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Leaders: L. R. Wager and W. A. Deer

GEOLOGICAL INVESTIGATIONS IN EAST GREENLAND

Part XI

THE MINOR PERIPHERAL INTRUSIONS, KANGERDLUGSSUAQ, EAST GREENLAND

BY

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WITH 4 FIGURES, 7 TABLES AND 8 PLATES

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Abstract

The minor peripheral syenitic and granite intrusions associated with the main Kangerdlugssuaq alkaline intrusion are described. The earlier intrusions—Peak 2005 Syenite; Kærven Syenite; Augite Syenite; and Bagnæsset Syenite—and the later Granite and Snout Series generally have the compositions of slightly oversaturated nordmarkites. They differ chemically from the syenites of the main intrusion, especially in their contents of alumina, total iron, and alkalis. The ferromagnesian minerals include aegirine, ferroaugite, magnesioarfvedsonite, and katophorite, and the accessory mineral chevkinite, together with perthitic alkali feldspar, quartz, and minor minerals. The Snout Series, Kærven Syenite, and, especially, the Augite Syenite are heavily contaminated by basaltic inclusions. The overall composition of the main and minor peripheral intrusions, including the Granite, is that of a slightly oversaturated nordmarkite, differing little from that of the main intrusion. The minor intrusions are generally regarded as early and late pulses emanating from the same magma source as that which supplied the main intrusion, although there is evidence that the later Snout Series and Granite, and possibly the earlier Bagnæsset Syenite, were emplaced at a higher temperature, or cooled more quickly, and may have derived from differentiated liquid fractions.

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Contents

I. INTRODUCTION

The form and petrology of the Tertiary Kangerdlugssuaq alkaline intrusion has been described by WAGER (1965) and KEMPE, DEER & WAGER (1970), and the mineralogy by KEMPE & DEER (1970). In these papers, little reference was made to the minor peripheral intrusions which surround the main mass of syenites on the eastern and parts of the other three sides (Plate 1).

Most of the minor intrusions were emplaced before the main alkaline mass, as suggested by the (outward) dip of the contacts and the field evidence generally. The minor intrusions are syenitic in composition and, compared with the four major types of the Kangerdlugssuaq alkaline intrusion (KEMPE *et al.*, 1970), are notable for the greater range in their mineralogy. Two of the intrusions are considered to be younger than the main mass: the Snout Series Syenite, spanning Søndre Syenitgletscher, and the Biotite Granite, south of Amdrup Fjord.

An estimate of the relative volumes of the four major units of the main intrusion, by measuring their areal extent and treating them as saucer-shaped spherical segments, has already been made (KEMPE *et al.*, 1970). In order to assess the effects of the minor intrusions on the bulk composition of the whole complex, their areas, except for the small peridotite bodies, have now also been measured. No attempt has been made to postulate their form at depth and the proportions given in Table I are based solely on their areal extents, with approximate ad-

Table I. *Relative Areal Proportions of the Minor Intrusions.*

		area per cent	totals
Later plutonic intrusions	Snout Series Syenite	3.47	6.9
	Biotite Granite	3.44	
Main Kangerdlugssuaq intrusion		82.56	82.6
Earlier plutonic intrusions	Peak 2005 Syenite	1.81	10.5
	Kærven Syenite	1.17	
	Augite Syenite	3.67	
	Bagnæsset Syenite	1.49	
	Kærven Gabbro	0.41	
	Admiraltinden Gabbro	1.98	

justments where areal overlap occurs (e.g. at Kærven), and where their precise extent is unknown because of erosion or snow cover (e.g. at Admiraltinden). It can be seen that the main intrusion occupies some 82.5% of the total area, the earlier intrusions some 10.5%, and the later some 7%. Syenite intrusions also occur outside the immediate Kangerdlugssuaq area at Jagtlejren, Kraemer Ø, and at Kap Deichmann, Kap Boswell, and Hutchinson Gletscher, in the Kap Edvard Holm region, where they are associated with layered gabbros (Deer & Abbott, 1965; Elsdon, 1969; 1970; 1971a and b; 1972; Abbott & Deer, 1972; Elsdon, Deer & Abbott, in preparation). Of the above, the Jagtlejren rocks are chemically similar in some respects to the peripheral intrusions of the Kangerdlugssuaq alkaline complex and two analyses are included in Table VI. The syenites associated with the Kap Edvard Holm complex are not considered further in the present work but will form the subject of a later communication.

In the following pages are described the petrography, mineralogy, and chemistry of each intrusion. The majority, as in the case of the two or three outer units of the main mass, contain xenoliths of basalt. Their effect on the average composition of the whole intrusive complex is then discussed.

The authors would like to express their gratitude to colleagues in the Department of Mineralogy and Petrology, Cambridge, and the Department of Mineralogy, British Museum (Natural History), London, and to Dr. C. K. Brooks, for their help in various aspects of the work. In addition to the analysts named in the text, thanks are especially due to Mr. R. F. Symes for the mineral separations, and to Dr. R. J. Davis for confirming the presence of chevkinite by X-ray powder photography.

II. PETROGRAPHY AND MINERALOGY OF SOME OF THE MINOR INTRUSIONS

a. Peak 2005 Syenite

The dark coloured syenite from this intrusion (Plate 3, Fig. 1) contains about 85 per cent large alkali feldspar crystals, some of which are sub-phenocrystic. A little quartz is present, together with ferromagnesian and accessory minerals. The rock is thus a nordmarkite, and although somewhat finer-grained resembles those of the main intrusion. Of the two types discussed below, the first (Table VI, no. 11) is considered typical, whilst the second shows contamination by basaltic xenoliths which, when partly digested, result in fine-grained or microsyenitic textures. These rocks are more mafic and show some degree of parallel orientation of the tabular feldspars. Reaction or symplectic bands of fine-grained sphene and blue amphibole are sometimes present.

Table II. *Alkali Feldspar X-ray Powder Data.*

Intrusion	E.G. No.	Composition from $_2$01 method (Or)	Corrected composition (Or)	Obliquity of triclinic phase
Snout Series.......	4891	42.0	44	0
	5044	42.0	44	0
Kærven...........	2683	30.7	33	0.85
	2686	24.0	26	0.94
Peak 2005.........	4636	27.0	29	0.84
	2820	36.0	38	0.75

The alkali feldspar is a low-albite-microcline hair microperthite, for which the composition and structural state have been determined on two samples (Table II) by the $\overline{2}01$ X-ray diffraction method. With bulk compositions of Or_{29} and Or_{38}, and obliquities of 0.84 and 0.75, the feldspar, although less potassic, closely resembles that from the groundmass in the nordmarkites and transitional pulaskite of the main intrusion (Kempe & Deer, 1970). The separation of the sodium and potassium phases, which averages 1.065°2θ (Cu$k\alpha$), is also similar. The larger, slightly zoned crystals are accompanied by small interstitial patches of perthite, but little interstitial albite is present even compared with the average content of 2.4% in the nordmarkites of the main intrusion.

The main ferromagnesian mineral is a blue sodic amphibole, accompanied by and possibly altering to, aegirine. In the analysed sample, the amphibole is magnesioarfvedsonite (Table IV, no. 1); in others it is reddish in colour and thus probably katophoritic in composition. The coexisting aegirine in the analysed rock (Table III, no. 1) is unzoned and has the composition $Tsch_2Ac{+}Jd_{77}Hd_{12}Di_9$; both minerals, including their high content of manganese, thus closely resemble their counterparts from the transitional pulaskite of the main intrusion. Some parts of the mass are more mafic in character due to the incorporation of basaltic material and in these rocks large relict crystals of augite are sometimes almost completely replaced by sodic amphibole and biotite. Accessory minerals present include yellow biotite, ilmenite, apatite, and a little sphene.

In summary, the Peak 2005 syenite can be described as a magnesioarfvedsonite-aegirine nordmarkite, with marked similarities to the nordmarkite and transitional pulaskite of the main intrusion.

Table III. *Alkali Pyroxenes—Chemical Analyses, some Trace Elements and Numbers of Ions on the Basis of 6 oxygens.*

	1	2		1	2
SiO_2	51.96	51.92	Si	1.982	1.999
TiO_2	1.11	0.55	Al	0.018	0.001
Al_2O_3	0.53	0.25			
Fe_2O_3	24.67	30.53	Al	0.006	0.010
FeO	4.35	3.10	Ti	0.032	0.016
MnO	0.81	0.19	Fe^{+3}	0.708	0.884
MgO	1.99	0.34	Fe^{+2}	0.139	0.100
CaO	5.25	1.41	Mn	0.026	0.006
Na_2O	10.30	11.89	Mg	0.113	0.020
K_2O	0.07	0.01	Ca	0.215	0.058
			Na	0.762	0.887
Total	101.04	100.19	K	0.003	0.001
	Trace elements (p.p.m.)*				
Cr	30	90	Y	1.02	1.04
Nb	100	200	X	0.98	0.95
Ni	100	50			
V	250	500	$Fe^{+3}/(Fe^{+3}+Fe^{+2})$	0.84	0.90
Zr	4000	750			
Y	30	75	Tsch	2	–
Sr	50	nil	Ac+ Jd	77	89
Ba	100	300	Hd	12	9
			Di	9	2

1. Aegirine, syenite, Peak 2005, E.G. 4636. Anal. C. J. Elliott, V. K. Din and A. J. Easton.
2. Aegirine, fayalite syenite, Kærven, E.G. 2683. Anal. C. J. Elliott, V. K. Din and A. J. Easton.

* Determined semi-quantitatively by emission spectroscopy.

