyllite and låvenite.

Veins and pegmatitic segregations

The nordmarkites are cut by a number of veins and pegmatites, many of them penecontemporaneous. Some of these are described briefly below.

The typical aplitic veins are medium-grained and consist of euhedral, coarse microperthite, a dark green acmitic pyroxene and arfvedsonite (pleochroic from fawn-yellow to very dark grey-brown). Quartz occurs interstitially, reaching some 20 per cent, and is thus more abundant than in the main nordmarkite. Accessory minerals are scarce and include iron oxide, sphene, fluorite and låvenite. In contrast to the main nordmarkite the amphibole of these aplites is arfvedsonite and not katophorite, evidence that the vein crystallized at a lower temperature and thus later than the main rock. The habit of the quartz similarly suggests a residual origin.

Other aplitic veins are characterized by a high proportion of albite laths and acicular pyroxene, often aligned parallel to the walls of the veins. Others consist of mosaics of quartz and albite, sometimes containing abundant sphene and pale yellow-green pyroxene, and in others, zircon, perovskite and chevkinite.

Occasional glassy veinlets occur which contain abundant small laths and crystals of albite, together with very long acicular pyroxenes enclosed in a glass which makes up 30 per cent of the rock. These veinlets appear to have penetrated between large perthite crystals in the veins. Where basalt blocks are veined by syenitic magma, graphic intergrowths are present, the alkali feldspars of which show curvilinear fractures filled with sericitic alteration material. Large, euhedral pyroxenes, probably of augitic composition, and alkali amphiboles, are enclosed within the graphic intergrowth of quartz and feldspar.

Basalt inclusions

The basalt inclusions (Plate 5) occur in clusters in the nordmarkites and occasionally in the transitional pulaskite. Many have been more or

2*

Table IV. *Basalt Inclusions—Analyses*

	Basalt inclusions		Inclusions with porphyritic feldspars	
	1	2	3	4
No. on diagrams	–	–	17	18
SiO_2	50.77	57.05	62.47	58.12
TiO_2	2.62	1.95	0.86	1.33
Al_2O_3	16.47	16.82	17.75	18.20
Fe_2O_3	3.25	2.02	1.83	2.67
FeO	6.23	4.59	2.25	3.46
MnO	0.14	0.13	0.09	0.14
MgO	4.47	2.87	0.97	1.89
CaO	7.87	5.35	1.61	2.84
Na_2O	5.19	4.93	7.11	7.24
K_2O	1.33	3.85	4.57	3.56
H_2O^+	0.64	0.37	0.12	0.32
H_2O^-	0.17	0.26	0.11	0.08
P_2O_5	0.47	0.31	0.33	0.58
SrO	0.16	0.03	–	–
Total	99.78	100.53	100.07	100.43

Norms

q	–	–	–	–
or	7.86	22.76	27.01	21.04
ab	38.51	41.71	60.16	53.43
an	17.72	12.40	3.03	6.66
ne	2.93	–	–	4.24
di	14.71	9.83	2.28	2.95
hy	–	4.94	1.36	–
ol	6.30	0.89	0.96	3.98
mt	4.71	2.93	2.65	3.87
il	4.98	3.70	1.63	2.52
ap	1.11	0.73	0.78	1.37

1. Basalt inclusion in quartz-nordmarkite, E. G. 2785, Hovedvejsnunatakker. Anal. W. A. DEER. (SrO excluded from calculation of the norm).
2. Basalt inclusion in quartz-nordmarkite, E. G. 2785, Hovedvejsnunatakker. Anal. W. A. DEER. (SrO excluded from calculation of the norm).
3. Inclusion with porphyritic feldspars, E. G. 2089, nunatak northwest of Stakken. Anal. W. A. DEER and D. R. C. KEMPE.
4. Inclusion with porphyritic feldspars, E. G. 2085. Small nunatak southwest of Trebjørnebjerget. Anal. W. A. DEER and D. R. C. KEMPE.

less modified to syenite or microsyenite by digestion in the magma and contain minerals appropriate to both stages in their history. Two analyses of the less modified inclusions are given in Table IV, although by comparison with the composition of the basalts (Table I) they have

undergone considerable alkali, especially potassium, metasomation. The basalt inclusions which contain porphyritic alkali feldspars (Table IV) are more highly modified and are described below.

The large, porphyritic, fine microperthites, dark grey-blue in colour, which occur in these rocks occur in comparable amounts to those in the syenites but in some xenoliths are much larger and are over 50 mm in length (Plate 7, Fig. 1). They are strongly zoned, with a central core rich in sodium and calcium, and become progressively more potassic towards the margins which sometimes merge into the normal coarse microperthite which has replaced much of the remainder of the original basalt. They are crowded with very small inclusions of biotite, amphibole and pyroxene; of the latter two, many are the sodic varieties found in the syenites but others are hornblendes and augitic pyroxenes more characteristic of the basalts. Although, for compositional and crystal-structural reasons these large feldspar crystals are regarded as 'porphyritic' with respect to the enclosing syenitic magma, they are porphyroblasts in relation to the basalt inclusions. They are greatly modified in composition through having grown in altered basalt, in which some may have been nucleated by original plagioclase crystals; their calcium content is higher than in the normal phenocrysts of the syenites, as might be expected, and their potassium content considerably lower. Their average content of Or is 18.5 per cent compared with 29 per cent in the phenocrysts of the normal syenite.

Apart from the fine microperthites the remainder of the digested basalt inclusions (Plate 7, Fig. 2) usually consists of a microsyenitic mosaic of medium-sized microperthite crystals. In one such inclusion the composition of the feldspar is essentially identical (Or_{39}) with the composition of the coarse microperthites in that part of the enclosing rock which contains no inclusions. In this example modification of the groundmass is complete, except for the presence of relict ferromagnesian minerals.

The groundmass of the inclusions contains innumerable small crystals of all the dark minerals occurring in the enclosing syenite: amphibole and pyroxene, with some biotite, iron oxide, apatite (often acicular), and sphene. Some of the pyroxenes are normal basaltic varieties, mantled by a rim of green acmitic pyroxene. Aegirine also occurs as discrete crystals and most of the amphibole is of the sodic type. An approximate analysis of a typical relict basaltic pyroxene was made by electron microprobe analysis and gave a composition within the augite (*sensu stricto*) field.

The basaltic inclusions described above are those which have been highly modified and contain alkali feldspar phenocrysts. All stages, however, in the alteration of the basalts occur, and range from slightly

modified basalts consisting of plagioclase, augite, biotite and olivine, with local development of alkali amphibole, through melanocratic microsyenite to normal syenite.

Xenoliths of gneiss must be extremely rare as only one, associated with a basalt block, was observed during the course of the fieldwork at the southwestern end of Hovedvejsnunatakker. This, a biotite gneiss, contains relict intermediate plagioclase and potassium feldspar, and is partly modified to a microsyenite with alkali amphibole and some pyroxene, in the same way as the basalt inclusions.

b) Transitional pulaskite

The transitional pulaskites differ from the nordmarkites mainly in the absence of quartz. The coarse microperthites have an average composition of Or_{36} and the phenocrysts of fine microperthite, Or_{28}. These compositions are both slightly less potassic than the corresponding feldspars in the nordmarkite and result from the crystallization of the feldspar from a slightly less siliceous liquid. Slight zoning is again present in some of the phenocrysts, and the coarse microperthites are rimmed by sodic plagioclase (An_4), sometimes showing the 'swapped rim' effect (Voll, 1960; Hall, 1966), in which two rims between two perthite crystals show optical continuity between the non-adjacent rim and perthite. Both types of feldspar contain abundant, small inclusions of alkali pyroxene and amphibole, both randomly and linearly orientated. The inclusions in the phenocrysts tend to be smaller, mainly acicular needles of pyroxene, whilst those in the coarse microperthites are larger crystals of both amphibole and pyroxene. Both types of perthite are similar in size to those in the nordmarkites.

The amphibole is a magnesioarfvedsonite, pleochroic from straw yellow-red to greyish-blue or green; it shows patchy extinction and

Table V. *Modal analyses of transitional pulaskites*

Specimen number	Distance from centre	Number of points counted	Perthitic alkali feldspar	Sodic plagioclase	Alkali amphibole	Alkali pyroxene	Biotite	Accessories
2776......	.531	2409	80.6	14.9	2.0	1.8	0.3	0.4
2344......	.519	3225	89.7	0.5	0.2	2.0	4.7	2.9
2356......	.502	2281	85.8	3.3	2.8	1.9	3.6	2.6
2696......	.485	2264	85.8	3.8	0.8	4.7	3.5	1.4
Average mode			85.5	5.6	1.5	2.6	3.0	1.8

anomalous interference colours and is much less abundant than in the nordmarkites (see Tables II and V). The pyroxene, medium green to dark green to yellow and slightly zoned, takes the place of much of the amphibole. Where the pyroxene is adjacent to coarse microperthite crystals it sometimes shows a ragged reaction border which is associated with the unmixing of the perthite. A similar border is exhibited more rarely by the biotite, and the latter, which also takes the place of some of the amphibole, is commonly dusted with exsolved iron oxide.

As in the nordmarkites, the ferromagnesian and accessory minerals usually occur in intergrown clusters (Plate 8, Fig. 1). The common accessories are apatite and ilmenite, the latter often partially altered to sphene which is abundant in the transitional pulaskite. Haematite and låvenite are occasionally present. Basalt xenoliths, except in the northeast, near the Kærven basic intrusion, are absent.

Veins and pegmatitic segregations

The transitional pulaskite contains some of the best examples of pegmatitic veins containing rare zirconium minerals. One such vein, some 12 cm in width, consists of large, coarse, microperthite crystals, of which the composition (Or_{80}) is the most potassic of all the samples measured; subhedral nephelines; large crystals, pools and veinlets of sodalite; and albite laths. The latter either form felt-like patches in which the above felsic minerals are absent, flow between and around them, or are poikilitically enclosed by them. Innumerable acicular laths of a yellow-green pyroxene, nearly pure aegirine in composition, may be associated with the albite or take its place, and have a similar habit, flowing round, or enclosed in, the felsic minerals. The amphibole, an arfvedsonite, is much rarer but occurs as localised clusters of large crystals 5 to 7 cm in length. Biotite and bladed iron oxide occur sparsely, as also do small crystals and patches of astrophyllite, perovskite, låvenite, analcite, fluorite and eudialyte, the latter sometimes forming large red patches or segregations, 8 to 10 cm long.

Long very narrow aegirine needles also occur in large nepheline crystals and have grown from a narrow veinlet of aegirine needles which encircles the nephelines (Plate 8, Fig. 2). Similar veins occur in the main pulaskite.

Other veins consist of euhedral nepheline crystals and a few microperthites porphyritically enclosed in a felt of albite laths interspersed with prismatic crystals of aegirine. Låvenite, commonly twinned, is present in these veins, and in some there are occasional large corroded euhedral haematite pseudomorphs after pyrite. In some veins, microcline cross-hatched twinning is present in the perthites, a feature which is rare in the rocks of the intrusion.

The general characteristic of the veins in the transitional pulaskite is the dominance of albite and pyroxene, the latter with a composition, based on one analysed specimen, of nearly pure aegirine. Nepheline and sodalite, both absent in the host rocks, are common and the rare zirconium minerals are found locally in relatively large amounts.

c) Main pulaskite

The typical pulaskite (Table VI and VII) is grey in hand specimen, and consists mainly of coarse microperthite in which the perthitic lamellae are conspicuously coarser than in the nordmarkites and transitional pulaskite, and from which the fine microperthite phenocrysts are absent. Locally, the pulaskites show a marked parallelism of the perthites, the crystals of which are usually tabular and attain a length of 20 mm. They have an average composition of Or_{41} and are thus rather more potassic than the alkali feldspars of the nordmarkites and transitional pulaskite. Multiple Carlsbad twinning, often comprising six individuals, is common and the twin planes usually are oriented parallel to the fluxion structure. The sodic plagioclase (An_4) rims around the perthites have the same composition as those around the perthites of the transitional pulaskite.

The feldspathoids, nepheline and sodalite, are essential constituents of the main pulaskite; they commonly occur as subhedral crystals, closely associated with and enclosed within the microperthites. Although the sodalite is altered and contains much exsolved iron oxide, the mineral appears to be a primary phase. The ferromagnesian minerals – acmitic pyroxene, magnesioarfvedsonitic amphibole and biotite – are similar to those in the transitional pulaskite and are found in similar proportions, but rather less biotite is present in the rock.

