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THE GEOLOGY OF TWO SMALL LAYERED HORNBLENDE PERIDOTITE (PICRITE) PLUTONS IN SOUTH GREENLAND

BY

JEVAN P. BERRANGÉ

WITH 19 FIGURES AND 4 TABLES IN THE TEXT, AND 2 PLATES

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI A/S
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Abstract

Two ultramafic dykes, which pinch and swell both vertically and horizontally and have a form similar to some kimberlite bodies, were intruded 1700 to 1335 m.y. ago during the 2nd episode of Ketilidian plutonism. Contact metamorphism of the adjacent granite was slight – albite-epidote hornfels facies. Petrological, mineralogical and chemical evidence indicates that the parent magma was picritic in composition, that it underwent flowage differentiation as a result of rapid intrusion, and then magmatic differentiation with gravity settling. The internal picritic (chemical classification) layered group crystallised first and includes hornblende peridotites, hornblende-hypersthene peridotites and rare harzburgite. The border group which crystallised later is formed of hypersthene-olivine hornblendites that chemically are picrites, and mica hornblendites that chemically are monzonites with affinities to kentallenite. Hornblende gabbro is a minor late differentiate. Steeply dipping banding cuts the earlier rhythmic layering and is thought to have formed by diffusion of material into cooling cracks developed prior to complete solidification. There are local concentrations of sulphides and platinoids. Three complete silicate analyses and a number of analyses for the platinoids, Au, Cr, Co, Cu, Ni, Ag, Pb and Zn are presented.

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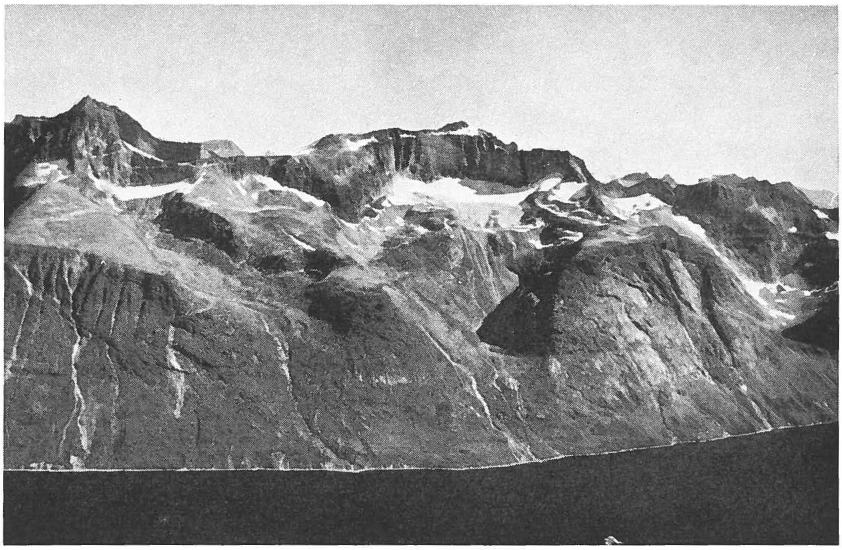

Fig. 1. Location of the Sarqâ pluton. The peak in the centre is the 1246 m summit. The Sarqâ pluton is seen as a dark dyke-like body cutting the ridge to the right of the summit. The fjord arm Sarqâ occupies the foreground. Photo by K. ELLITSGAARD-RASMUSSEN.

I. INTRODUCTION

This paper is a preliminary first account of the geology of two small layered hornblende peridotite (picrite) plutons mapped by the author whilst working for the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse). It is based mainly on the field observations but supplemented by a brief examination of thin and polished sections. In addition, three peridotite samples have been analysed for their major elements, the composition of the olivine in 39 samples has been determined by the X-ray diffraction technique of YODER & SAHAMA (1957), and the tenor of selected heavy metals, including those of the platinum group, has been determined by spectrographic analysis.

1. History of discovery and location

In September 1960 M. LORÉTAN found several boulders of mineralised ultramafite in a cirque facing Sarqâ fjord off Søndre Sermilik. Analysis of several samples showed some to be rich in copper, nickel and the platinoids and as a result the author was requested by the Director of GGU to find the source of the boulders and undertake any necessary detailed studies with a view to proving the possible existence of an ore body. In July 1962 a camp was made at 700 m on a small shelf on the east side of Sarqâ, and a small ultramafic pluton that was given the same name was discovered at *c.* 900 m by tracing boulders upslope (fig. 1). The following winter during a coordination meeting of GGU geologists, J. WATTERSON, who had been mapping in the area, mentioned the probable existence of two similar bodies on the opposite side of the fjord on Amitsoq and Angmalortoq islands. A helicopter reconnaissance of the islands in July confirmed the existence of these two suspected plutons.

The location of the bodies is shown on the index map accompanying Plate 1.