Table IV. *Alkali Amphiboles—Chemical Analyses, some Trace Elements and Numbers of Ions on the Basis of 24 (O, OH, F).*

	1	2	3	A
SiO_2	52.32	52.67	48.50	40.26
TiO_2	1.22	0.89	1.32	2.08
Al_2O_3	1.34	1.45	3.28	9.24
Fe_2O_3	9.91	9.31	2.72	4.56
FeO	10.24	14.49	23.74	22.16
MnO	1.51	1.35	2.73	0.63
MgO	10.08	8.24	6.35	5.22
CaO	2.37	3.76	8.86	10.41
Na_2O	7.78	6.20	2.29	2.13

(continued)

Table IV. *Continued.*

	1	2	3	A
K_2O	1.29	1.09	0.77	1.25
H_2O+	0.90	1.09	1.54	0.52
H_2O-	–	–	–	–
F	2.35	1.62	0.48	2.5
O ≡ F	0.99	0.68	0.20	1.00
Total	100.32	101.48	99.68	99.96
	Trace elements (p.p.m.)*			
Cr	15	5		
Nb	100	100		
Ni	100	60		
V	200	70		
Zr	400	250		
Y	25	50		
Sr	70	25		
Ba	200	70		
Si	7.726	7.792	7.223	6.37
Al	0.233	0.208	0.610	1.63
Al	–	0.045	–	0.09
Ti	0.136	0.099	0.157	0.25
Fe^{+3}	1.101	1.037	0.323	0.54
Fe^{+2}	1.265	1.793	3.131	2.93
Mn	0.189	0.169	0.365	0.09
Mg	2.219	1.817	1.493	1.23
Ca	0.375	0.596	1.497	1.77
Na	2.227	1.778	0.700	0.65
K	0.243	0.206	0.155	0.25
OH	0.887	1.076	1.620	0.55
F	1.098	0.758	0.239	1.25
Z	7.96	8.00	7.83	8.00
Y	4.91	4.82	5.47	5.13
X	2.85	2.58	2.35	2.67
$Fe^{+3}/(Fe^{+3}+Fe^{+2})$	0.47	0.37	0.09	0.16
$100\ Mg/(Mg+Fe^{+3}+Fe^{+2}+Mn)$	46.5	37.7	28.1	25.7

1. Magnesioarfvedsonite, syenite, Peak 2005, E.G. 4636. Anal. C. J. Elliott, V. K. Din and A. J. Easton.
2. Magnesioarfvedsonite, fayalite syenite, Kærven, E.G. 2683. Anal. C. J. Elliott, V. K. Din and A. J. Easton.
3. Ferroedenitic hornblende, syenite, Snout Series, E.G. 4891. Anal. C. J. Elliott, V. K. Din and A. J. Easton.

A. Hastingsite, A. 16, porphyritic quartz syenite, R. 16, Marangudzi complex, Rhodesia (Henderson, 1968). Anal. C. M. B. Henderson.

* Determined semi-quantitatively by emission spectroscopy.

b. Kærven Syenite

The Kærven fayalite syenite is coarser-grained than the Peak 2005 rock. It consists mainly of large, rimmed, phenocrystic microperthite crystals, between which finer-grained areas consisting of small perthites and the ferromagnesian minerals may be present (Plate 3, Fig. 2). The phenocrysts themselves often contain ferromagnesian inclusions. In addition to rocks containing partly digested basalt xenoliths (Plate 4, Fig. 1) resulting in the characteristic microsyenitic texture, there appears to be every gradation of contamination by the earlier peridotite and gabbro (OJHA, 1966). These hybrid rocks consist mainly of bytownite, clinopyroxene, and iron oxide, with some olivine and brown biotite, and locally chevkinite; the texture is usually fine-grained and spotty.

Typical syenites contain feldspars which are low-albite-microcline microperthite, varying in composition from Or_{33} to Or_{26} and in obliquity from 0.85 to 0.94 (Table II); the composition of the feldspar thus resembles that of the phenocrysts from the main nordmarkites and transitional pulaskite. The perthitic lamellae are somewhat coarser than in the Peak 2005 syenite, and the feldspar is accompanied by some microcline and, less frequently, by a small amount of albite; a little quartz is usually present. Acicular crystals of aegirine are included in some of the large perthite crystals, similar to those in the feldspars of the main intrusion (KEMPE *et al.*, 1970).

Clusters of a dark blue sodic amphibole, magnesioarfvedsonite, again form the main ferromagnesian mineral (Table IV, no. 2), accompanied by a few large crystals of patchily zoned aegirine, $Ac+Jd_{89}Hd_{9}Di_{2}$ (Table III, no. 2). Fayalite occurs sporadically and forms large colourless crystals, with $2V_{\alpha}\sim55°–60°$. Some secondary yellow biotite is present, and the accessory minerals are iron oxide, ilmenite and occasional hematite, apatite and sphene. It is of interest to note that the 'ore potential' diagram (KEMPE & DEER, 1970, Fig. 20), applied to the analysed rock, predicts a predominance of ilmenite, with some hematite.

Some Kærven syenites have a granophyric texture, with intergrowths of quartz and feldspar accompanied by the alteration of augitic pyroxenes to brown biotite and pale sodic amphiboles. Like the Peak 2005 intrusion, the Kærven syenite has close affinities with the nordmarkites, although the feldspar is rather more sodic than that of the groundmass in the rocks of the main Kangerdlugssuaq intrusion. The pyroxene, though having a much lower Mn content, is closest in composition to those from the more acid veins (KEMPE & DEER, 1970), whilst the magnesioarfvedsonite has a similar composition to that in the main pulaskite.

The Kærven layered gabbro (OJHA, 1966), an analysis of which is given in Table VI (no. 2), together with an analysis of the peridotite northwest of Kærven (Table VI, no. 1), is not considered further in the present work.

c. Augite Syenite

The augite syenites forming the nunataks to the west and southwest (the so called 'Junction' and 'January' intrusions) are white to grey, medium-grained rocks. They differ from the other peripheral intrusions, emplaced earlier than the main mass (Peak 2005 and Kærven), in presenting much evidence of an origin by digestion and metasomatic alteration of basalts by alkaline syenitic magma (Plate 5). A suite of thin sections from the 'January' rocks represents a gradational series from olivine gabbro through oligoclase-andesine monzonitic syenite to alkaline perthite syenite.

The olivine gabbro (Plate 4, Fig. 2) is fine-grained, consisting mainly of clinopyroxene and labradorite, with some olivine, and iron oxide. Late stage apatite occurs interstitially and there are small altered crystals of a dark, iron-rich mineral. The pyroxene is considerably altered to an amphibole, with reddish-brown pleochroism zoned outwards to green, resembling the katophorite in the more syenitic members of the suite, to which it is probably similar in composition. The monzonitic syenites (Table VI, no. 5) are grey rocks, consisting largely of plagioclase (oligoclase-andesine), and some potassium feldspar. Perthitic textures occur locally and are of a coarse, irregular type. There are some late stage interstitial quartz, prisms of apatite, and iron oxide. The ferromagnesian mineral is an augitic pyroxene, locally exhibiting exsolution lamellae parallel to (001), and highly altered to a pale greenish-brown hornblende, with some green to yellow-brown biotite. The final stages in the syenitization of the basaltic rocks give rise to pale coloured rocks, resembling the nordmarkite of the main intrusion (Table VI, no. 6). They contain large crystals of highly zoned and often perthitic feldspar, resembling the phenocrysts of the nordmarkites and transitional pulaskite of the main intrusion. Small patches of myrmekite are present and there is some five per cent of interstitial quartz. The only pyroxenes appear to be relict, greenish sodic ferroaugites, progressively made over to katophoritic amphiboles; with an Na_2O content of little over 1% (Table V, nos. 1 and 2) they contrast strongly with the aegirines from the Peak 2005 and Kærven syenites (Table III). Some of the pyroxenes contain exsolution lamellae. The amphiboles are richteritic low-Al_2O_3 katophorites, pleochroic from red, yellow-grey, and brown colours to greens and blues. The alteration sequence appears to be:

Pyroxene (total FeO, 20%) $\rightarrow$ greenish amphibole (31%) $\rightarrow$ brownish amphibole (26%). Thus the green amphibole, which envelops the relict

Table V. *Pyroxene and Amphibole Analyses from the Augite Syenite*

	1	2	3	4	5	6	7
SiO_2	50.64	50.78	48.41	47.55	48.50	48.49	50.4
TiO_2	0.47	0.07	1.82	1.53	1.74	1.73	
Al_2O_3	0.38	0.40	1.68	1.73	1.73	1.77	
[Fe_2O_3]	[2.00]	[2.00]	[10.00]	[10.00]	[9.00]	[9.00]	
FeO	18.71	17.32	20.75	23.06	18.10	17.48	26.0(tot.)
MnO	1.67	1.17	1.26	1.35	1.07	1.10	
MgO	7.84	8.33	3.84	2.59	6.41	6.51	5.9
CaO	18.30	16.77	6.00	5.58	6.43	6.42	17.9
Na_2O	1.10	1.21	5.02	4.45	5.33	4.69	2.0
K_2O	0.02	0.10	1.05	1.10	0.90	0.94	
[H_2O^+]	–	–	[0.17]	[1.06]	[0.79]	[1.87]	
Total	[101.13]	[98.15]	[100.00]	[100.00]	[100.00]	[100.00]	
	Numbers of ions on the basis of:						
	6 Oxygens			24 (O, OH, F)			
Si	1.969	2.008	7.720	7.579	7.573	7.442	
Al	0.017	–	0.280	0.325	0.318	0.320	
Al	–	0.019	0.036	–	–	–	
Ti	0.014	0.002	0.218	0.183	0.204	0.200	
Fe^{+3}	0.058	0.060	1.200	1.200	1.058	1.039	
Fe^{+2}	0.608	0.573	2.768	3.074	2.364	2.244	
Mn	0.055	0.039	0.170	0.182	0.142	0.143	
Mg	0.454	0.491	0.913	0.615	1.492	1.489	
Ca	0.762	0.711	1.025	0.953	1.076	1.056	
Na	0.083	0.093	1.552	1.375	1.614	1.396	
K	0.001	0.005	0.214	0.224	0.179	0.184	
OH			0.181	1.127	0.823	1.914	
Z	1.99	2.01	8.00	7.90	7.89	7.76	
Y	1.19	1.18	5.31	5.25	5.26	5.12	
X	0.85	0.81	2.79	2.55	2.87	2.64	
Mg	23.4	26.2	100 Mg/				
Fe	37.2	35.9	($Mg+Fe^{+3}+Fe^{+2}+Mn$)				
Ca	39.4	37.9	18.1	12.1	29.5	30.3	

1 and 2. Sodic ferroaugite, augite syenite, January nunatak, E.G. 4681.