The common accessory minerals are again sphene, which is more abundant than in the transitional pulaskite, apatite, which is slightly less plentiful, and iron oxide. The latter is now mostly magnetite, although some ilmenite is present. The ferromagnesian and accessory minerals again occur in intergrowths and clusters, and there is some evidence that pyroxene replaces amphibole. Fluorite, perovskite, haematite and låvenite occur less commonly than in the transitional pulaskite.

Some pulaskites show a highly developed parallelism of the tabular feldspars and mafic segregations, in which the ferromagnesian minerals, magnesioarfvedsonite, biotite, a little aegirine, and abundant iron oxide, sphene and apatite, have a similar lamination (Plate 9, Figs. 1 and 2). Other mafic schlieren occur including clots of large crystals of sphene embedded in a mosaic of apatites. The formation of the pulaskite is thus

Table VI. *Transitional Pulaskites and Main Pulaskites—Analyses*

	7	8	9	10	11
Distance from centre	.519	.485	.393	.370	.231
SiO_2	61.32	63.04	61.70	61.22	58.97
TiO_2	0.42	0.90	0.80	1.18	0.71
Al_2O_3	21.20	17.92	18.35	18.83	21.21
Fe_2O_3	1.32	2.11	1.63	1.24	1.64
FeO	1.38	1.23	1.62	1.56	1.14
MnO	0.07	0.11	0.32	0.13	0.13
MgO	0.33	0.73	0.61	0.63	0.55
CaO	1.86	0.93	0.95	1.53	1.35
Na_2O	7.58	7.62	7.50	7.32	6.63
K_2O	4.52	5.15	5.53	5.92	6.48
H_2O^+	0.10	0.21	0.73	0.33	0.46
H_2O^-	0.12	0.02	0.04	0.18	0.35
P_2O_5	0.36	0.27	0.08	0.11	0.18
Total	100.58	100.24	100.08	100.18	99.80

Norms

	7	8	9	10	11
q	–	–	–	–	–
or	26.72	30.44	32.69	34.99	38.30
ab	56.53	58.62	52.29	47.26	40.40
an	6.88	–	0.08	1.04	5.62
ne	4.12	2.65	6.05	7.95	8.46
cor	1.32	–	–	–	1.21
ac	–	0.85	–	–	–
di	–	2.22	3.35	3.64	–
wo	–	–	–	0.50	–
ol	1.26	0.55	0.58	–	0.96
mt	1.91	1.71	2.36	1.80	2.04
hm	–	0.63	–	–	0.23
il	0.80	1.71	1.52	2.24	1.31
ap	0.85	0.64	0.19	0.26	0.43

7. Transitional pulaskite, E. G. 2344, Amdrup Fjord. Anal. W. A. DEER and D. R. C. KEMPE.

8. Transitional pulaskite, E. G. 2696, nunatak north of Nordre Syenitgletscher. Anal. J. H. SCOON.

9. Pulaskite, E. G. 1300, western nunatak, Nordre Syenitgletscher (WAGER, 1934). Anal. H. F. HARWOOD. (Includes CO_2, 0.07; ZrO_2, 0.02; Cl, 0.04; SO_3, 0.09; all excluded from calculation of the norm).

10. Pulaskite, E. G. 2986, west end of mountains, south of Nordre Syenitgletscher. Anal. W. A. DEER and D. R. C. KEMPE.

11. Pulaskite, E. G. 2939, small nunatak, north of the head of Søndre Syenit-gletscher. Anal. W. A. DEER and D. R. C. KEMPE.

Table VII. *Modal analyses of main pulaskites*

Specimen number	Distance from centre	Number of points counted	Perthitic alkali feldspar	Sodic plagioclase	Nepheline	Sodalite	Alkali amphibole	Alkali pyroxene	Biotite	Accessories
2850.....	.414	2112	53.4	5.6	7.2	0.5	9.6	5.3	1.2	17.2
1298.....	.400	1557	81.3	7.7	0.8	1.1	1.5	4.1	1.8	1.7
1300.....	.393	1577	80.1	9.7	—	3.2	0.6	3.1	1.8	1.5
2986.....	.370	2488	80.7	6.2	1.8	3.0	2.1	2.1	2.5	1.6
2939.....	.231	4378	79.8	0.9	11.6	3.8	2.0	0.1	0.2	1.6
Average mode			75.1	6.0	4.3	2.0	3.2	3.0	1.5	4.7

marked by a passage from the porphyritic texture of the earlier nord-markites and transitional pulaskite to a structure which persists through-out the pulaskite and foyaite and is more characteristic of a layered series.

Veins and pegmatitic segregations

The veins in the main pulaskite are similar to some of the rare zirconium mineral-bearing veins that occur in the transitional pulaskite. Most consist of a felt of small or medium-sized albite laths containing scattered aegirines and other minerals, which in part display a flow texture around the larger crystals of nepheline, sodalite and perthite (Plate 10, Fig. 1). Locally, the felt of albite gives way to one of analcite or acicular aegirine The rare minerals are patchily developed and cata-pleiite is present in addition to eudialyte, astrophyllite and låvenite. Some albite-rich veins have a microsyenitic texture in which aegirine, arfvedsonite and other minerals are scattered through a mosaic of small perthites and albite laths. Other veins are very similar to the host rock, differing only in their greater richness in feldspathoids.

Some veins, rich in sodalite, are notable for containing two gene-rations of sodalite. The first, which carries exsolved iron ore, is primary, whilst the second occurs in veinlets and is probably secondary after nepheline. In these rocks the aegirine, some of which shows well developed lamellar twinning, can be seen in hand specimen aligned both parallel and normal to the lineation of the vein. A small number of aplitic veins contain a local development of large fluorite crystals enclosing many small crystals of perthite and albite. These veins also contain zircon, an uncommon mineral in the intrusion, and galena.

d) Foyaite

The foyaite is greyish in colour and both the pink nepheline and white sodalite are conspicuous in hand specimen; on weathered surfaces the sodalite occurs as white patches with dark centres. Directional textures are restricted to a weak orientation of the tabular feldspars. In contrast to the very gradual mineral changes that occur during the passage between the rocks of the earlier units of the intrusion, the transition from the pulaskite to the foyaite is marked by a rapid change in the modal content of the main constituents (Table VIII). Thus the amount of both nepheline and sodalite is increased by some 10 per cent and there is a compensating decrease in microperthite, sodic plagioclase, alkali amphibole and pyroxene, and accessory minerals. There is a marked change in the composition of the microperthite, the average composition of which is Or_{55} compared with Or_{41} in the microperthite of the main pulaskite. Likewise the pyroxene, hitherto very acmitic in composition, changes abruptly to a strongly zoned aegirine-augite with distinct core and rim, and in some of the foyaites there is a notable amount of melanite garnet.

Table VIII. *Modal analyses of foyaites*

Specimen number	Distance from centre	Number of points counted	Perthitic alkali feldspar	Sodic plagioclase	Nepheline	Sodalite	Alkali pyroxene	Melanite	Accessories
2765.....	.204	1944	82.5	1.2	11.7	1.4	1.6	–	1.6
2107.....	.191	1588	69.2	0.4	6.9	16.0	2.5	–	5.0
2108.....	.187	2962	65.1	1.3	16.3	13.2	1.5	–	2.6
2760.....	.179	3421	48.9	0.2	23.6	22.8	1.1	2.4	1.0
Average mode			66.4	0.8	14.6	13.4	1.7	0.6	2.5

The typical foyaite, of which analyses are given in Table IX, consists of a mosaic of subhedral microperthite, nepheline and sodalite, with scattered clusters of aegirine-augite and accessory minerals (Plate 10, Fig. 2). The perthites are sometimes tabular and twinned, but the tabular habit is less conspicuous than that of the pulaskite microperthites. The feldspars are also more altered than those of the earlier rocks, and show extensive clouding along the exsolution lamellae, due in part to the presence of a little sericite. Local hydrothermal alteration to cancrinite, gieseckite mica, and calcite is common in the nepheline. The primary sodalite shows considerable exsolution of iron oxide and has enlarged its boundaries at the expense of nepheline and, possibly, also

Table IX. *Foyaites and veins in foyaite—Analyses*

	12	13	14	15	16
Distance from centre	.187	.179	.139	–	–
SiO_2...............	54.48	53.21	55.21	58.06	57.87
TiO_2	0.38	0.29	0.52	0.02	0.08
Al_2O_3.............	24.06	24.78	23.08	21.16	23.45
Fe_2O_3	1.38	1.73	1.89	3.93	1.36
FeO	0.82	0.73	0.87	0.75	0.38
MnO	0.08	0.07	0.11	0.17	0.10
MgO	0.26	0.21	0.30	0.04	0.06
CaO	1.59	1.69	1.88	1.54	0.62
Na_2O	9.95	10.84	8.97	9.99	10.25
K_2O...............	6.68	5.59	6.64	4.82	4.93
H_2O^+.............	0.47	0.75	0.55	0.21	0.59
H_2O^-.............	0.14	0.15	0.14	0.05	0.11
P_2O_5	0.19	0.12	0.24	tr.	0.01
Total	100.48	100.16	100.40	100.74	99.81
			Norms		
q	–	–	–	–	–
or................	39.48	33.04	39.25	28.49	29.14
ab	16.41	18.13	20.96	39.18	38.80
an	1.27	2.46	3.11	–	3.01
ne................	36.71	39.86	29.76	23.20	25.96
cor	–	–	–	–	0.15
ac................	–	–	–	2.21	–
di	1.40	1.13	1.61	0.22	–
wo	1.50	1.54	1.08	3.08	–
ol	–	–	–	–	0.11
mt	1.80	1.74	1.66	2.91	1.32
hm..............	0.14	0.53	0.75	1.16	0.45
il	0.72	0.55	0.99	0.04	0.15
ap	0.45	0.28	0.57	–	0.02

12. Foyaite, E. G. 2108, west end Citadellet. Anal. W. A. DEER and D. R. C. KEMPE.

13. Foyaite, E. G. 2760, nunataks at the head of Søndre Syenitgletscher. Anal. J. H. SCOON.

14. Foyaite, E. G. 2866, nunataks at the head of Søndre Syenitgletscher. Anal. W. A. DEER and D. R. C. KEMPE.

15. Vein in foyaite, E. G. 2867, nunataks at the head of Søndre Syenitgletscher. Anal. W. A. DEER and D. R. C. KEMPE.

16. Vein in foyaite, E. G. 2869, nunataks at the head of Søndre Syenitgletscher. Anal. W. A. DEER and D. R. C. KEMPE.

of feldspar; the secondary sodalite is clearly demarcated from the primary crystallization by the absence of iron exsolution, although it is considerably clouded with other materials. Locally, secondary overgrowth is also displayed by the nepheline, in which faint rings of inclu-

sions within the crystals outline the original crystal boundaries. The zoned aegirine-augite, with a diopsidic core and acmitic rim, occurs singly or in small clusters, together with abundant lamellar-twinned euhedral sphene, magnetite and a little apatite. Where melanite is present it occurs both in single crystals and in clusters, and in some rocks is concentrated in veins or layers. Minor accessories are fluorite, which is common, hiortdahlite, and rarely, eudialyte.

Some of the foyaites contain 1 or 2 per cent of cancrinite and muscovite, and a green biotite in place of the yellow-brown biotite of the pulaskites; all are probably primary minerals. In other specimens of the foyaite some analcite occurs. The presence of nepheline, the hydrated minerals cancrinite and analcite, muscovite, and minerals containing F_2, Cl_2, CO_2 and SO_3, such as fluorite, sodalite, cancrinite and calcite, demonstrates the marked increase in volatile constituents in the foyaite, which is further illustrated by the much greater amount of hydrothermal alteration in the foyaites in comparison with all the earlier rocks.