2. Field work

The Sarqâ pluton was mapped at a scale of 1:200 and the Amitsoq body at 1:400, but the Angmalortoq peridotite was not mapped as it is only exposed over an area of 9 × 8 m. Strategically located baseline control points were established at intervals along the length of the two larger bodies and painted on the rocks for future reference. A tape and Brunton transit survey was made of the baseline, and crosslines offset every 10 m. All geological detail and the location of every collected sample has been tied in with relation to this grid. As the Sarqâ and Amitsoq bodies have rhythmic layering and are exposed respectively over a vertical interval of 200 m and 335 m, the altitude of the control points and all collected samples was measured as accurately as possible with an altimeter. It is estimated that the maximum error in the absolute altitudes recorded on the map is 5 m, but that the altitude of one point or sample relative to nearby ones is accurate to within 2 m.

Wherever possible, samples were collected for a petrochemical study at a vertical interval of less than 20 m. In addition, samples were taken of layers, pockets and inclusions of differing composition, of the finer grained margins, and of the granite occurring as inclusions and adjacent to the contacts. Selected chip samples or representative chip samples were taken wherever mineralised rock was found. The rock was blasted wherever necessary in order to collect a large fresh sample or to determine the extent of the mineralisation.

II. AGE AND GEOLOGICAL SETTING

The Precambrian rocks of South Greenland have been assigned to three chronological periods—Pre-Ketilidian, Ketilidian and Gardar (Allaart, 1967). Table 1, based on Allaart (op. cit.), shows the generalised sequence of events and the rocks developed in the region.

The ultramafic plutons were intruded into the "microcline granites of Sermersôq-Tasermiut" (Allaart, 1964, p. 28) which have been mapped as early Sanerutian although "there is still not enough field evidence to rule out the possibility that they are late-Ketilidian in age" (Allaart, op. cit.; old terminology). The plutons have contact-metamorphosed the granite country rock and inclusions. They are not cut by any basic, granitic or pegmatitic dykes and are not faulted. Therefore, on the basis of field evidence the most that can be deduced is that the plutons are post-Ketilidian, i.e. younger than *c.* 1700 m.y.

A K/Ar age determination on a phlogopite-talc concentrate from a sample (GGU 24147, Age Determination Unit No. 65-2) from the Sarqâ pluton gave an age of 1335 ± 35 m.y. (Larsen & Møller, 1968) which would assign the bodies to the Gardar period. However, study of thin sections has shown that the phlogopite occurs late in the paragenesis and that the talc is of secondary origin. Furthermore the secondary alteration is so extensive as to suggest that it was not only due to autometasomatism but also to static recrystallisation (aided by abundant water), possibly resulting from the rocks being held at an elevated temperature for a considerable length of time. The date of the phlogopite-talc crystallisation can therefore only be regarded as a minimum for the emplacement of the plutons.

Prior to dating of the sample, Berrangé (1967) advanced reasons for supposing that the plutons were emplaced during the Gardar period. This was questioned by Emeleus (1967), and Walton (1967) who suggested that they belonged to the Sanerutian appinitic suite rather than the Gardar. In support of a Sanerutian age it should be noted that the Sarqâ-Amitsoq bodies appear to have some petrological affinity with the ultramafic layered masses (dated as 1650 m.y.) and associated with the Sydprøven granite (Bridgwater, 1963, p. 171, fig. 1; 1965, pp. 12, 31 and 52), and with early Sanerutian hornblende gabbro-olivine norite

Table 1. *Generalised geochronological table for South Greenland.*

		EVENTS AND PRODUCTS	GGU NOMENCLATURE 1962–1965
GARDAR *c.* 1450–1020 m.y.		Intrusion of alkaline, agpaitic & carbonatitic plutons	GARDAR
		Intrusion of DOLERITE DYKES	
		Extrusion of basic lavas	
		Sedimentation of continental arenites	
KETILIDIAN	2nd EPISODE PLUTONISM *c.* 1655–1530 m.y.	Intrusion of THOLEIITE DYKES	SANERUTIAN
		Development of NET-VEINED DIORITES	
		Passive remobilisation & emplacement of granites	
		Intrusion of SYNKINEMATIC BASIC & INTERMEDIATE DYKES	
		Migmatisation of older basic bodies	
		Emplacement of PYROXENE DIORITES & GABBROS, & HORNBLENDITES (APPINITIC SUITE)	
		Deformation, recrystallisation and emplacement of allochthonous granites	
		Intrusion of DOLERITE DYKES & HYPERSTHENE GABBRO	
	1st EPISODE PLUTONISM *c.* 1900–1700 m.y.	Plutonic activity, regional metamorphism, repeated deformation producing a gneiss and granite complex with metadolerites	KETILIDIAN
		Sedimentation, volcanism and pre-orogenic BASIC DYKING	
PRE-KETILIDIAN *c.* 2500 m.y.		Intrusion of BASIC DYKES	PRE-KETILIDIAN
		Plutonism, regional metamorphism, repeated deformation	
		Sedimentation & volcanism	

plutons in the "Vatnahverfi" area (BERRANGÉ, 1966). Furthermore, the chemistry of the Sarqâ-Amitsoq rocks is more typical of Sanerutian rather than Gardar intrusives (see p. 30).