3 and 4. Greenish richteritic low-Al_2O_3 katophorite, augite syenite, January nunatak, E.G. 4681.

5 and 6. Brownish richteritic low-Al_2O_3 katophorite, augite syenite, January nunatak, E.G. 4681.

7. Green amphibole enclosed within brownish katophorite, augite syenite, January nunatak, E.G. 4681 (partial analysis).

Anal. R. F. Symes (by microprobe).

Total iron is reported as FeO. The probe analyses were made using a Cambridge Instruments Geoscan at an accelerating voltage of 15Kv and a current of 0.6×10^{-7} amps. Analysed silicates, oxides and pure metals were used as standards. Results were corrected after the method outlined in Sweatman & Long (1969) using the B.M.–I.C.–N.P.L. Computer Programme. For the purpose of calculation, the Fe_2O_3 values (in square brackets) have been estimated, and H_2O^+ given by difference from total of 100.00 %.

pyroxene crystals, shows a gain in total iron (Table V, nos. 3 and 4) whilst the brown amphiboles, forming large discrete crystals, show a loss (relative to the green amphiboles) of iron accompanied by an increase in MgO and a very slight loss in K_2O (Table V, nos. 5 and 6). Occasional small pyroxenes, of which an example was found within one of the discrete brown amphibole crystals, have been converted to amphibole with the usual high iron content but retaining the high CaO, moderate to high MgO, and low Na_2O of the pyroxenes (Table V, no. 7). Small prisms of apatite are abundant, usually enclosed in the ferromagnesian minerals, and other accessories include iron oxide, biotite, sphene (absent from the less syenitic rocks) and, more rarely, zircon. There are some examples of prismatic crystals probably of amphibole pseudomorphed by a felt of small crystals of lepidomelane. Occasionally the highly syenitized rocks contain some albite, interstitial to the larger alkali feldspars, augitic pyroxene completely replaced by aegirine-augite, and an amphibole in which the dominant pleochroism is yellow and red, and which partially replaces the sodic pyroxene.

The 'Junction' nunatak rocks also show a gradation from basaltic types to syenite, although a less precise series is apparent. A section containing a residual xenolith of basalt illustrates the transition to syenite. The basalt consists of small crystals of pyroxene, hornblende and iron oxide, in a groundmass of granular andesine. There is a little biotite and scattered altered phenocrysts of pyroxene. The syenitic areas have large alkali feldspars, a little quartz, pale katophoritic amphibole, very pale green pyroxene and iron oxide. The intermediate, monzonitic stage (Table VI, no. 8) is represented by rocks containing large crystals of albite-oligoclase, locally coarsely perthitic. Some three per cent of quartz is present and the augite is altered to an amphibole strongly zoned from olive-green to the yellow-red-blue of the katophorite. Apatite, again enclosed in the ferromagnesian minerals, is the main accessory, together with iron oxide and a few small crystals of chevkinite. The syenites themselves (Plate 6; Table VI, no. 7) are very similar to those of the 'January' mountains; chevkinite is an additional accessory mineral and the rocks resemble the outer quartz-nordmarkite of the main intrusion.

d. Bagnæsset Syenite

The main mineral forming the Bagnæsset syenite (Table VI, nos. 3 and 4) is a coarse perthitic alkali feldspar. It is relatively enriched in the potassium phase and has an obliquity ranging from 0.37 to 0.78, with separation of the $\overline{2}01$ peaks of the sodium and potassium phases of 1.03 and 1.10°2θ, respectively. A little quartz is present, locally enriched in veins where it is associated with albite.

This nordmarkitic rock contains largely altered greenish pyroxene crystals (probably augitic), apparently altering to a greenish-brown amphibole resembling that from the Snout Series (Table IV, no. 3). The total amount of pyroxene and amphibole is approximately constant, whilst the relative proportions vary. A brown biotite is present in small amounts, together with a little muscovite, very small crystals of sphene and apatite—sometimes occurring as inclusions—and iron oxide. Finally, the accessory mineral chevkinite is present in probably the greatest abundance of all the Kangerdlugssuaq syenitic rocks. It forms square or prismatic crystals and occasionally has apophyses extending between cumulus crystals of alkali feldspar, thus revealing itself as a late-stage (although high-temperature) mineral. Possibly the Bagnæsset syenite also resembles the Snout Series syenite in having crystallized at a higher temperature than the remainder of the minor syenites; some support for this suggestion derives from the relatively low obliquity of some of the feldspars.

e. Snout Series and Biotite Granite

The Snout Series syenite and the Granite south of the Amdrup Fjord both post-date the main plutonic series (Plates 1 and 2). South of Søndre Syenitgletscher, the syenite contains partially digested basaltic, and locally, doleritic xenoliths (Plate 7), giving rise, as with the earlier minor intrusions, to augitic microsyenite in which the diopsidic augite is mantled by sodic pyroxene. The granite consists of quartz, perthite, andesinic plagioclase, and partially chloritised brown biotite, with skeletal iron oxide, apatite, and zircon as accessory minerals. There are intermediate sodic granites ('syenogranites'), containing some 20 per cent of quartz (Plate 8, Fig. 1).

About 90 per cent of the pale, fine- to medium-grained syenite is a coarse low-albite-orthoclase microperthite, differing from the feldspar of the earlier intrusions in the coarseness of the exsolution lamellae, the well-twinned (Carlsbad and Manebach) tabular habit, more potassic composition (Or_{44}) and monoclinic symmetry. In the first three respects it closely resembles the alkali feldspar in the main pulaskite, although in the latter the feldspar has a high obliquity. The Snout Series feldspar, however, locally occurs in large fine-lamellaed phenocrystic crystals, sometimes zoned or mantled by coarser perthite. The separation of the $\bar{2}01$ peaks of the sodium and potassium phases in the microperthite averages $1.035°2\theta$; in this respect also it resembles the monoclinic phenocrystic microperthites of the main intrusion (Kempe & Deer, 1970). Fine-grained albite occurs interstitially and, in contrast to the earlier minor intrusions, quartz forms up to 6% of the rocks so that the Snout Series contains the most acid of the minor syenites.

Amphibole is the dominant ferromagnesian mineral, varying locally from a greenish-brown amphibole, mantling aegirine-augite and thus possibly derived from it, to scattered crystals of a sodic amphibole, either pale, dark greyish-green or reddish in colour. The pale variety appears to be the most common and an analysis is given in Table IV (no. 3): the amphibole (ferroedenitic hornblende) has affinities with katophorite and hastingsite. By comparison with the katophorite from the main quartz-nordmarkite (KEMPE & DEER, 1970, Table XII, no. 1), it is poorer in SiO_2, Fe_2O_3, Na_2O, and K_2O; and richer in FeO, but with a similar content of total iron, MnO, MgO, and CaO. A hastingsite from a porphyritic quartz syenite from the Marangudzi complex, Rhodesia, is included in Table IV (analysis A) for comparison. The amphibole may be associated with biotite, sometimes dark brown in colour, large euhedral sphene, and magnetite, the two latter minerals predictable by application of the 'ore potential' diagram (KEMPE & DEER, 1970, Fig. 20), together with chevkinite and sporadic zircon, apatite, and fluorite.

The Snout Series syenite differs from the earlier minor intrusions in its pale colour and often rather finer-grained texture, but more significantly in the monoclinic symmetry of the potassium phase of the microperthite, the nature of the amphibole, and the frequent presence of chevkinite (Plate 8, Fig. 2), indicating, by analogy with the outer, porphyritic quartz-nordmarkite of the main intrusion, a higher temperature of intrusion and/or faster rate of cooling. Other mineralogical features are the almost total absence of a sodic pyroxene, which is either altered or present only as an accessory, and the abundance of sphene and magnetite, in contrast with the ilmenite of the early minor intrusions.

III. CHEMISTRY OF THE MINOR INTRUSIONS

Although the syenites of the minor intrusions show variations in their mineralogy they can all broadly be classified as nordmarkites, in that they carry modal and normative quartz, the latter in amounts varying in the analysed rocks (Table VI and Plate 1) from 0.2% in the syenite of Peak 2005, to 1 to 6% in the Bagnæsset and augite syenites, 2 to 6% in the fayalite syenite of Kærven, and up to 10% in the syenites of the Snout Series. One of the latter (Table VI, no. 12) is exceptional in that although it contains 0.3% normative quartz its silica content is similar to that in the foyaites, the most undersaturated group of the main intrusion. The Kærven gabbro (no. 2) is also quartz normative which, together with normative hypersthene, indicates that it is tholeiitic and similar to the olivine gabbro of the southern marginal border group of Skærgaard (WAGER & DEER, 1939). Nepheline, both normative and modal, is absent from the peripheral intrusions, whilst normative acmite appears in only two of the analysed rocks: the syenite of Peak 2005, containing *ac* 8.0 and also 0.2 sodium disilicate; and a Kærven

Table VI. *Minor Periphera*

	1	2	3	4	5	6	7
SiO_2	38.36	51.57	64.92	65.30	57.76	64.16	60.6
TiO_2	0.32	0.74	0.54	0.50	1.43	0.68	1.5
Al_2O_3	1.60	18.58	17.53	17.14	17.14	16.08	16.5
Fe_2O_3	1.76	1.79	1.02	1.48	3.46	1.81	2.0
FeO	8.17	4.52	2.11	1.95	3.91	3.00	4.8
MnO	0.15	0.08	0.23	0.18	0.31	0.24	0.1
MgO	40.37	7.64	0.30	0.26	1.55	0.45	1.0
CaO	1.46	11.39	0.78	0.65	3.31	1.35	2.4
Na_2O	0.17	2.41	6.11	6.10	6.55	6.83	6.6
K_2O	0.01	0.78	6.12	5.91	2.61	4.02	3.6
H_2O+	5.32	0.15	0.27	0.41	0.32	0.27	0.
H_2O-	0.18	0.29	0.10	0.20	0.38	0.18	0.1
P_2O_5	0.04	0.02	0.06	0.06	0.79	0.25	0.
Total	99.51	99.96	100.09	100.14	100.31	99.72	100.
							Norn
q	–	0.27	3.08	4.93	1.92	5.70	1.
or	0.06	4.61	36.17	34.93	15.43	23.76	21.
ab	1.44	20.39	51.70	51.61	55.42	57.79	56.
an	3.57	37.58	2.34	1.94	9.67	1.35	4.
cor	–	–	–	–	–	–	
ns	–	–	–	–	–	–	
ac	–	–	–	–	–	–	
di	1.29	15.03	0.98	0.77	0.42	2.26	4.
hy	7.37	17.59	2.81	2.12	6.19	3.30	5.
ol	75.06	–	–	–	–	–	
mt	2.55	2.60	1.48	2.15	5.02	2.62	2.
hm	–	–	–	–	–	–	
il	0.61	1.41	1.02	0.95	2.71	1.29	2.
ap	0.09	0.05	0.14	0.14	1.86	0.59	0.