Veins and pegmatitic segregations

The pattern of veining developed in the pulaskites is repeated to a large extent in the foyaites. In some veins, large crystals of nepheline and, to a lesser extent, microperthite, enclose small albite laths, or are surrounded by a felt of albite crystals and, less commonly, by laths of perthite, but the flow texture seen in the pulaskite veins is rather less strongly developed. Some veins are rich in analcite, others in sodalite, and as in the host rocks, there is much hydrothermal alteration, including the development of cancrinite and sericite. Pegmatitic segregations show a similar texture and mineralogy to the typical foyaite but are distinguished by local concentrations of feldspathoid or pyroxene. The overall composition of most of the pyroxenes is closely similar to that of the aegirine-augite in the main foyaites, but, whilst they are zoned, they lack the strong core and rim compositional change of the pyroxenes in the host rocks. Some albite-rich veins, on the other hand, contain acicular pyroxenes which, although they have not been analysed are, on the basis of their optical properties, closer in composition to the aegirine of the pulaskites.

e) Summary of the petrography

Perthitic alkali feldspar, including the phenocrysts in the nordmarkites and transitional pulaskite, is the main constituent in the rocks of the intrusion. In the most feldspar-rich nordmarkites the content is greater than 90 per cent; it averages 85 per cent in the transitional pulaskite and thereafter decreases to 75 and 66 per cent in the main pula-

Fig. 5. The mineralogy of the main rock types expressed graphically. The widths of the shafts representing the main minerals are approximately proportional to their modal percentages. (Figures in brackets for alkali feldspars refer to the phenocryst compositions).

skite and foyaite respectively, and is as low as 50 per cent in some of the latter rocks. This variation in the feldspar content, together with the distribution of the other constituents in the rocks of the intrusion, is illustrated graphically in Fig. 5. The alkali feldspar is commonly rimmed by sodic plagioclase, the amount ranging from as little as 0.8 per cent in the foyaite to 6 per cent in the main pulaskite. Quartz is restricted to the nordmarkites and amounts to more than 12 per cent in some quartz-nordmarkites; it is present in only relatively small quanti-
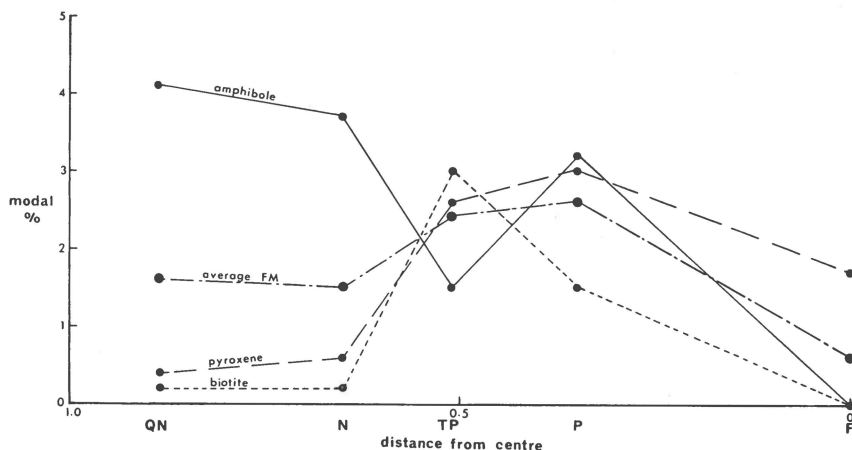
Fig. 6. The average modal occurrence of the main ferromagnesian minerals. The line marked 'average FM' represents a third of the total ferromagnesian minerals in the rocks.

ties in the nordmarkite and ceases to crystallize in the latest rocks of this unit. The transitional pulaskite contains neither quartz nor feldspathoids. The feldspathoids first appear in the main pulaskite, in which as much as 14 per cent of these constituents may be present. Subsequently there is a rapid increase in these constituents and the average feldspathoidal content of the foyaite is 28 per cent.

Nepheline is usually present in greater amounts than sodalite but in some of the rocks of the main pulaskite and foyaite this relationship is reversed. The main ferromagnesian minerals are sodic amphibole, sodic pyroxene and biotite. Amphibole is the most abundant of these constituents in the nordmarkite in which the average content is 4 per cent; it decreases to an average of 1.5 per cent in the transitional pulaskite, rises again to over 3 per cent in the main pulaskite but is commonly absent in the foyaite. Pyroxene is not an important constituent in the nordmarkites but increases in amount to an average of 2.6 and 3 per cent in the transitional and main pulaskites respectively prior to decreasing to 1.7 per cent in the foyaite. Biotite is present only as an accessory
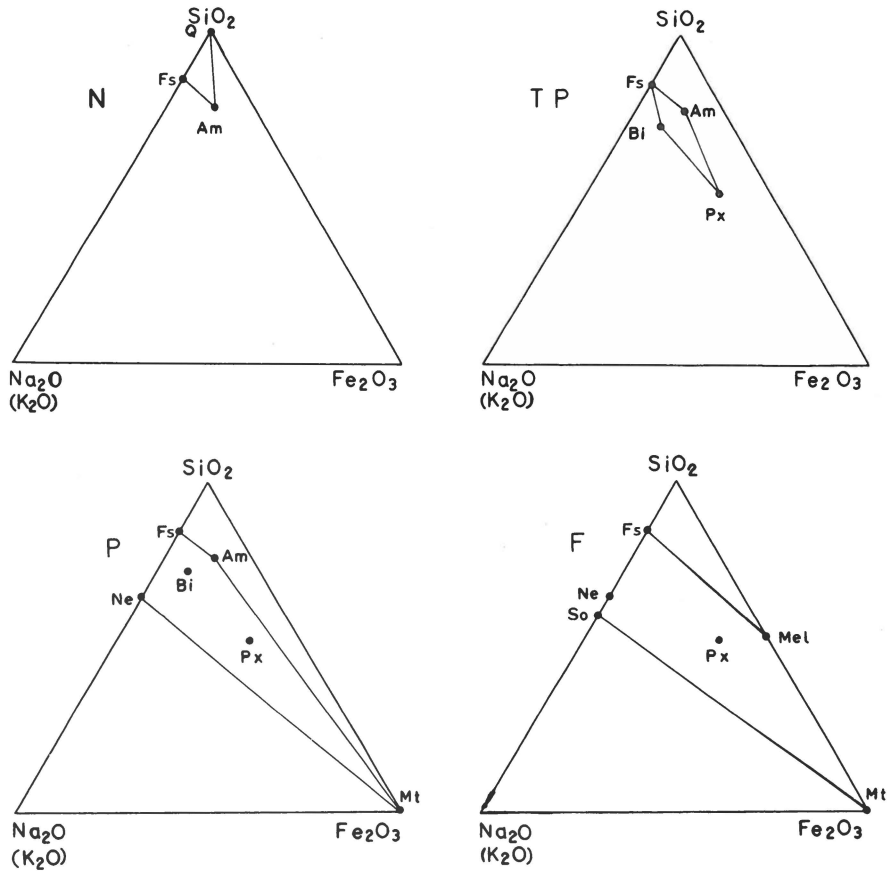
Fig. 7. The mineralogy of the main rock types expressed in terms of $SiO_2 - Na_2O + K_2O - Fe_2O_3$. (Nordmarkites, N; transitional pulaskite, TP; main pulaskite, P; foyaite, F).

mineral in the nordmarkites, increases to 3 per cent in the transitional pulaskite and then decreases to 1.5 per cent in the main pulaskite; it is absent or present in very minor amounts in the foyaite. The variation in the average modal percentage of the three principal ferromagnesian minerals, in the main units of the intrusion, is illustrated in Fig. 6. The figure also shows the mean value of the ferromagnesian minerals, excluding melanite and the accessory minerals. Melanite garnet occurs only in the foyaite and is restricted to the upper parts of that unit. Accessory minerals are present in the rocks of all the units and include iron oxides, principally ilmenite in the earlier and magnetite in the later rocks, with a little haematite in the pulaskite; sphene, most abundantly in the main pulaskite and foyaite; and apatite. Analcite is a relatively common

constituent of the foyaite, which rock also contains some fluorite. The rarer minerals occur throughout the sequence but are especially characteristic of the veins and pegmatitic segregations. Most of the important minerals can be expressed in terms of SiO_2, $Na_2O + K_2O$, and Fe_2O_3. The predominant minerals and most important mineral assemblages, expressed in terms of these oxides, are illustrated in Fig. 7 in which the transition from nordmarkite to foyaite is marked by a progressive shift of the main assemblage fields from the SiO_2 apex towards the $Na_2O +$ K_2O and Fe_2O_3 apices.

IV. CHEMISTRY OF THE SYENITES

The analyses and norms of six quartz-nordmarkites and nordmark-ites, two transitional pulaskites, three pulaskites, three foyaites, two veins in the foyaite, and four modified basalts have been presented earlier in Tables III, IV, VI and IX. Within each of these groups of syenites the analyses are arranged in order of their distance from the centre of the intrusion. Since the saucer-shaped unit are upturned towards the outer margin, and since cooling took place from the outer margin inwards, these steps represent successive stages in the crystallization of the magma in the same way as the rocks, at increasing height, in a basic layered in-trusion represent evolutionary stages in the cooling history of such in-trusions. The semi-quantitative trace element contents of the syenites, basalt inclusions and the basalts and gneiss of the country rocks are given in Table X. The average composition of the intrusion (Table XI) cor-responds to that of a quartz-poor nordmarkite and this composition is considered to represent a close approximation to the composition of the initial magma.

The rocks of the four main units are fairly typical syenites and their average compositions plot within, or close to, the higher contour areas of Fig. 8 which shows the compositional distribution of plutonic rocks containing more than 80 per cent normative Ab + Or + Ne and normative Ab + Or + Q (HAMILTON and MACKENZIE, 1965; TUTTLE and BOWEN, 1958). The compositions of the rocks of the main units are metaluminous in character, except for one transitional and one main pulaskite which are peraluminous; and one quartz-nordmarkite, one transitional pulaskite, and a vein cutting the foyaite, which are peral-kaline, and show acmite in their norms. In metaluminous rocks the molecular proportions of Al_2O_3 exceed $(Na_2O + K_2O)$ but are less than $(Na_2O + K_2O + CaO)$, a feature which is illustrated by the presence of small amounts of normative corundum in many of them. The occurrence of one or more sodic ferromagnesian constituents in the Kangerdlugssuaq syenites is thus not always accompanied by the presence of acmite as a normative mineral. This feature of the syenites is, however, not at variance with the observation of BAILEY and SCHAIRER (1966) that many rocks of peralkaline affinities do not show normative acmite due to the method used in calculating the CIPW norm.

Table X. *Trace elements (semi-quantitative) in some Kangerdlugssuaq rocks, with comparisons*

Rock type	Sensitivity p.p.m.	Ionic radius (Å)	QN	N	N	TP	P	F	A	Basalt inclusions		Ba-salt*	Grey gneiss	B	C	D
Specimen No.....			2784	2084	2690	2696	2986	2760		2089	2085	−	1867			
Distance from centre			.996	.677	.616	.485	.370	.179		−	−	−	−			
Ga³⁺............	1	0.62	25	20	40	40	35	20	29	25	40	20	20	74 (60)	30	15
Li¹⁺	1	0.68	25	60	3	15	15	5	28	40	100	4	20	200 (37)	28	65
Ni²⁺	2	0.69	2	12	−	−	3	3	5	10	8	60	4	3	4	80
Co²⁺	2	0.72	−	−	2	2	−	−	1	−	3	−	6	tr	1	23
Cu²⁺............	10	0.72	<10	<10	20	<10	20	<10	10	<10	10	200	−	16	5	70
V³⁺.............	5	0.74	−	20	20	20	30	70	~20	15	50	200	20	30 (108)	30	150
Zr⁴⁺	10	0.79	1000	1000	200	200	300	500	687	1000	1000	80	250	5500 (4300)	500	220
Sc³⁺	10	0.81	−	−	−	−	−	−	−	−	−	7	−	tr	3	5
Y³⁺	30	0.92	100	200	50	100	80	100	117	150	200	−	−	234	20	28
Sr²⁺	10	1.12	50	500	20	300	200	200	194	1000	2000	200	2000	900 (702)	200	300
La³⁺............	30	1.14	600	300	100	100	100	200	309	200	250	−	30	155	70	18
Ba²⁺............	5	1.33	1500	400	500	3000	200	25	841	1000	2000	−	3000	1100 (680)	1600	250
Rb¹⁺	20	1.47	300	300	70	100	200	150	214	200	100	130	250	10–50 (260)	110	310

* Basalt: Average of three basalts from the Kangerdlugssuaq region (nos. 1057, 1093 and 1112, from WAGER, 1934).