At present it is only possible to state with certainty that the Sarqâ-Amitsoq plutons were emplaced not more than 1700 m.y.—and not less than 1335 m.y. ago.

III. CONTACT METAMORPHISM

The country rock that is not contact metamorphosed by the plutons is a very light grey (N8)*), medium-grained, hypidiomorphic-granular biotite granite containing scattered K-feldspar megacrysts. Thin sections of samples taken more than 50 m from the contacts show this granite to consist essentially of oligoclase, very finely perthitic microcline, quartz, myrmekite and relatively large crystals of brown biotite. All these minerals show undulose extinction indicative of straining. The textures are as described for hand specimens. Accessory minerals include opaque oxide, sphene, apatite, zircon and a trifle secondary chlorite, pistacite and sericite.

The first signs of contact metamorphism are seen 100 cm, and in most places only 50 cm, in from the contacts. This manifests itself by a darkening of the granite which changes from the normal very light grey (N8) through a light grey (N7) *c.* 50 cm from the contact to a medium light grey (N6) at the contact. Thin section study shows that this darkening can be correlated with progressively increasing alteration of the feldspars which become completely clouded with very fine secondary material that includes sericite and calcite. Other changes are the disappearance of sphene, and reddening of the biotite which is progressively recrystallised until it all occurs as a decussate aggregate of tiny flakes. Some of the biotite is chloritised. There is an increase in strain phenomena and intergrowth textures—microperthite, myrmekite and micropegmatite, this last not being found in the unaltered granite.

Granite samples from immediately adjacent to the contact or from inclusions within the plutons have abundant secondary calcite, and the biotite is mostly broken down either into green chloritic material or a clino-amphibole, identified in one sample as actinolite. The quartz has been redistributed and is either very scarce or occurs in large "pools". A thin section taken 10 cm from the contact of a granite inclusion measuring *c.* 100 × 30 cm has a mineral assemblage comprising K-feldspar?-andesine-quartz-calcite-actinolite which would apparently assign it to

*) Rock colours determined by comparison with the Rock Colour Chart distributed by The Geological Society of America.

the albite-epidote hornfels facies that attains equilibrium at temperatures between 400° and 540° C (WINKLER, 1967).

It will be shown that the parent magma of the plutons was picritic in composition. Even allowing for lowering of the temperature by partial crystallisation (olivine) and saturation with water, its temperature at depth must have been in the order of 1200° C (DREVER & JOHNSTON, 1967b). The low thermal metamorphism can be accounted for as follows: although the country rocks were apparently only metamorphosed to the albite-epidote hornfels facies, a granite would tend to be less sensitive than metasediments to thermal effects and so the facies may not be a reliable guide to the physical conditions in the adjacent and included rocks. The tendency of the plutons to become narrower with increase in altitude suggests that the bodies are not feeders up which large volumes of magma moved to supply high-level plutons. It will be shown that the magma underwent flowage differentiation during intrusion. This requires that it was emplaced at a high velocity or that it had a low viscosity, or both. From the above considerations it follows that a small volume of magma was intruded at a considerable velocity over an appreciable vertical interval. Contact metamorphism under these conditions can be expected to be minimal.