1. Peridotite, northwest of Kærven, E.G. 4867. Anal. J. H. Scoon. (Total includes CO_2, 0.28; Cr_2O_3, 0.95; NiO, 0.37).
2. Gabbro, Kartografvig, Kærven, E.G. 2751 (Ojha, 1966). Anal. W. A. Deer.
3. Syenite, southwest side of Bagnæsset, E.G. 2320. Anal. J. H. Scoon.
4. Syenite, southwest side of Bagnæsset, E.G. 2313. Anal. J. H. Scoon.
5. Augite syenite, January nunatak, E.G. 2078. Anal. C. J. Elliott and V. K. Din. (Total includes CO_2, 0.17; BaO, 0.57; SrO, 0.05).
6. Augite syenite, January nunatak, E.G. 4681. Anal. C. J. Elliott and V. K. Din. (Total includes CO_2, 0.17; BaO, 0.22; SrO, 0.01).
7. Augite syenite, 0.8 km north of E.G. 2047, Junction nunataks, E.G. 2050. Anal. W. A. Deer.
8. Augite syenite, southeast corner of Junction nunataks, E.G. 2047. Anal. W. A. Deer.

'ntrusions—Rock Analyses.

8	9	10	11	12	13	14	15	16
64.62	62.06	64.73	63.58	54.93	63.94	72.03	66.34	66.71
0.75	0.22	0.89	1.07	1.38	0.52	0.31	0.69	0.46
17.91	15.87	16.45	16.12	17.06	17.61	15.41	15.91	17.68
1.01	2.32	1.69	2.77	2.57	2.14	0.48	0.92	1.00
2.18	5.52	1.80	1.21	5.89	2.32	0.17	3.34	2.44
0.13	0.04	0.20	0.26	0.07	0.12	0.03	0.26	0.10
0.52	0.51	0.71	0.86	3.86	1.14	0.59	0.21	0.27
1.36	3.01	0.75	0.73	6.35	3.12	1.33	1.14	1.37
7.13	4.88	7.24	7.61	4.74	5.13	3.77	4.93	4.74
3.84	5.02	5.00	5.12	2.18	4.16	4.62	5.49	4.79
0.25	0.51	0.30	0.30	0.33	0.22	0.13	0.21	0.34
0.09	0.23	0.03	0.02	0.06	0.07	0.06	0.31	0.07
–	0.18	0.15	0.30	0.61	0.18	0.06	0.20	0.14
99.79	100.37	99.94	99.95	100.11	100.67	98.99	99.95	100.11
4.03	5.70	1.97	0.24	0.27	9.79	28.86	12.31	16.46
22.97	29.67	29.55	30.26	12.89	24.59	27.31	32.45	28.31
60.33	41.29	56.78	54.42	40.11	43.40	31.90	41.71	40.11
5.31	6.58	–	–	18.84	12.74	6.21	4.35	5.88
–	–	–	–	–	–	1.93	0.27	2.54
–	–	–	0.20	–	–	–	–	–
–	–	3.94	8.02	–	–	–	–	–
1.02	6.26	2.28	1.34	7.09	1.27	–	–	–
2.95	5.94	2.57	2.43	12.69	4.07	1.47	5.24	3.75
–	–	–	–	–	–	–	–	–
1.46	3.36	0.48	–	3.73	3.10	–	1.33	1.45
–	–	–	–	–	–	0.48	–	–
1.42	0.42	1.69	2.03	2.62	0.99	0.42	1.31	0.87
–	0.43	0.35	0.71	1.44	0.43	0.14	0.47	0.33

9. Fayalite syenite, northeast side of Notch Mountain, Kærven, E.G. 2670. Anal. W. A. Deer.
10. Fayalite syenite, Kærven, E.G. 2683. Anal. J. H. Scoon.
11. Syenite, Peak 2005, E.G. 4636. Anal. J. H. Scoon.
12. Syenite, 1320 m peak north of Søndre Syenitgletscher, at 2500 feet, Snout Series, E.G. 2626A. Anal. W. A. Deer. (Total includes SrO, 0.08).
13. Syenite, 1320 m peak north of Søndre Syenitgletscher, at 2500 feet, Snout Series, E.G. 2626B. Anal. W. A. Deer.
14. Biotite granite, Bear Ridge, south of Amdrup Fjord, E.G. 3142. Anal. W. A. Deer.
15. Red syenite, Jagtlejren, Kraemer Ø, E.G. 2380. Anal. W. A. Deer.
16. Grey syenite, Jagtlejren, Kraemer Ø, E.G. 2382. Anal. W. A. Deer.

syenite, *ac* 3.9. These rocks are, as discussed below, two of the three most closely resembling chemically the syenites of the main intrusion. Corundum (about 2%) is present in the norm of the Jagtlejren syenites and the granite; the latter also contains a little normative hematite. Thus, allowing for the higher proportion of ferromagnesian minerals in many of the minor syenites, their normative compositions are not greatly dissimilar compared with those of the units of the main intrusion.

It has been shown experimentally (Bailey, 1969) that acmite crystallizes only from a liquid containing excess sodium (di)silicate, either as a reaction relationship between iron oxide and liquid or by direct precipitation. The only rock from the Kangerdlugssuaq main or peripheral syenites to show *ns* (0.2) in the norm is the Peak 2005 syenite (Table VI, no. 11), which also has the highest normative *ac* (8.0). If excess sodium silicate is essential under all conditions for the formation of acmite in igneous rocks, it is considered by Bailey that it is the result of 'the continuous crystallization of other phases such as pyroxene (i.e. aegirine-augite) and feldspar, rather than by separation of iron oxides from a melt that had already achieved peralkalinity', and he has also questioned the compatibility of iron oxides and primary aegirine. In the Kûngnât series of syenites (Upton, 1960) and at Tugtutôq (Macdonald, 1966), oxides cease to be present in the modes coincident with the appearance of aegirine, and in the latter rocks *ns* appears in the norm as aegirine first shows in the mode. In the syenites of Sakhalin (Yagi, 1953), however, iron oxide and primary aegirine coexist, and in the main Kangerdlugssuaq intrusion limited amounts of oxide (ilmenite in the transitional, magnetite in the main pulaskite) occur with aegirine. In the syenites from Peak 2005 and Kærven such compatibility is again observed, and emphasises Bailey's plea for more detailed petrography and petrochemistry on peralkaline rocks. Bailey has also shown that under reducing conditions an arfvedsonitic amphibole is the stable phase in equilibrium with the liquid, instead of acmite, according to the equation:

5 acmite $+ 2H_2O \rightleftarrows 2$ arfvedsonite $+ 2\ (Na_2O.2SiO_2) + 2O_2$. Thus, as $\underline{P}_{O_2}$ increases, the reaction moves to the left with the formation of acmite. This is borne out in the main Kangerdlugssuaq intrusion where it has been shown that aegirine progressively coexists with and replaces arfvedsonite as the major ferromagnesian mineral up to and including the main pulaskite (after which, in the foyaite, it is replaced by aegirine-augite and melanite) as the partial pressure of oxygen increased.

In general, the minor syenites differ from the main nordmarkites in containing larger amounts of lime, magnesia, and (especially) iron, and smaller contents of alumina, potash and silica. These differences are especially marked in the Snout Series syenite which, as already noted,

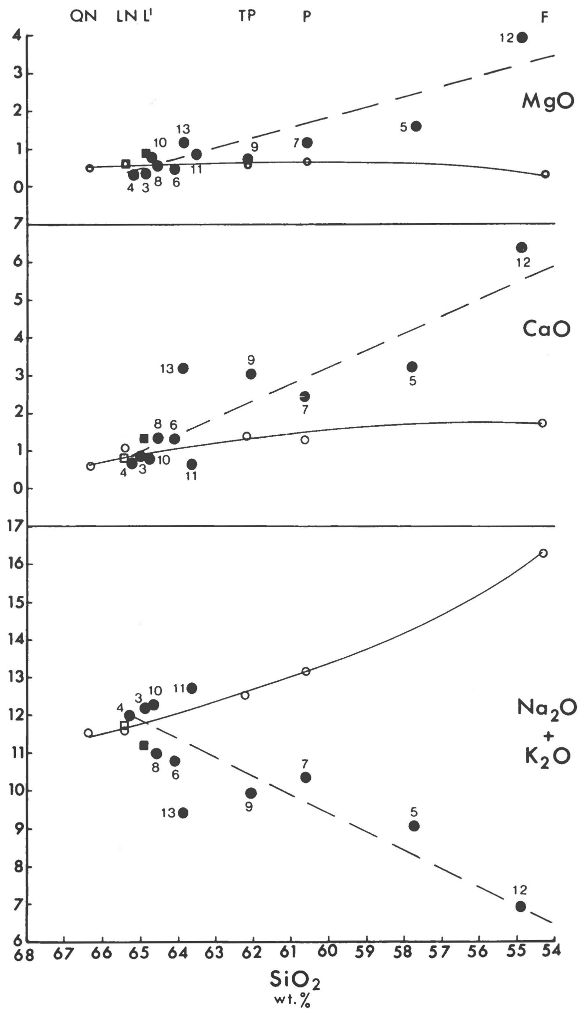

Fig. 1. Oxide variation in the peripheral syenites, plotted against SiO_2. Numbers (solid circles) refer to analysed rocks (Table VI); open circles: QN, average quartz-nordmarkite; N, average nordmarkite; TP, average transitional pulaskite; P, average pulaskite; F, average foyaite; L (open square), average composition of the main Kangerdlugssuaq intrusion (all from Kempe *et al.*, 1970); L' (solid square), average of the main and minor peripheral intrusions (Table VII).