A. Average for the main rocks (calculated on the basis of the relative proportions of the main units of the intrusion; see page 14).

B. Average for the Lovozero massif (VLASOV *et al.*, 1966); figures in brackets after GERASIMOVSKII and co-workers.

C. Average for syenites (TUREKIAN and WEDEPOHL, 1961).

D. Average for igneous rocks (RANKAMA and SAHAMA, 1950).

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Table XI. *Kangerdlugssuaq Intrusion—Average Composition*

		Norm	
SiO_2	65.40		
TiO_2	0.71		
Al_2O_3	16.99	q	5.33
Fe_2O_3	1.40	or	30.74
FeO	1.83	ab	54.83
MnO	0.12	an	1.92
MgO	0.54	di	1.02
CaO	0.86	hy	2.10
Na_2O	6.48	mt	2.03
K_2O	5.20	il	1.35
H_2O^+	0.22	ap	0.40
H_2O^-	0.08		
P_2O_5	0.17		
Total	100.00		

This composition was calculated by allocating the averages of the analyses of the main rock types (QN + N, TP, P and F) in their volumetric proportions present in the intrusion.
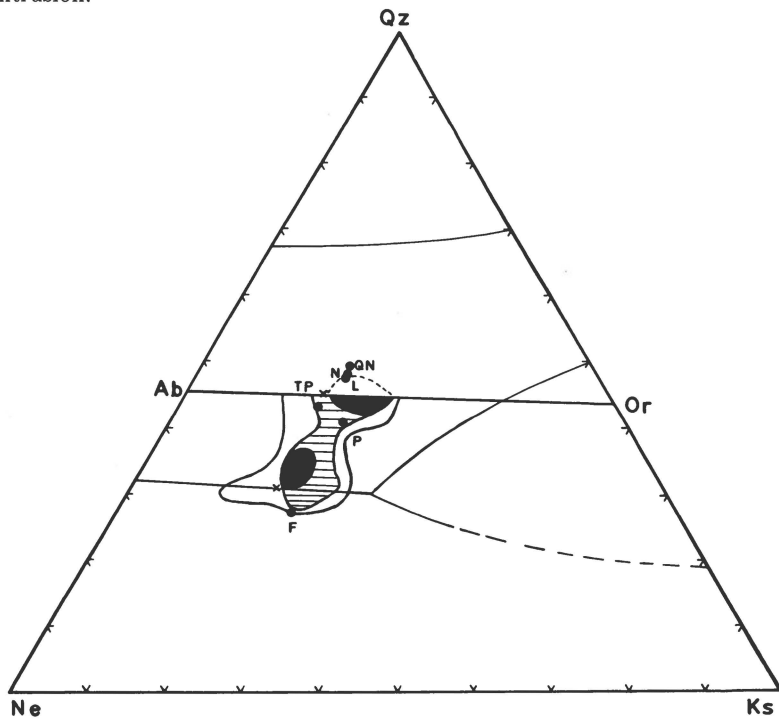
Fig. 8. Averages of rock analyses; normative plot in the system Qz − Ne − Ks, fields drawn as at P_{H_2O} = 1000 bars. Contours are drawn to illustrate the distribution of analyses from Washington's tables of plutonic rocks carrying 80 per cent or more normative Ab + Or + Ne (Hamilton and MacKenzie, 1965) or (dashed line) Ab + Or + Q (Tuttle and Bowen, 1958). ×: indicates feldspar and undersaturated minima.
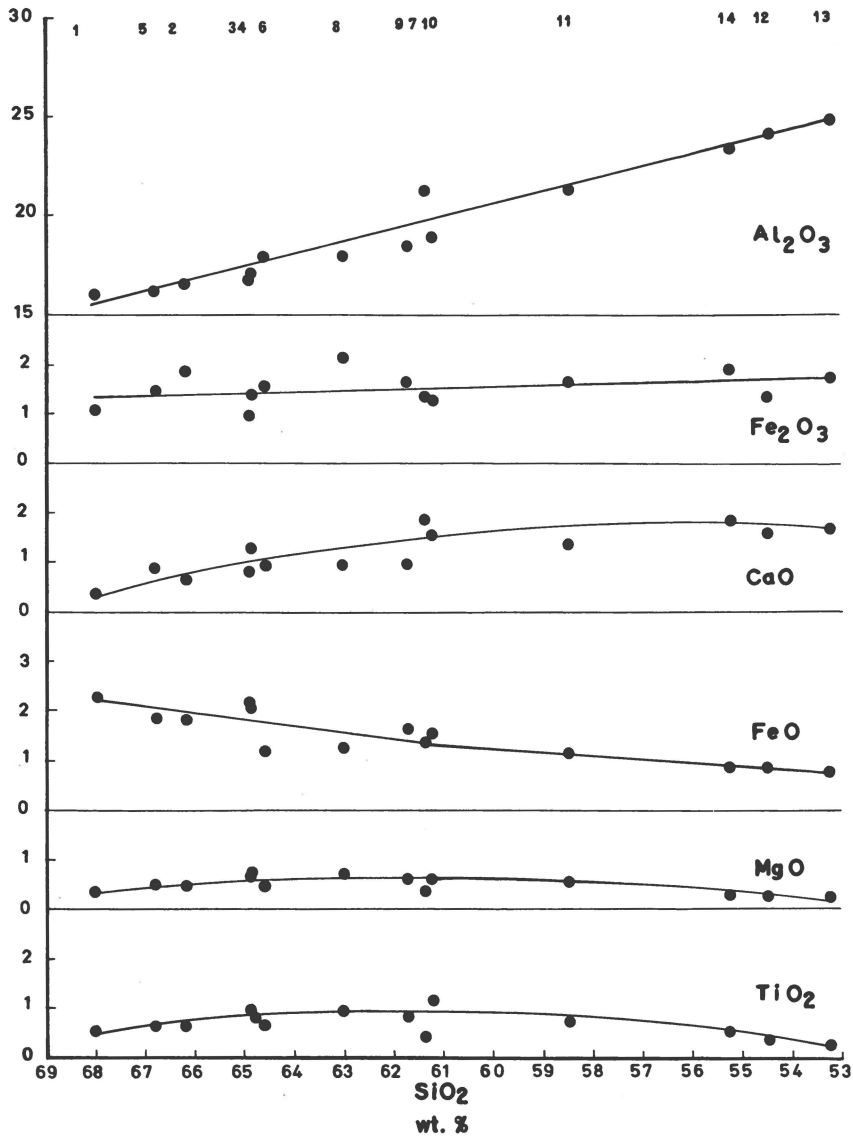
Fig. 9. Oxide variation in the syenites, plotted against SiO_2.

The term agpaitic was first used by USSING (1912) to describe nepheline syenites with a ratio $(Na_2O + K_2O)/Al_2O_3$, expressed as molecular proportions, greater than 1.2. FERSMAN (1929) gave this ratio the name agpaitic coefficient, and this term was later adopted by ZLOBIN (1959) to describe the atomic ratio $Na/(Al - K)$. In a recent discussion of the usefulness of the term agpaitic, NOLAN (1966) favoured the retention of the term agpaitic coefficient but recommended that the division be-
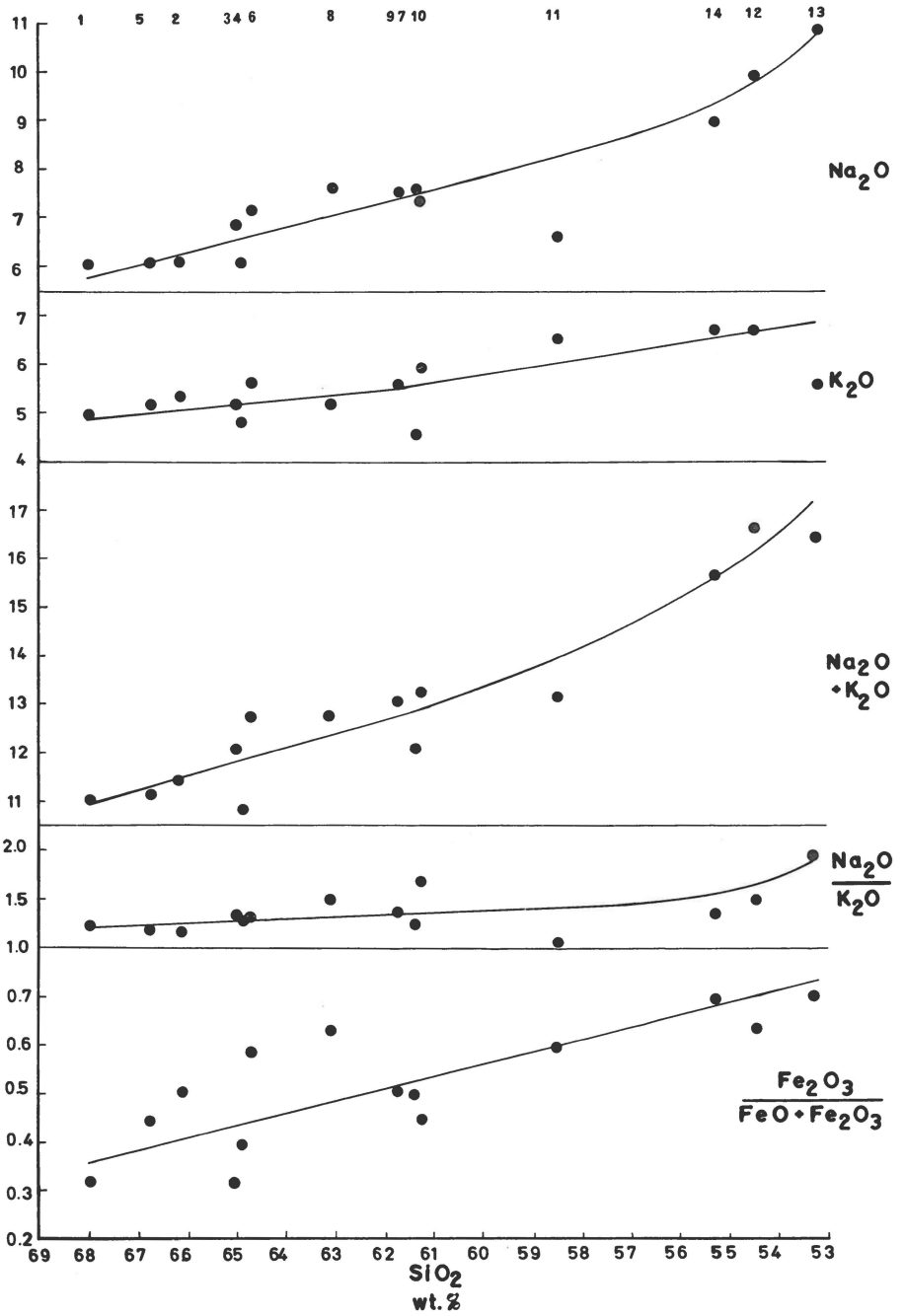
Fig. 10. Oxide and ratio variation in the syenites, plotted against SiO_2.
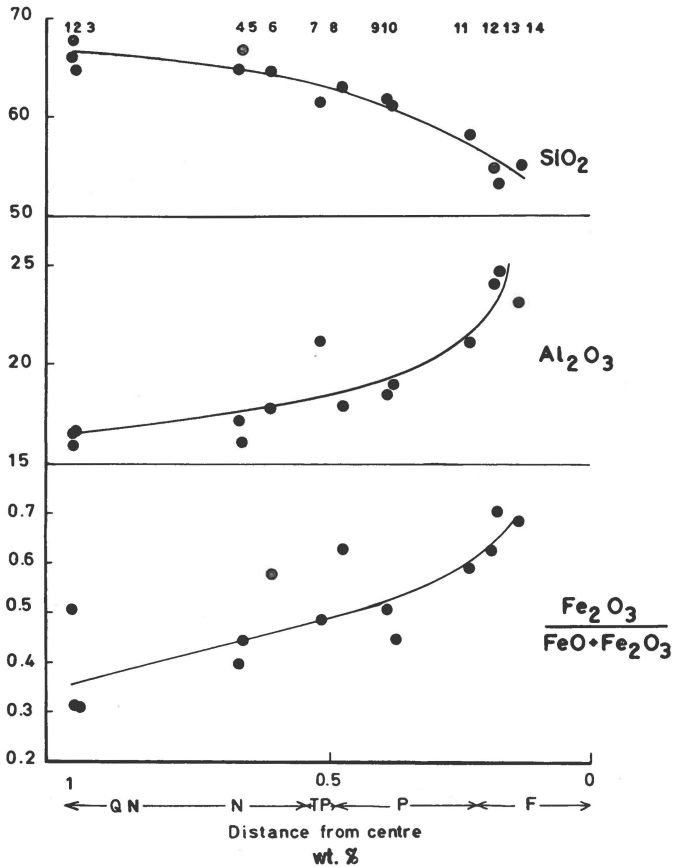
Fig. 11. Oxide and ratio variation in the syenites, plotted against distance from the centre.

tween agpaitic (peralkaline) and miaskitic alkaline rocks would be better placed at a ratio of 1.0. The Kangerdlugssuaq syenites have agpaitic coefficients ranging from 0.82 to 1.01, with an average for all the main rocks of 0.95, and thus even on the basis of NOLAN's revised definition would be classified as miaskitic in spite of the universal presence of sodic pyroxene and amphibole in the rocks of the intrusion.

The variation in composition of the fourteen syenites is shown in Figs. 9 and 10, in which the oxides and oxide ratios are plotted against silica content. The most striking changes associated with decreasing SiO_2 percentages are shown by Al_2O_3 and Na_2O; the former increases linearly whereas Na_2O shows an approximately linear increase, with the exception of analysis 11, from quartz-nordmarkite to pulaskite, and then a more marked increase in the foyaites. The pulaskite, analysis no. 11 is, however, enriched in K_2O relative to the general increase in
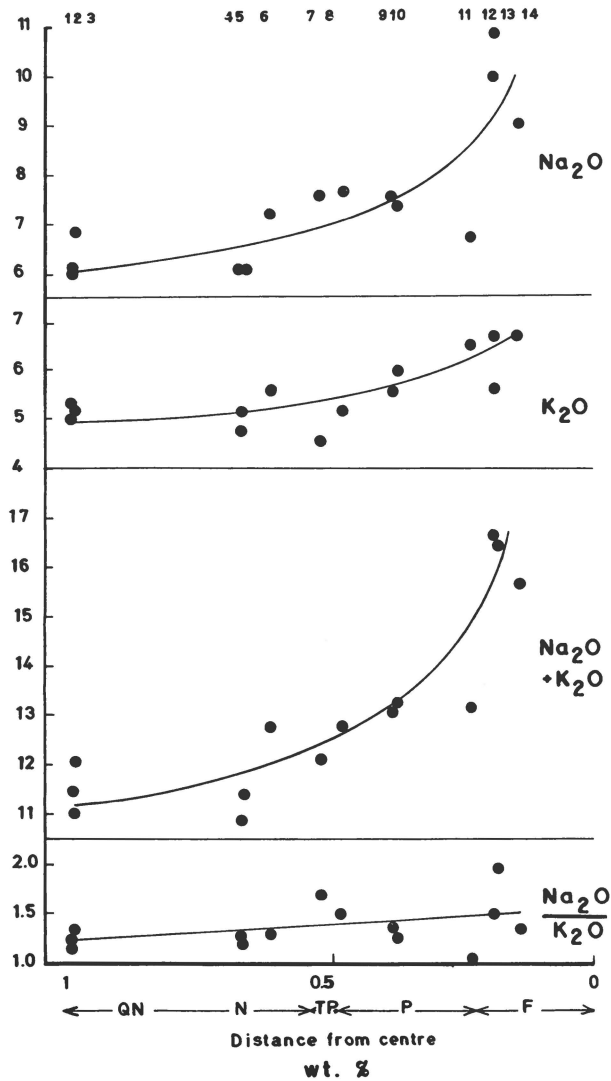
Fig. 12. Oxide and ratio variation in the syenites, plotted against distance from the centre.

this oxide as the SiO_2 content of the series decreases, and the sum of the alkalis shows a more nearly linear increase than either of the two oxides individually. CaO shows only a slight increase, while FeO and, to a lesser extent, MgO and TiO_2 decrease. There is no regular or significant change in the Fe_2O_3 content, but the $Fe_2O_3/(Fe_2O_3 + FeO)$ ratio shows an irregular but distinct rise with decreasing SiO_2 percentage.

In Figs. 11 and 12 some of the oxides and oxide ratios are plotted against the proportional distance from the centre of the intrusion.

There is a general decrease in silica, and increase in Al_2O_3, Na_2O and K_2O, from the margin to the centre of the intrusion, and the increase in the latter oxides is particularly marked in the transition from pulaskite to foyaite. The iron oxidation ratio also shows a more marked rise in the foyaites than in the earlier rocks of the intrusion. The two methods, described above, to illustrate the chemistry of the intrusion display a similar pattern of sequential changes of which the main features are the marked increase in Al_2O_3, $(Na_2O + K_2O)$, and iron oxidation, and decrease in SiO_2, from the margin to the centre.
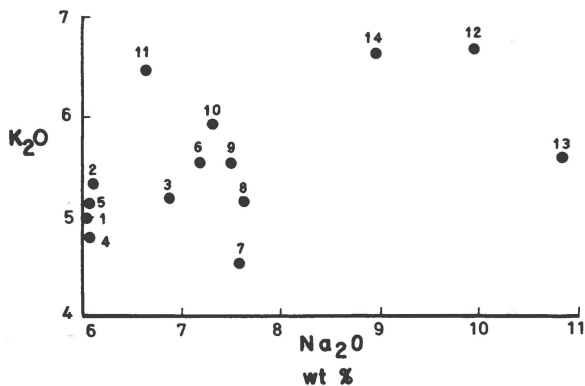
Fig. 13. Plot of Na_2O against K_2O in the syenites.

A plot of Na_2O against K_2O (Fig. 13) presents an irregular distribution pattern which, together with the relationship of their ratios relative to SiO_2 and distance from the intrusion centre, indicates that, although there is a greater general increase in Na_2O compared with K_2O, the two components are to some extent interchangeable.

Two three-component diagrams may be used to illustrate further the compositional variation in the intrusion. Thus in Fig. 14, total iron (as FeO) is plotted against alkalis and MgO, and illustrates that, although there is some overlap between the nordmarkites (nos. 1 to 6) and pulaskites (nos. 7 to 11), the later rocks are in general poorer in iron and magnesia, and the foyaites constitute a more distinctly alkali-enriched group. The final depletion in iron during the course of crystallization thus presents a striking contrast to the trend of iron enrichment in a fractionated series of basic rocks such as the Skærgården intrusion. A similar depletion in total iron oxides and magnesia but with continuing iron enrichment has been reported for the alkali series of Hawaiian lavas by TILLEY, YODER and SCHAIRER (1965), which trend contrasts with the tholeiite series of lavas from the same area. The preferential subtraction of the mafic minerals in the Hawaiian alkali series, reported by

these authors, is also a characteristic of the Kangerdlugssuaq syenites and is especially marked in the foyaites.
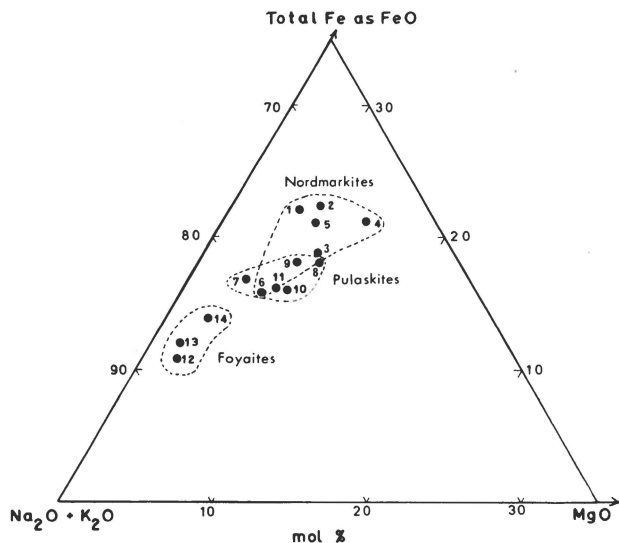

Fig. 14. Rock analyses: triangular plot of (total) FeO − Na₂O + K₂O − MgO.

The normative feldspar components are shown in Fig. 15. Here the chief feature of the diagram is the distinct isolation of the foyaite compositional field due to the high proportion of Na_2O that is fixed in the
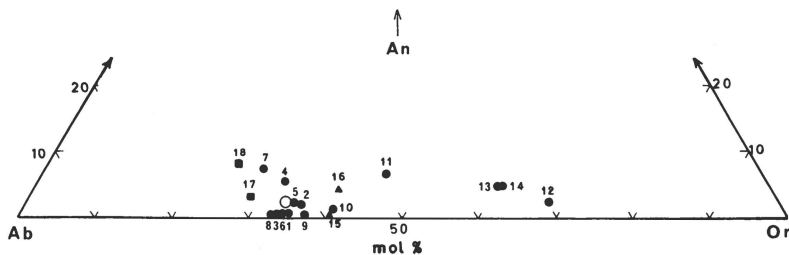

Fig. 15. Rock analyses: triangular plot of normative feldspars (Ab − Or − An).
Open circle represents the average composition of the intrusion.

feldspathoidal components of the rock. The veins in the foyaite (nos. 15 and 16, indicated by triangles) show a notably larger normative albite content than the host rock. This feature arises from the greater richness in the veins of modal feldspar relative to feldspathoids and in this way they differ from the veins in the other units of the complex, in being less undersaturated than the rocks in which they occur. The modified basalt inclusions containing porphyroblastic feldspars (Fig. 15,

nos. 17 and 18, shown by squares), have a similar total normative feldspar content, but with a less albitic composition, compared with the nordmarkite in which they are enclosed.

Normative plots of the Kangerdlugssuaq syenites in relation to the system quartz—nepheline—kalsilite are presented in Figs. 16 and 17.
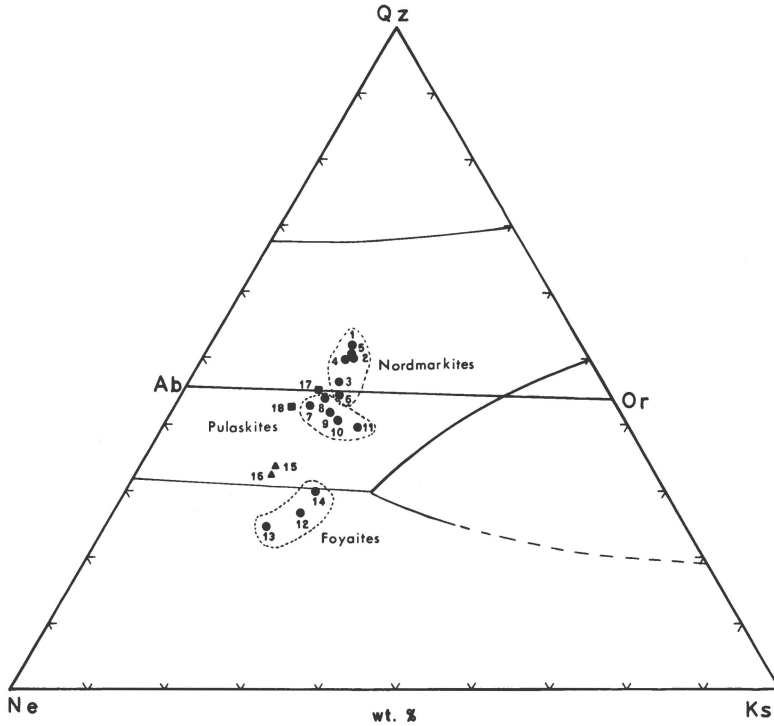
Fig. 16. Rock analyses: normative plot in the system $Qz - Ne - Ks$. Fields drawn as at $P_{H_2O} = 1000$ bars.