appears to have crystallized at a higher temperature than the other minor intrusions. Total iron as Fe_2O_3, CaO, MgO, Al_2O_3, and ($Na_2O + K_2O$) are plotted against SiO_2 content, superimposed on the curves showing the variation of average amounts of these oxides for the five units of the main Kangerdlugssuaq intrusion (Figs. 1 and 2). Apart from the differences noted above, it can be seen that alumina remains approximately constant with change in silica content, lime and magnesia follow

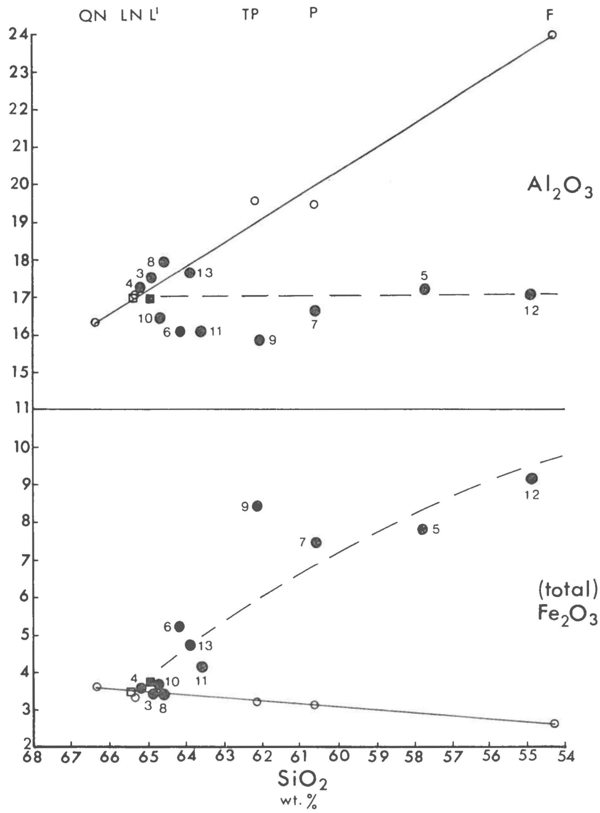

Fig. 2. Oxide variation in the peripheral syenites, plotted against SiO_2. Lettering and symbols as in Fig. 1.

similar curves to those of the main intrusion, whilst total iron rises steeply, inversely proportional to silica content, in contrast to its gentle decrease in the main intrusion. Finally, total alkalis decrease sharply but irregularly with silica, also in contrast to the increase shown by the rocks of the main intrusion. The plots for the Peak 2005 and Bagnæsset syenites and for one analysis each of the 'Junction', 'January', and Kærven syenites fall close to the curves for the main intrusion, indicating strong consanguinity, although the Bagnæsset syenite may have crystallized at a slightly higher temperature than the others. The second analyses of these last three intrusions have lower alkali and higher iron contents, due to their contamination by basalt xenoliths. As mentioned earlier, the Jagtlejren, Kraemer Ø, syenites (Table VI, nos. 15 and 16) show some degree of similarity with the inner minor intrusions. An unpublished analysis of a gneiss inclusion in the Bagnæsset syenite closely resembles that of a Kærven syenite (Table VI, no. 9), especially in alkali contents, except that the norm contains some 2.5 per cent *cor.* Gneiss

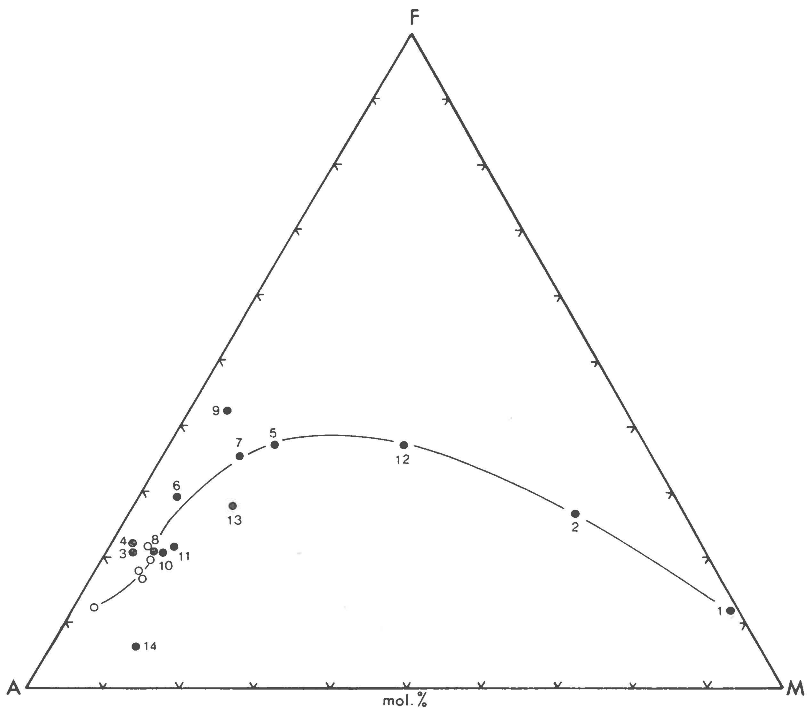

Fig. 3. FMA diagram of the Kangerdlugssuaq peripheral syenites. Numbers refer to analysed rocks (Table VI). Open circles, from F towards A, are the average quartz-nordmarkite, nordmarkite, transitional pulaskite, pulaskite, and foyaite.

inclusions are remarkable for their rarity, and only one other example—from the main Kangerdlugssuaq intrusion—has been noted (Kempe *et al.*, 1970, p. 22).

The biotite granite and the Snout Series are chemically dissimilar. The contrast of the latter, which is also contaminated locally by basalt xenoliths, in relation to the other minor syenite intrusions, may result from a higher temperature of crystallization, as shown by its mineralogy, and is perhaps indicative of its formation from a differentiated magmatic fraction. However, its high temperature of crystallization may result partially from its intrusion into the main Kangerdlugssuaq alkaline intrusion when the latter was still hot; in contrast, the earlier minor intrusions were intruded into cold country rock, the basement gneiss. Plotted on the FMA diagram (Fig. 3), it can be seen that both earlier and later peripheral intrusions are less highly fractionated than the main mass. This is most noticeable in the case of the contaminated samples, especially that from the Snout Series (Table VI, no. 12), supporting the suggestion that this group originated from a different liquid. From this extreme position, the other analysed rocks trend towards, and almost reach, the average nordmarkitic compositions.

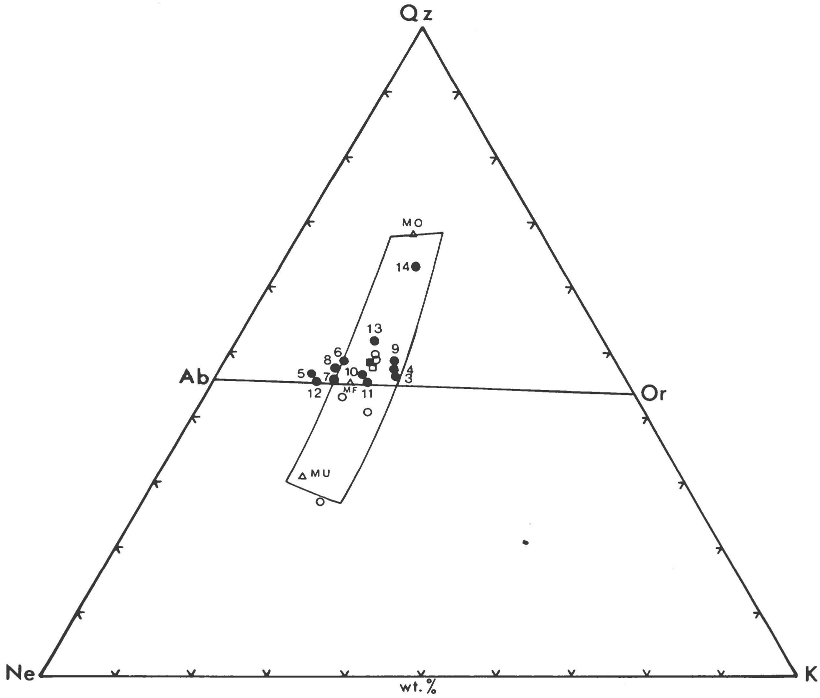

Fig. 4. Peripheral intrusion rock analyses plotted in the normative system Qz–Ne–Ks. Numbers refer to analysed rocks (Table VI). Open circles, from Qz to Ne, are the average quartz-nordmarkite, nordmarkite, transitional pulaskite, pulaskite, and foyaite. Open square, average composition of the main Kangerdlugssuaq intrusion. Solid square, average composition of the main and minor peripheral intrusions. Minima, drawn at P_{H_2O} = 1000 bars: MO, oversaturated minimum at 715° C; MF, feldspar minimum at 865° C (both from Tuttle & Bowen, 1958); MU, undersaturated minimum at 750° C (Hamilton & MacKenzie, 1965). Low-temperature valley after Bowen (1937).

The normative constituents of the analysed rocks are plotted in the triangular system Qz–Ne–Ks (Fig. 4). The uncontaminated Kærven and Peak 2005 syenites lie within the cluster of main unit analyses, represented by five average compositions (Table VII, nos. 1 to 5), whilst the 'Junction' and 'January' augite syenites fall closer to the albite composition. The Bagnæsset syenites lie on the potassic side of the group, whilst the Snout Series and granite compositions follow the fractionation curve, trending towards the low temperature (granitic) minimum. The average composition (L') of the whole intrusive complex (Table VII, no. 7), calculated from the proportional areal values, is fractionally poorer in Ks and richer in Qz than the average (L) for the main intrusion (Table VII, no. 6). Thus the earlier conclusion (Kempe *et al.*, 1970), that the average composition of the main intrusion, corresponding to a quartz-poor nordmarkite, and considered closely to approximate the quartz-trachytic composition of the initial magma, is not materially affected when all the peripheral intrusions are included. It is therefore concluded that the minor intrusions represent earlier plutonic events that emanated from the same source as the main Kangerdlugssuaq intrusion, and a few later events emanating from the same magma source, now depleted in some components and enriched in others.

Table VII. *Kangerdlugssuaq Alkaline Intrusions—Average Compositions.*

	1	2	3	4	5	6	7
SiO_2	66.36	65.40	62.18	60.63	54.30	65.40	64.90
TiO_2	0.70	0.70	0.66	0.90	0.40	0.71	0.72
Al_2O_3	16.37	17.04	19.56	19.46	23.97	16.99	16.96
Fe_2O_3	1.29	1.46	1.71	1.50	1.67	1.40	1.46
FeO	2.09	1.67	1.31	1.44	0.81	1.83	2.02
MnO	0.14	0.10	0.09	0.19	0.09	0.12	0.12
MgO	0.50	0.58	0.53	0.60	0.26	0.54	0.79
CaO	0.59	1.02	1.40	1.28	1.72	0.86	1.32
Na_2O	6.33	6.43	7.60	7.15	9.92	6.48	6.26
K_2O	5.16	5.17	4.83	5.98	6.30	5.20	4.96
H_2O+	0.25	0.15	0.16	0.51	0.59	0.22	0.23
H_2O-	0.09	0.06	0.07	0.19	0.14	0.08	0.09
P_2O_5	0.18	0.16	0.31	0.12	0.18	0.17	0.17
Total	100.05	99.94	100.41	99.95	100.35	100.00	100.00
			Norms				
q	7.59	5.56	–	–	–	5.33	5.71
or	30.50	30.56	28.55	35.35	37.24	30.74	29.30
ab	53.56	54.40	57.65	46.26	18.51	54.83	52.92
an	1.02	2.37	4.92	3.35	2.28	1.92	3.48
ne	–	–	3.60	7.71	35.44	–	–
cor	–	–	0.03	–	–	–	–
di	0.61	1.34	–	1.76	1.40	1.02	2.68
wo	–	–	–	–	1.37	–	–
hy	2.81	1.68	–	–	–	2.10	1.76
ol	–	–	0.98	0.67	–	–	–
mt	1.87	2.12	2.48	2.17	1.74	2.03	2.11
hm	–	–	–	–	0.47	–	–
il	1.33	1.33	1.25	1.71	0.76	1.35	1.37
ap	0.43	0.38	0.73	0.28	0.43	0.40	0.40

1. Quartz-nordmarkite, main Kangerdlugssuaq alkaline intrusion. Average of 3 analyses.
2. Nordmarkite, main Kangerdlugssuaq alkaline intrusion. Average of 3 analyses.
3. Transitional pulaskite, main Kangerdlugssuaq alkaline intrusion. Average of 2 analyses.
4. Main pulaskite, main Kangerdlugssuaq alkaline intrusion. Average of 3 analyses.
5. Foyaite, main Kangerdlugssuaq alkaline intrusion. Average of 3 analyses.
6. Average composition of main Kangerdlugssuaq intrusion (KEMPE *et al.*, 1970, Table XI).
7. Average composition of main and minor peripheral intrusions.

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Færdig fra trykkeriet 7. dec. 1976

PLATES

Plate 1

Geological map of the minor peripheral intrusions, Kangerdlugssuaq, East Greenland. The small numbers represent analysed rocks.

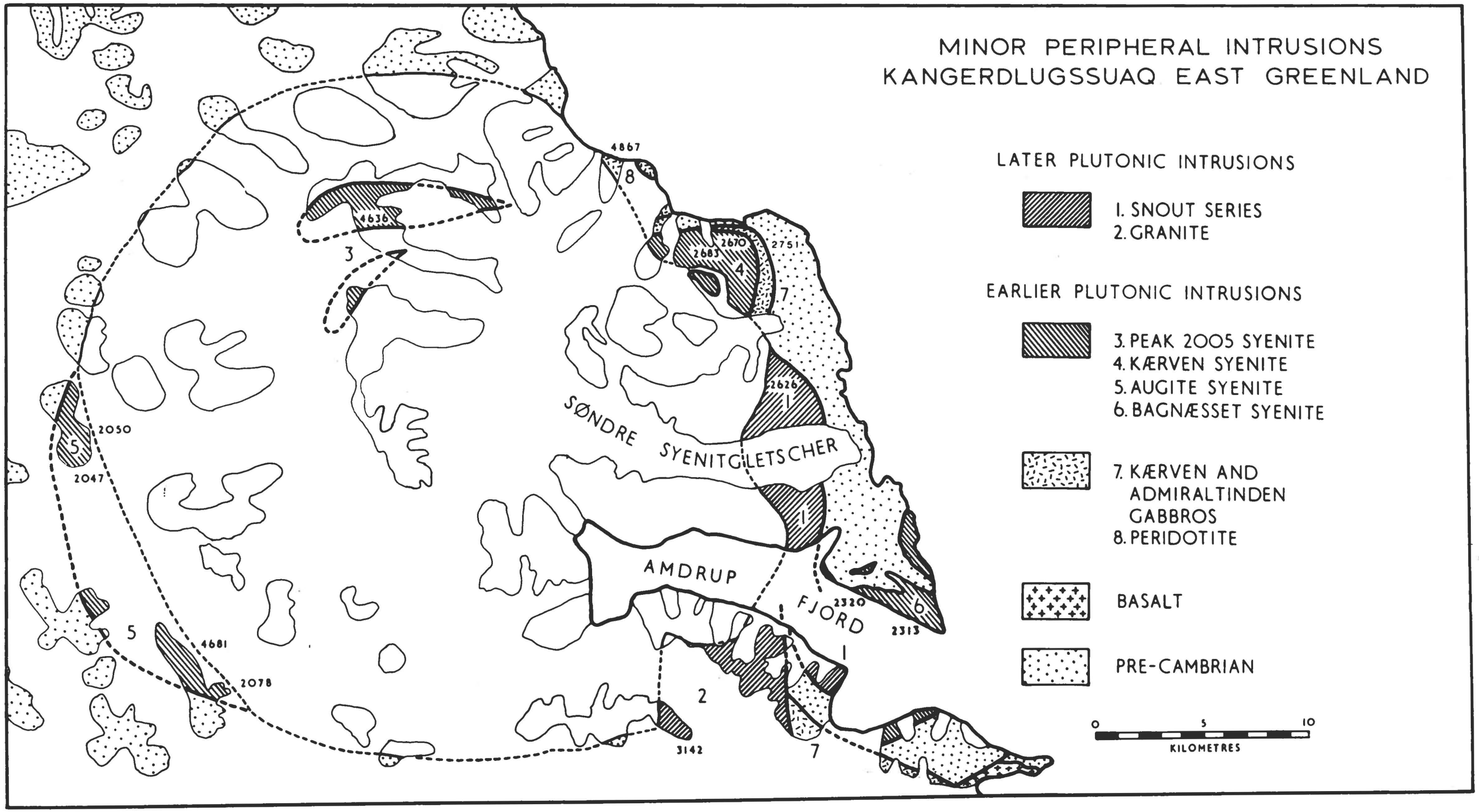
MINOR PERIPHERAL INTRUSIONS
KANGERDLUGSSUAQ EAST GREENLAND
LATER PLUTONIC INTRUSIONS
1. SNOUT SERIES
2. GRANITE
EARLIER PLUTONIC INTRUSIONS
3. PEAK 2005 SYENITE
4. KÆRVEN SYENITE
5. AUGITE SYENITE
6. BAGNÆSSET SYENITE
7. KÆRVEN AND ADMIRALTINDEN GABBROS
8. PERIDOTITE
BASALT
PRE-CAMBRIAN
0 5 10
KILOMETRES
SØNDRE SYENITGLETSCHER
AMDRUP FJORD
4867
4636
2683
2670
2751
2626
2050
2047
4681
2078
3142
2320
2313

Plate 2

The Kangerdlugssuaq intrusions from the Fjord, looking northwest. Photograph by L. R. WAGER, 1953. Gneiss stands for the basement complex of Precambrian metamorphic rocks; QN, quartz-nordmarkite and N, nordmarkite, of the main intrusion.