Equilibrium relations within this system were determined by SCHAIRER and BOWEN (1935), further discussed by BOWEN (1937) and a revised diagram given by SCHAIRER (1950). The original work was carried out on the dry system at atmospheric pressure, but more recently, the system has been reinvestigated by several workers at an H_2O pressure of 1000 bars (kg/cm²). TUTTLE and BOWEN (1958) determined the liquidus relationships within the more silica-rich field, SiO_2—$NaAlSi_3O_8$—$KAlSi_3O_8$; FUDALI (1963) and HAMILTON and MacKENZIE (1965) respectively investigated the potassium-rich and sodium-rich portions of the undersaturated area, $NaAlSi_3O_8$—$KAlSi_3O_8$—$KAlSiO_4$—$NaAlSiO_4$. The major differences between the anhydrous and hydrous systems are that in the latter there is a large reduction in the area of the leucite field and a

decrease in the temperatures of the oversaturated, undersaturated, and feldspar minima. Since the Kangerdlugssuaq intrusion, in common with similar syenite plutons, was intruded under an appreciable cover of country rocks, the field boundaries and other data relating to the hydrous system at P_{H_2O} = 1000 bars have been reproduced in Figs. 16 and 17.
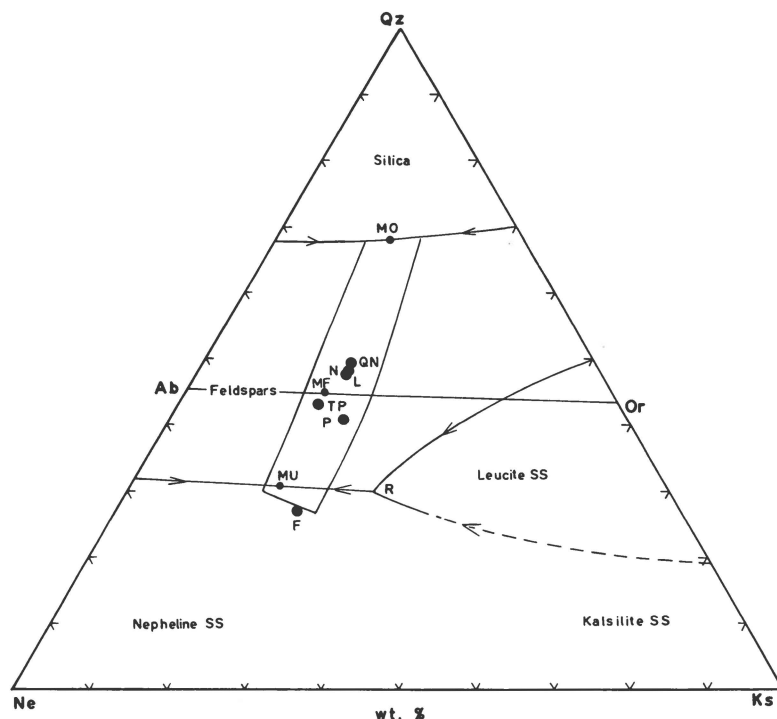

Fig. 17. Averages of rock analyses: normative plot in the system Qz – Ne – Ks. L, liquid, represents the average (magmatic) composition of the intrusion. Fields drawn as at P_{H_2O} = 1000 bars. MO, oversaturated minimum at 715° C; MF, feldspar minimum at 865° C (both from Tuttle and Bowen, 1958); MU, undersaturated minimum at 750° C (Hamilton and MacKenzie, 1965). R, reaction point (Fudali, 1963). Low temperature valley, after Bowen (1937).

The positions of the fourteen main rocks, two veins and the two basaltic inclusions with porphyritic feldspars, in relation to the quartz—nepheline—kalsilite system, are shown in Fig. 16. All the quartz-nordmarkites and nordmarkites are located on the silica side of the feldspar join, with the exception of no. 6, which, like the two transitional pulaskites (nos. 7 and 8), plot slightly on the undersaturated side of the Ab—Or join; the three main pulaskites (nos. 9 to 11) plot further into the undersaturated field and a little towards the potassium-rich corner. The foyaites (nos. 12 to 14) all plot in the nepheline field, while the veins

(nos. 15 and 16) lie close to the feldspar—nepheline boundary but within the feldspar field. The two modified basalt inclusions (nos. 17 and 18) fall close to, but on the albite side of, the transitional pulaskites.

The chemistry of the main rocks, in the context of the quartz—nepheline—kalsilite system, can be discussed with the aid of the average compositions of the main rock units. These are given in Fig. 17 in which analyses 1 to 3 and 4 to 6 have been averaged to give the positions of QN and N respectively; the other average unit compositions appear as TP, P and F. The average composition of the whole intrusion, which is considered to approximate closely to the initial magmatic composition, is represented by the position L. The three minima in the system at P_{H_2O} = 1000 bars are MO, the oversaturated sink, at a temperature of 715°C (TUTTLE and BOWEN, 1958); MF on the feldspar join at 865°C and a composition of about Or_{30} (Ibid); and MU, the undersaturated sink, at a temperature of 750°C (± 7°C) and composition $Ne_{50}Ks_{19}Qz_{31}$ (HAMILTON and MACKENZIE, 1965). R is the reaction or ternary invariant point (FUDALI, 1963), and the arrows indicate the directions along the field boundaries of decreasing temperature as the melt cools. The roughly rectangular area embracing the three minima is the low temperature valley, or trough, for the dry system (BOWEN, 1937). Many analyses of granitic and syenitic rocks plot within this area and BOWEN suggested that, since the experimental liquidus isobars in the dry system form a series of planes converging inwards towards this area, and assuming crystal-liquid equilibrium is maintained, it would be expected that natural magmas would follow the same cooling paths and that the final residual liquids would plot within the rectangle.

The more recent experimental work at P_{H_2O} of 1000 bars has shown that, although the liquidus temperatures are lowered at this water pressure, the positions of the thermal valley and the minima remain more or less unchanged. Within the thermal valley the feldspar join forms an energy barrier in that the feldspar minimum occurs at a higher temperature than the over- and undersaturated minima. Thus, although cooling liquids could converge on the valley, it is theoretically not possible for a cooling liquid to migrate from the over- to the undersaturated minimum across the feldspar join, since this would involve an upward movement along a temperature gradient. It can be seen from Fig. 17 that the average (magmatic) composition and that of the nordmarkites plot on the more siliceous side of the thermal barrier. It would thus be expected that a large proportion of the magma would precipitate nordmarkite phases, as is indeed the case, but that the residual liquid would give rise to a more siliceous rock such as an ekeritic alkaline granite. In the evolution of the Kangerdlugssuaq intrusion, however, it appears that the crystallization of the nordmarkitic liquid led to a change in magmatic

composition towards the feldspar join, *i.e.* up the thermal gradient, and the last 10 per cent of the liquid has given rise to the pulaskites and foyaite which plot respectively on or near the feldspar join and in the undersaturated portion of the system. The Kangerdlugssuaq intrusion thus poses once again the principal problem associated with the petrogenesis of alkaline rocks, *i.e.* the apparent derivation of an undersaturated from an oversaturated liquid.

The distribution of the composition of 102 plutonic rocks containing 80 per cent or more normative Ab + Or + Ne is shown in Fig. 8, and was used by HAMILTON and MACKENZIE (1965) to illustrate the relationship between the compositions of natural rocks and the unique fractionation curve or thermal valley, indicated by crosses, which runs between the feldspar and undersaturated minima in the quartz—nepheline—kalsilite system. A similar distribution diagram, was drawn by TUTTLE and BOWEN (1958) using a different counting method, for rocks containing 80 per cent or more normative Ab + Or + Q for the oversaturated low-temperature region around the third minimum (see Fig. 17); the low temperature contour on the silica side of the feldspar join shown by a broken line, in Fig. 8, is taken from their diagram. The compositions of the Kangerdlugssuaq syenites all lie within or close to the high contour areas. The position of the average foyaite composition, F, is notable since it lies some way from the undersaturated minimum in the direction of the nepheline—kalsilite join. HAMILTON and MACKENZIE (1965) have reported that preliminary experiments on the $NaAlSiO_4$—$KAlSiO_4$—SiO_2—H_2O system at P_{H_2O} of 2000 bars indicate that at this water pressure the nepheline—feldspar field boundary is displaced in a direction away from the feldspar join, and they commented that it is in consequence surprising that so few syenite compositions plot far from the field boundary at a P_{H_2O} of 1000 bars. Evidence that P_{H_2O} increased during the later stages in the crystallization of the Kangerdlugssuaq magma has been presented in the earlier petrography sections, and in consequence the position of the foyaite composition, beyond the high concentration area, is of more than local significance.

The plots of the transitional pulaskite and main pulaskite are offset from the unique fractionation curve running along the axis of the thermal valley shown in Fig. 17 and are also worthy of comment. As HAMILTON and MACKENZIE have noted (1965), this curve also represents a 'thermal barrier' since it is a three-phase boundary as well as a fractionation curve, and therefore, marks the course of fractionating liquids which can only depart from these compositions to a very limited extent. Thus liquids of compositions which lie on the potassium-rich side are likely to have been derived from liquids even richer in potassium, rather than sodium-rich liquids, and conversely those on the sodium-rich side

of the boundary are likely to have been derived from even more sodium-rich liquids. Since the nordmarkites, transitional and main pulaskites are mainly composed of alkali feldspar, (in some rocks as much as 90 per cent), the average compositions of these rocks largely represent the compositions of their feldspars: thus the nordmarkites contain a feldspar, the approximate composition of which is indicated by the point at which the tie-line from quartz to the composition of the nordmarkite meets the feldspar join. Similarly, a tie-line from the nepheline composition through P indicates the pulaskitic feldspar composition. This construction cannot, however, be used in the case of the foyaite because of the presence of appreciable quantities of sodalite in these rocks, and because, towards the kalsilite field, the three-phase boundaries become three-phase triangles (HAMILTON and MACKENZIE, 1965). The transitional pulaskite, containing neither quartz nor feldspathoid, plots, appropriately, near the feldspar minimum.

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PLATES

Plate 1

Central part of the Kangerdlugssuaq Intrusion from the east. Air photograph by H. G. WATKINS, August 1930. Gn, basement complex of metamorphic rocks, Precambrian; BS, syenite of Basnæsset; N, quartz-nordmarkite and nordmarkite; TP, transitional pulaskite; P, pulaskite; F, foyaite; Gr, granite.

Plate 2

Southern part of the Kangerdlugssuaq Intrusion from the east. Air photograph by H. G. WATKINS, August 1930. Gn, basement complex of metamorphic rocks, Precambrian; B, basalts; N, quartz-nordmarkite and nordmarkite; TP, transitional pulaskite; P, pulaskite; F, foyaite; BS, syenite of Bagnæsset; Gr, granite; Ga, gabbro.

Plate 3

Northern part of the Kangerdlugssuaq Intrusion from the east. Air photograph by H. G. WATKINS, August 1930. Gn, basement complex of metamorphic rocks, Precambrian; N, quartz-nordmarkite and nordmarkite; TP, transitional pulaskite; P, pulaskite; KS, Kærven syenite; Ga, Kærven gabbro; Pr, peridotite.

Plate 4

Looking south across the upper part of Søndre Syenitgletscher at Citadellet formed of pulaskites (from WAGER, 1965).

Plate 5

Cluster of basalt inclusions in nordmarkite dipping inwards at 40°. Hovedvejs-nunatakker (from WAGER, 1965).

Plate 6

Fig. 1

Nordmarkite showing phenocrysts of low-albite – orthoclase microperthites, southeast Fangetaarne.