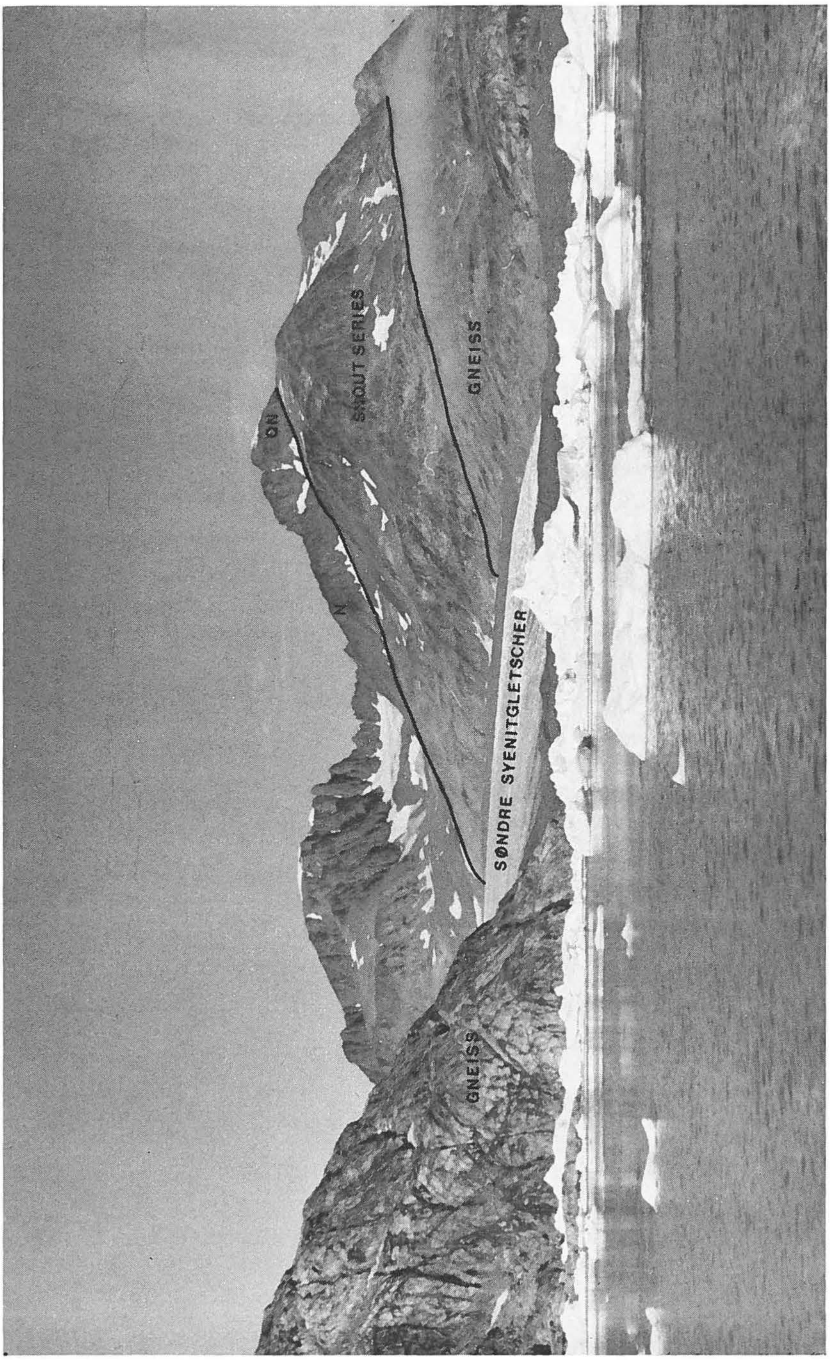
ON
N
SKOUT SERIES
GNEISS
SØNDRE SYENITGLETSCHER
GNEISS

Plate 3

Fig. 1. Photomicrograph of the Peak 2005 syenite. X17. Crossed nicols.

Fig. 2. Photomicrograph of the Kærven syenite, showing a crystal of fayalite (top right). X17. Crossed nicols.

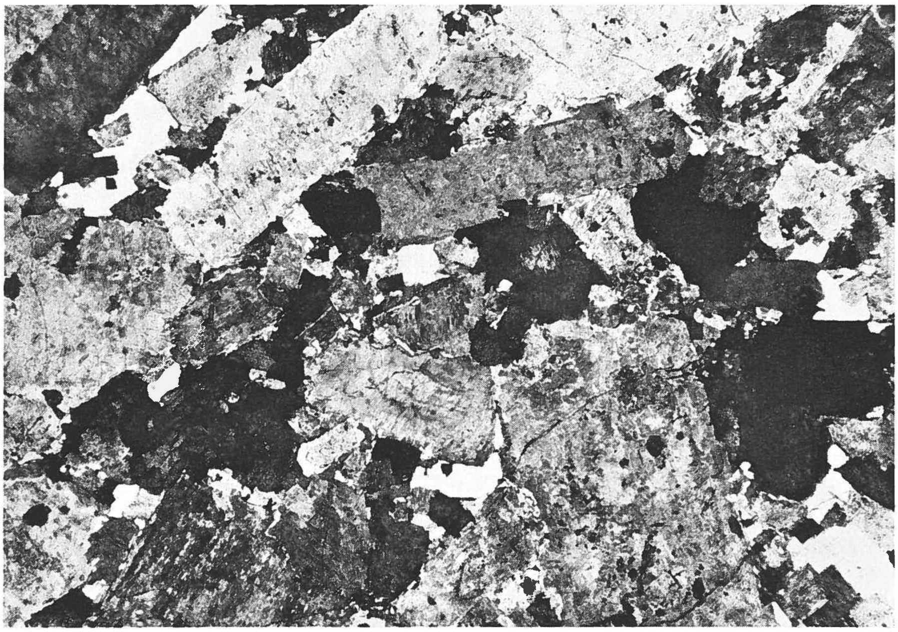

Fig. 1.

Fig. 2.

Plate 4

Fig. 1. Photomicrograph of partially digested basalt in the Kærven syenite. X17. Crossed nicols.

Fig. 2. Photomicrograph of an olivine basalt xenolith in the augite syenite, 'January' nunatak. X17. Crossed nicols.

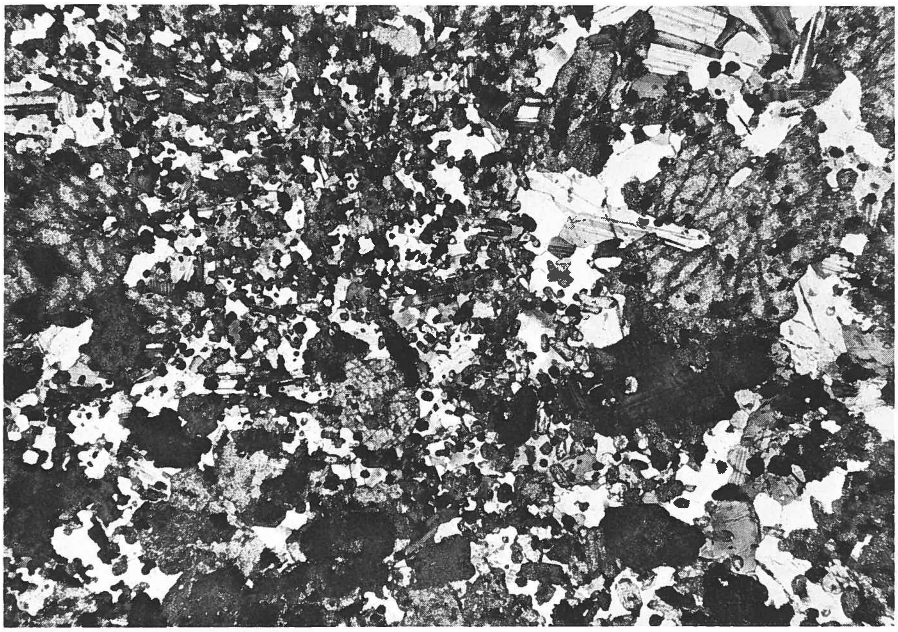

Fig. 1.

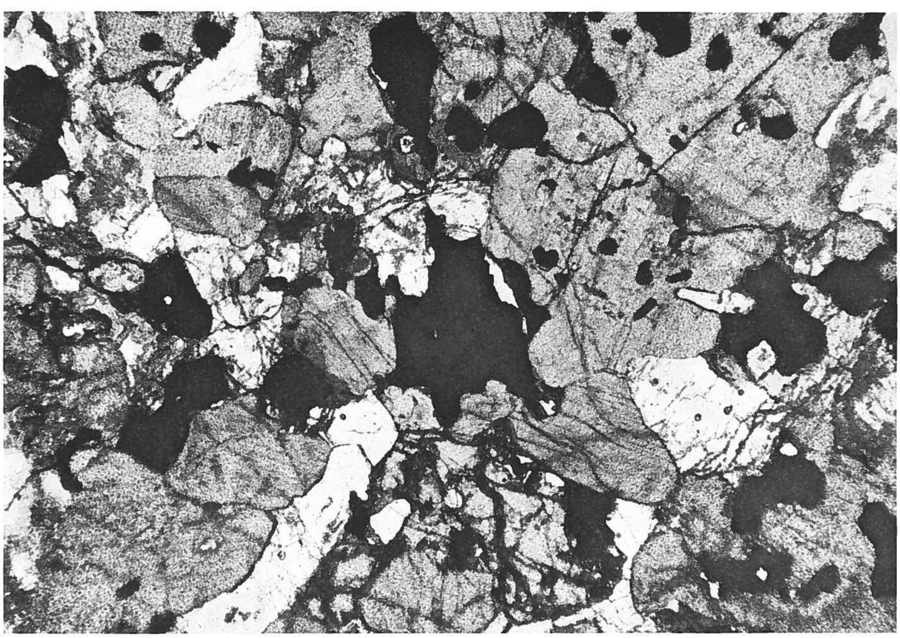

Fig. 2.

Plate 5

Figs. 1 and 2. Basalt xenoliths in the augite syenite, 'January' nunatak. Photographs by W. A. DEER, January 1930.

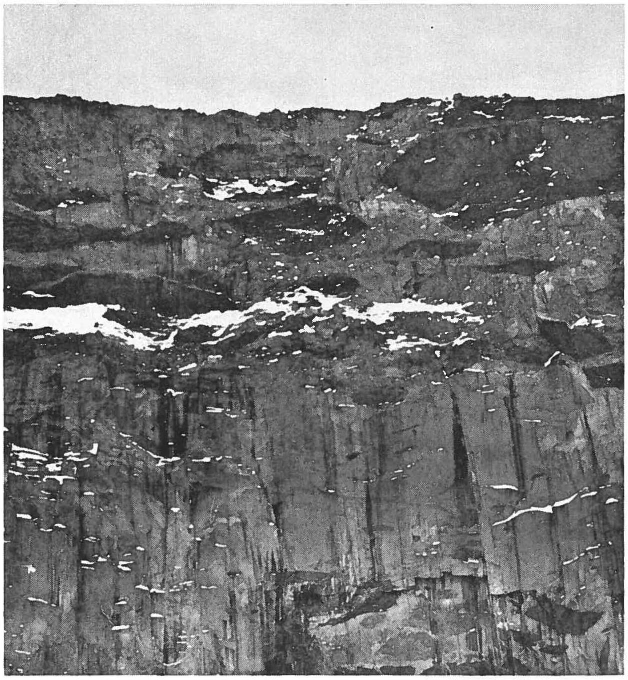

Fig. 1.

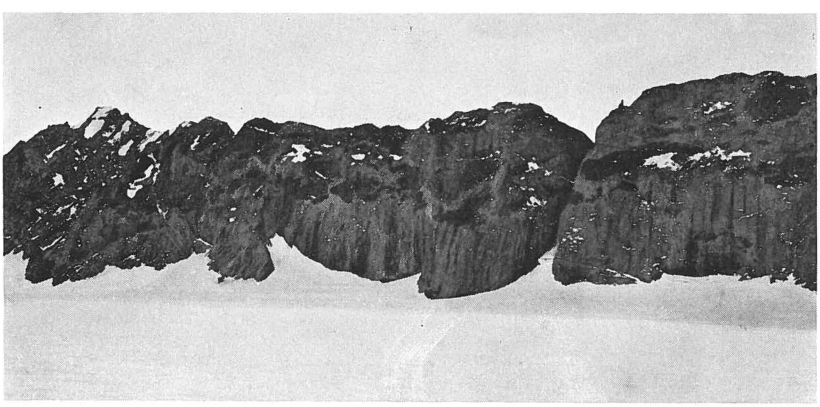

Fig. 2.

Plate 6

Fig. 1. Photomicrograph of the augite syenite, 'January' nunatak. X17. Crossed nicols.

Fig. 2. Photomicrograph of the augite syenite, 'Junction' nunatak, showing sodic amphibole and pyroxene and 'cored' alkali feldspar. X17. Crossed nicols.

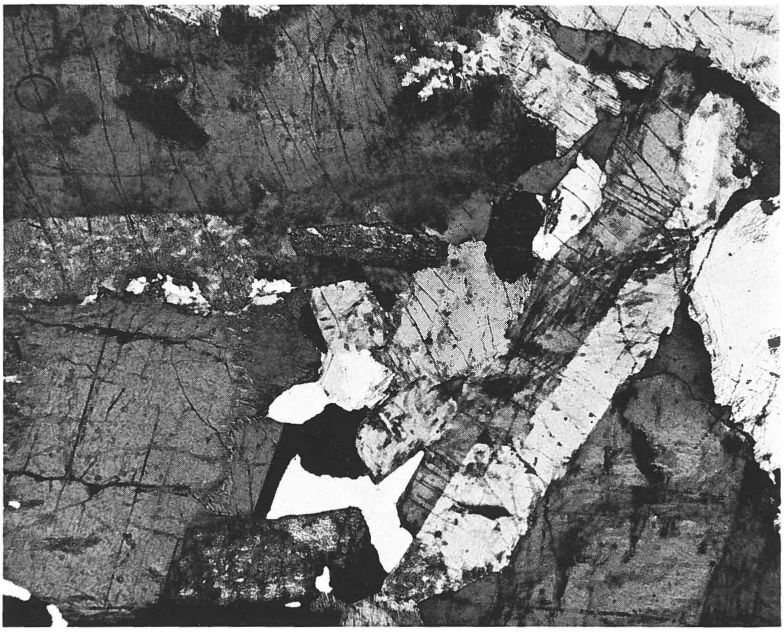

Fig. 1.

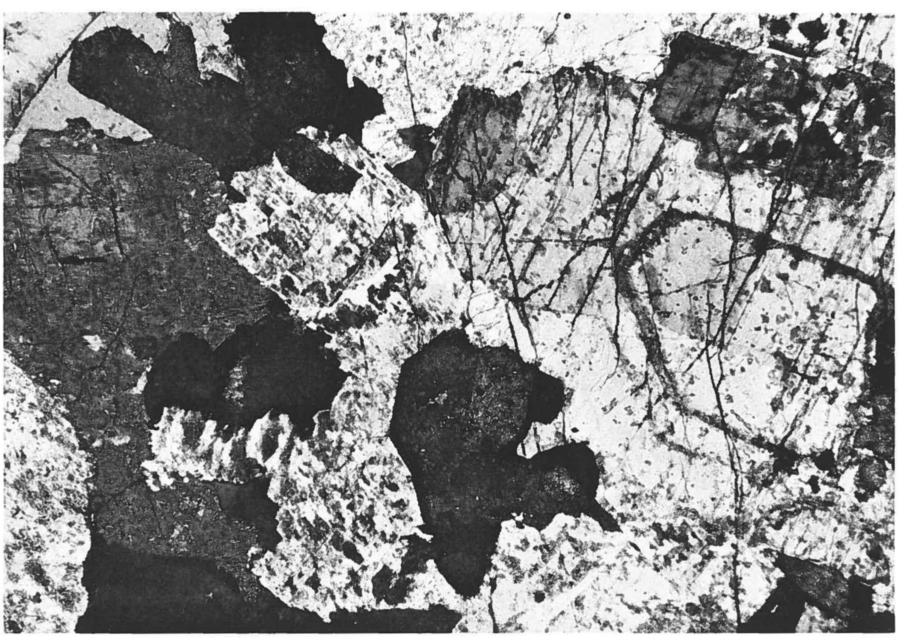

Fig. 2.

Plate 7

Fig. 1. Photomicrograph of a partially syenitized xenolith of poikilitic dolerite, showing the growth of large alkali feldspars, Snout Series. X17. Crossed nicols.

Fig. 2. Photomicrograph of microsyenite derived from a digested basalt xenolith, Snout Series. X17. Crossed nicols.

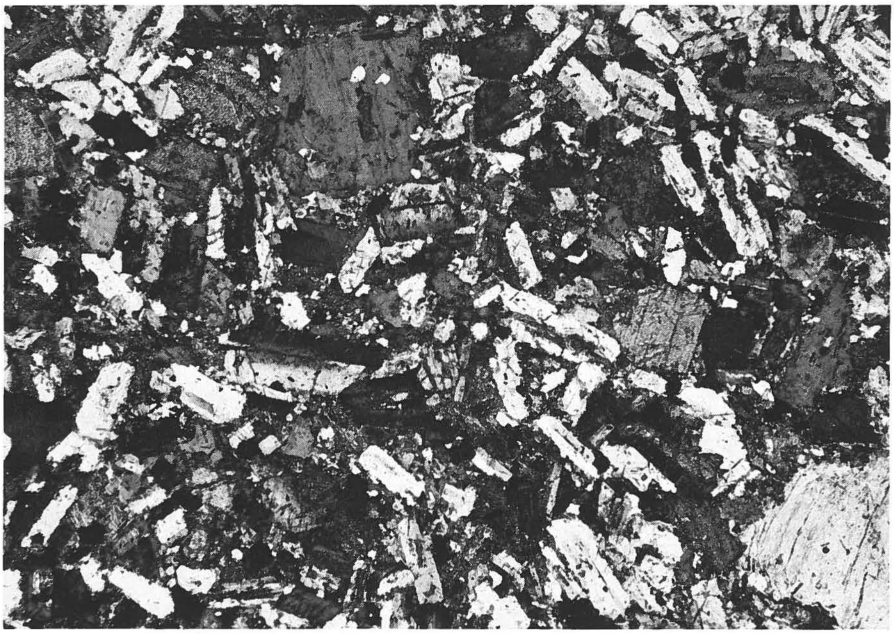

Fig. 1.

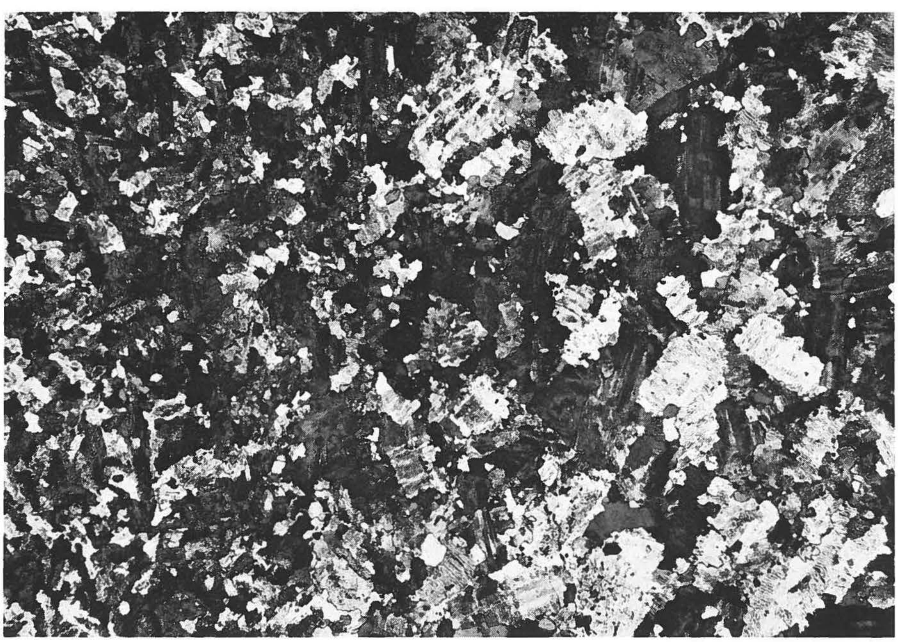

Fig. 2.

Plate 8

Fig. 1. Photomicrograph of the sodic granite ('syenogranite') from the Snout Series. X17. Plain light.

Fig. 2. Photomicrograph of the Snout Series syenite, showing a large crystal of chevkinite (top right, black, and kidney-shaped). X17. Plain light.

Fig. 1.

Fig. 2.