Fig. 2

Photomicrograph of quartz-nordmarkite showing, top right centre, fine microperthite, and left centre, coarse microperthite. $\times 14$. Crossed nicols.
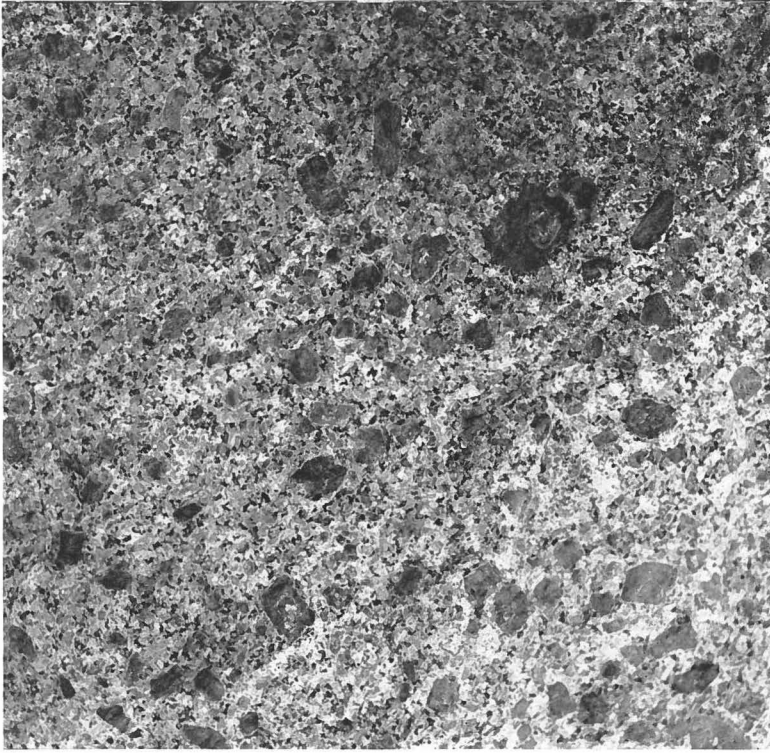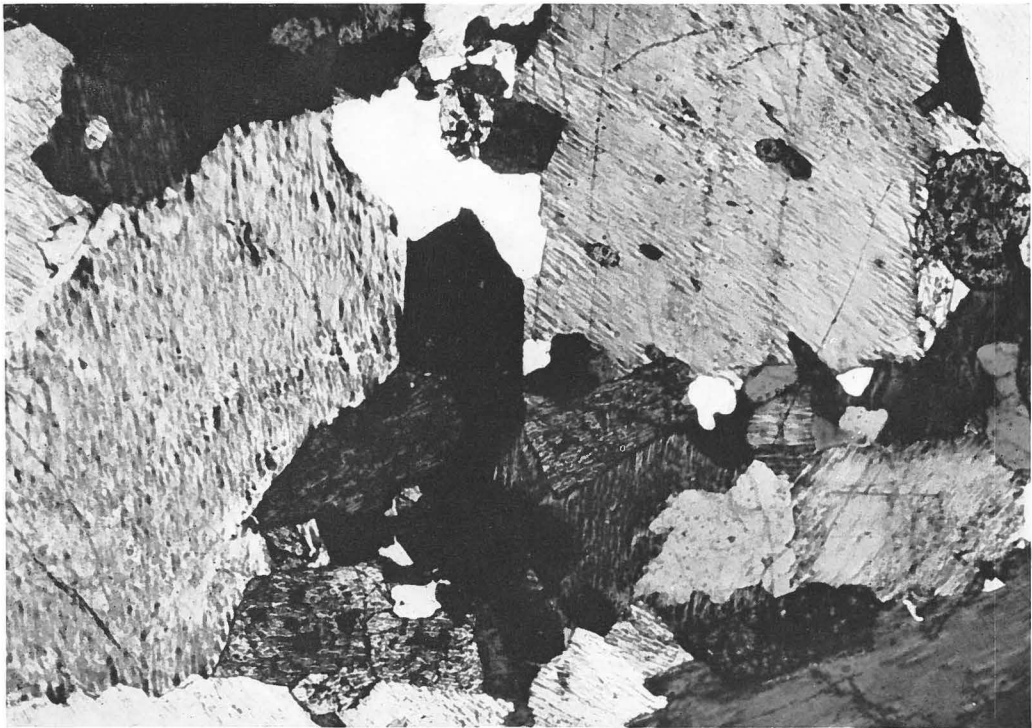
Fig. 1.

Fig. 2.

Plate 7

Basalt inclusion with large feldspar 'phenocrysts'. Note how, in the top phenocryst, the outer, potassic rim has been eroded away, exposing the inner, sodic core. Natural size.

Photomicrograph of zoned basalt phenocryst in microsyenitic groundmass in nordmarkite. ×14. Crossed nicols.
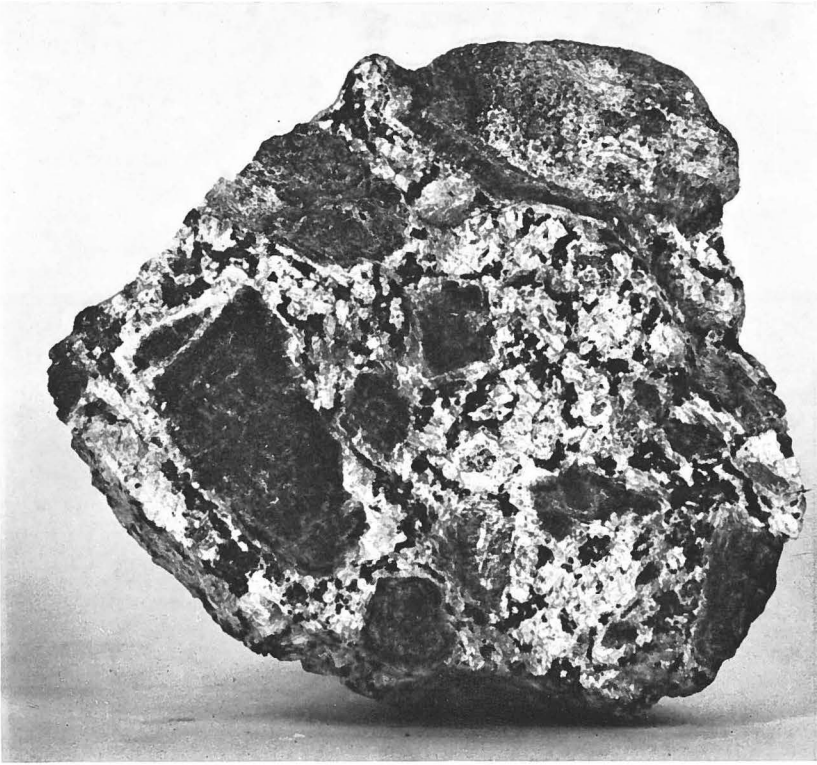
Fig. 1.

Fig. 2.

Plate 8

Fig. 1

Photomicrograph of transitional pulaskite, showing clustering of ferromagnesian minerals. The large crystal, lower right, is magnesioarfvedsonite. $\times$ 35. Plain light.

Fig. 2

Photomicrograph of vein in transitional pulaskite, showing aegirine needles growing into nepheline. $\times$35. Crossed nicols.
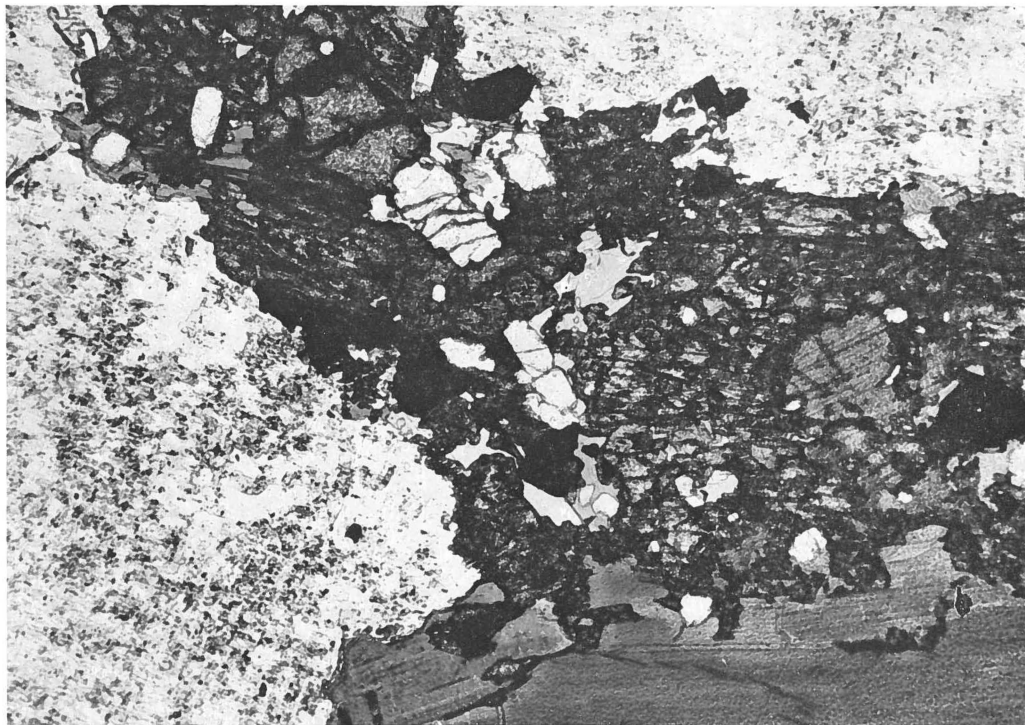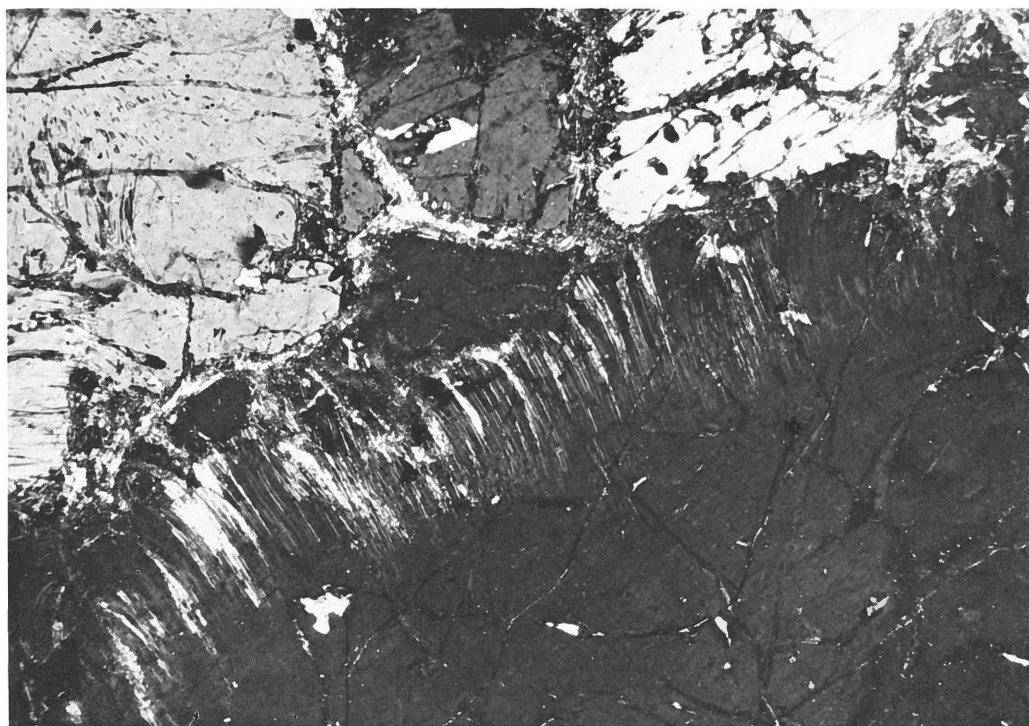
Fig. 1.

Fig. 2.

Plate 9

Fig. 1

Pulaskite showing parallelism of mafic segregations, south Trebjørnebjærget.

Fig. 2

Photomicrograph of main pulaskite, showing ferromagnesian layer or segregation. $\times 14$. Plain light.
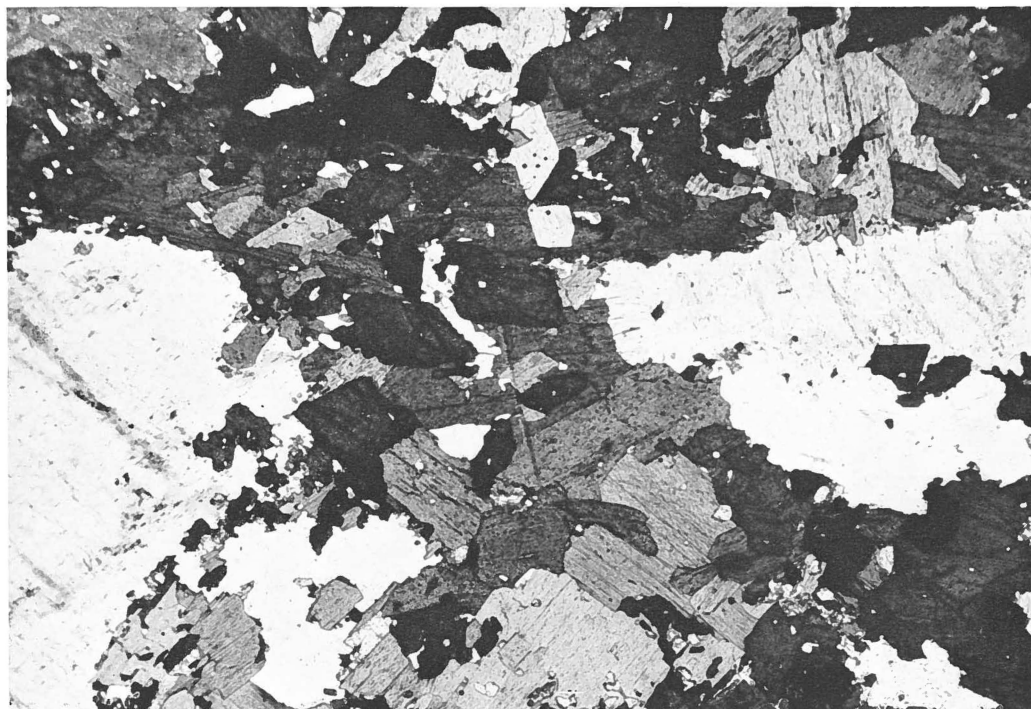
Fig. 1.

Fig. 2.

Plate 10

Photomicrograph of typical vein in the pulaskites, showing felt of albite crystals which flow around larger crystals of perthite or feldspathoid. ×14. Crossed nicols.

Photomicrograph of foyaite. Minerals include melanite (black), core and rim zoned aegirine-augite, sodalite showing two generations, nepheline and perthite. ×14. Plain light.
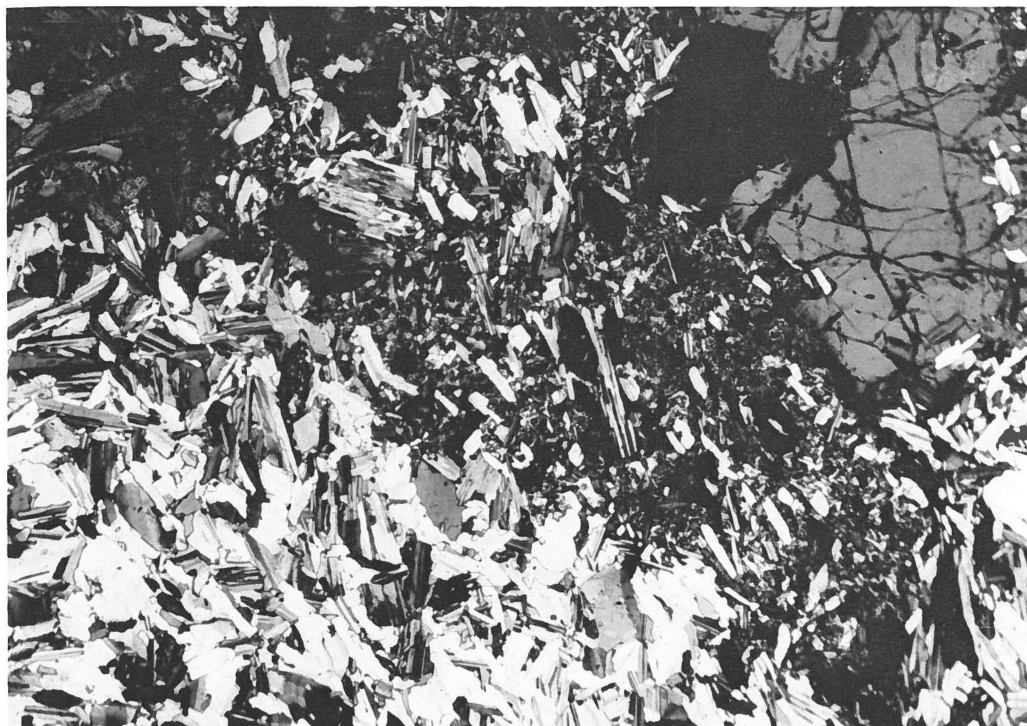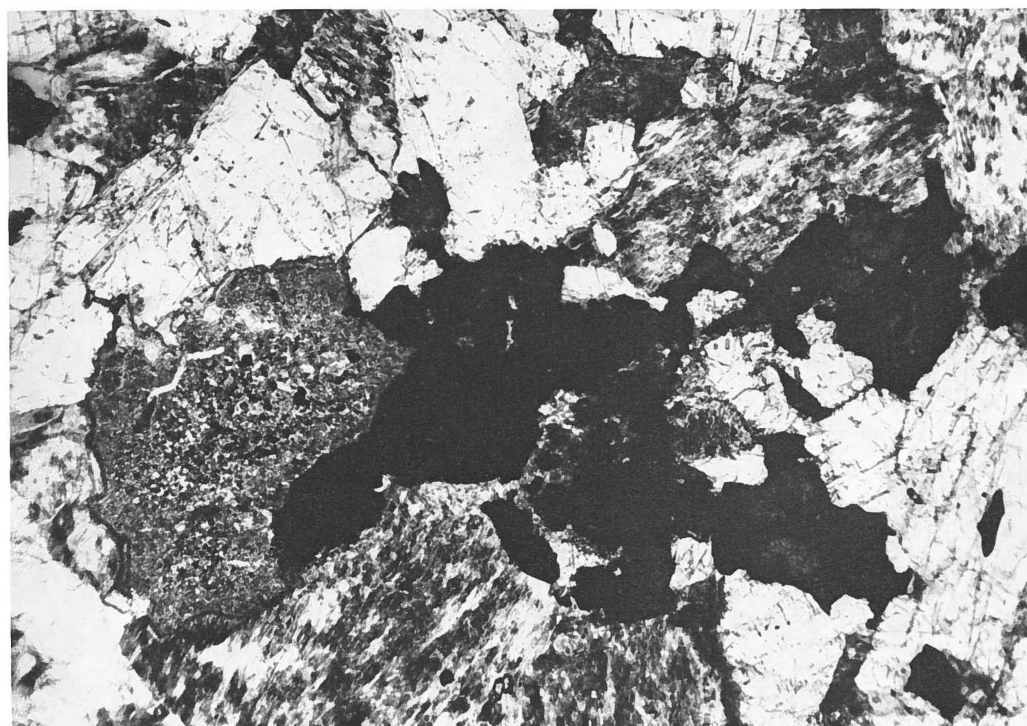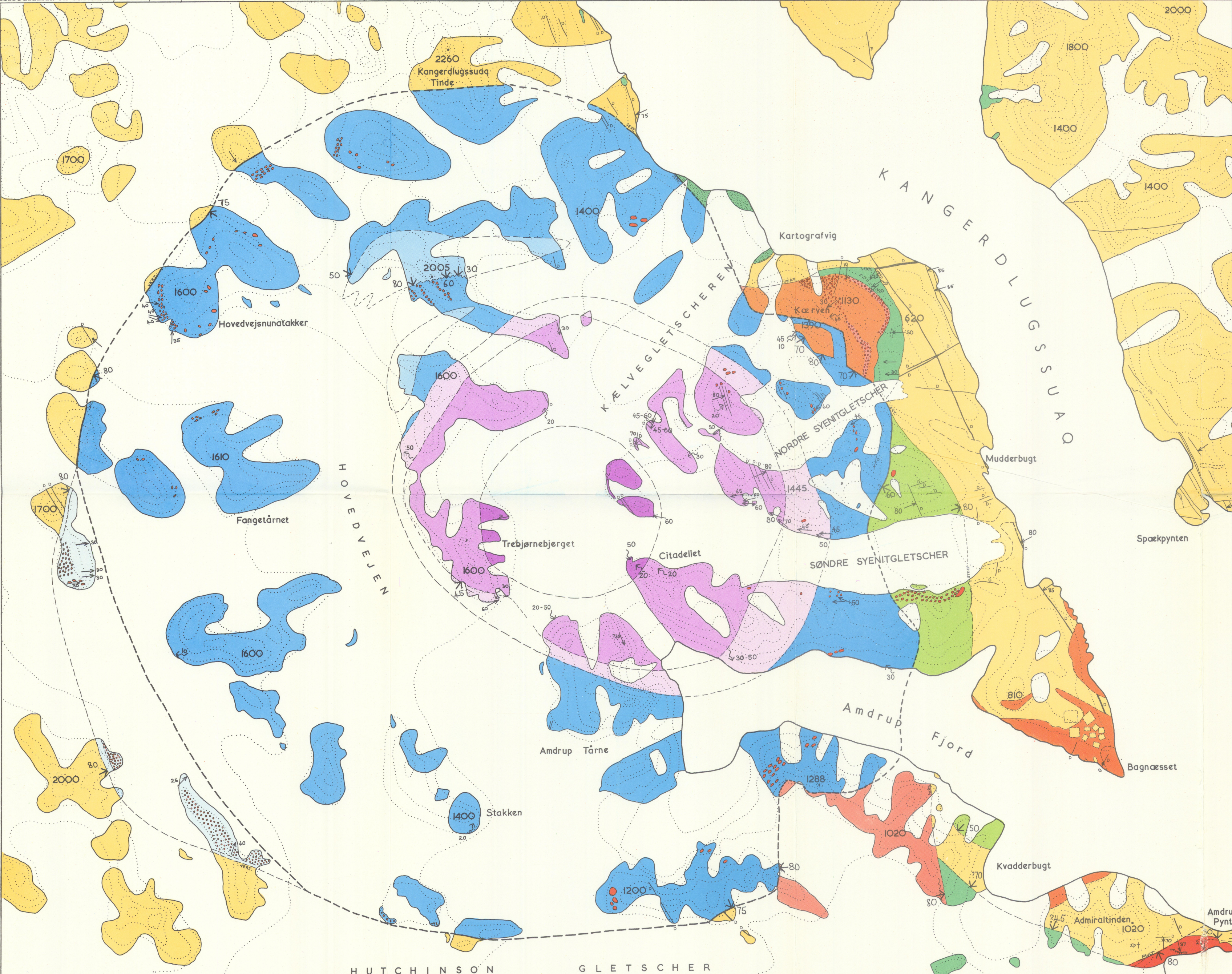
Fig. 1.

Fig. 2.

Meddelelser om Grønland, Bd. 190, Nr. 2. (D. R. C. Kempe, W. A. Deer and L. R. Wager).

MAP I.

KANGERDLUGSSUAQ ALKALINE INTRUSION

LATER PLUTONIC INTRUSIONS

- Biotite Granite
- Syenite, Snout Series
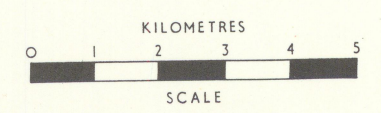
KANGERDLUGSSUAQ INTRUSION

- Foyaite
- Main Pulaskite
- Transitional Pulaskite
- Quartz Nordmarkite (outer part) Nordmarkite (inner part)

EARLIER PLUTONIC INTRUSIONS

- Augite syenite
- Fayalite syenite of Kærven Syenite of Bagnæsset
- Syenite of Peak 2005
- Gabbro of Kærven Volcanic Necks, E. side of Kangerdlugssuaq
- Peridotite

- Basic Dykes
- Basalt Basalt Inclusions in the Plutonic Rocks
- Metamorphic Complex. Pre-Cambrian Gneiss Inclusions in Plutonic Rocks

- Dip of contacts
- Dip of platy feldspars and zones of basalt inclusions
- Dip where wavy
- Contours intervals 200 metres
- Heights in Metres

KILOMETRES
0 1 2 3 4 5
SCALE

KANGERDLUGSSUAQ

Kangerdlugssuaq Tinde 2260
1700
2000
1800
1400
1400
Kartografvig
Kærven 1130
1390 620
Mudderbugt
Spækpynten
KÆLVEGLETSCHEREN
Hovedvejsnunatakker 1600
1400
1600
NORDRE SYENTGLETSCHER
1445
1610
Fangetårnet
HOVEDVEJEN
1700
Trebjørnebjerget
Citadellet
SØNDRE SYENITGLETSCHER
1600
810
Amdrup Tårne
Amdrup Fjord
Bagnæsset
2000
Stakken 1400
1288
1020
Kvadderbugt
Amdrup Pynt
1200
Admiraltinden 1020
HUTCHINSON GLETSCHER