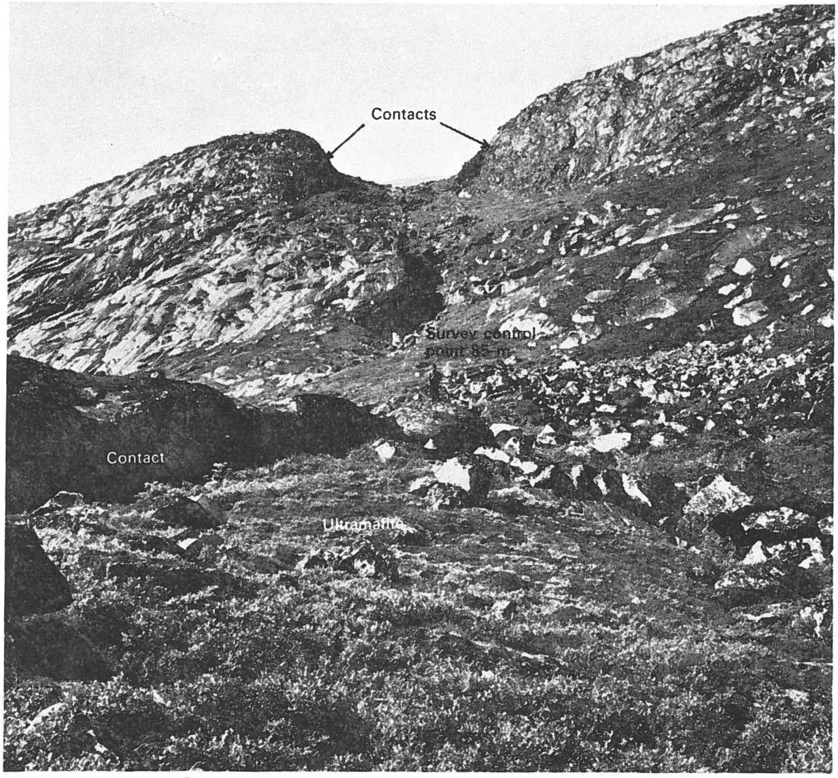

Fig. 2. Amitsoq viewed from near sea level.

IV. SHAPE AND SIZE

As shown on Plate 1 the plutons have a most unusual shape. Although not typical dykes they can be described as dyke-like bodies that pinch and swell in both the horizontal and vertical directions (figs. 2, 3, and 4). Their contacts are most commonly either vertical or dip steeply inwards at more than 45°, although locally, outward dips of up to 53° have been measured. The straighter and more dyke-like portions generally have the steep dips whereas the flatter inward-dipping portions of the contact occur around the bulbous swells or "blows". Where outward dips occur, as on the north wall of the Sarqâ pluton (fig. 3) it is reasonable to infer that the contact forms the roof of the bulbous swell underneath. In the upper portion (above the 185 m control point) of the Amitsoq body the granite floor is only a few metres below the present-day surface of peridotite outcrop and/or rubble and is in fact exposed at three localities. The asymmetrical shape of the topmost chamber as shown

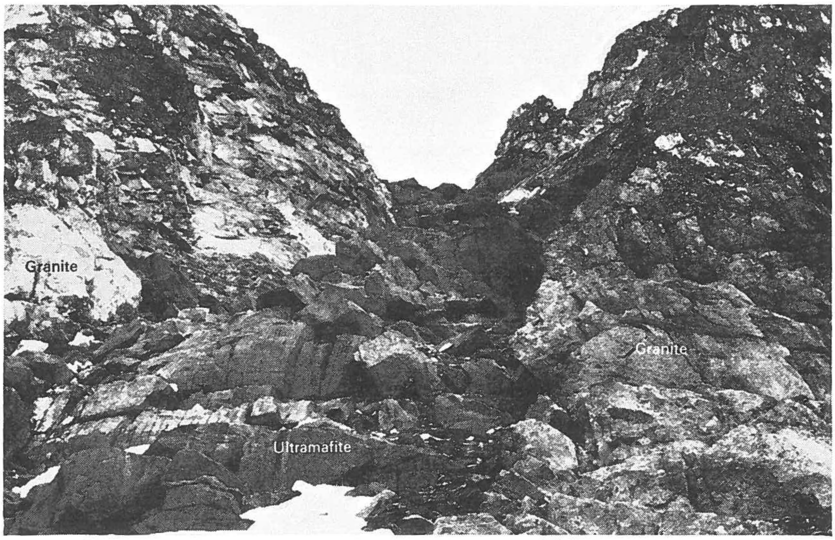

Fig. 3. Sarqâ pluton viewed from the southwest end. Note the pinch and swell form (photographically distorted) on the right and the outward dipping contact on the left. Rhythmic layering visible on the lower outcrops.

on the map of this body (Plate 1) is due to the intersection of an uneven topography with an uneven lower contact.

The Angmalortoq pluton is 9 m wide where exposed on the shore of the fjord. Its contacts here are vertical and trend approximately west. This exposure is near the western end of the pluton which does not extend more than *c.* 12 m inland, or higher than 20 m above sea level.

The Amitsoq pluton (fig. 2) trends approximately west and is exposed from sea level to a col at 335 m on the top of the island. Judging from the distribution of peridotite float and granite bedrock, the pluton may have once extended a few tens of metres further west across the col before pinching out. However, a magnetometer survey made by A. KETELAAR (verbal communication) in this area suggests that the extension must have been in the form of a floored chamber now completely eroded away. The mapped exposure is *c.* 660 m measured at a mean gradient of 32°. The pluton consists of two discrete portions probably connected at depth but separated at the surface by 53 m of granite. In the higher portion there is a very narrow neck only 8 m wide, a short distance above which the body widens to form large chambers up to 128 m wide.

The Sarqâ pluton (figs. 3 and 4) is exposed in the precipitous walls of two cirques separated by a ridge. The mapped portion varies in width between 13 and 36 m and trends approximately NNE for a distance of

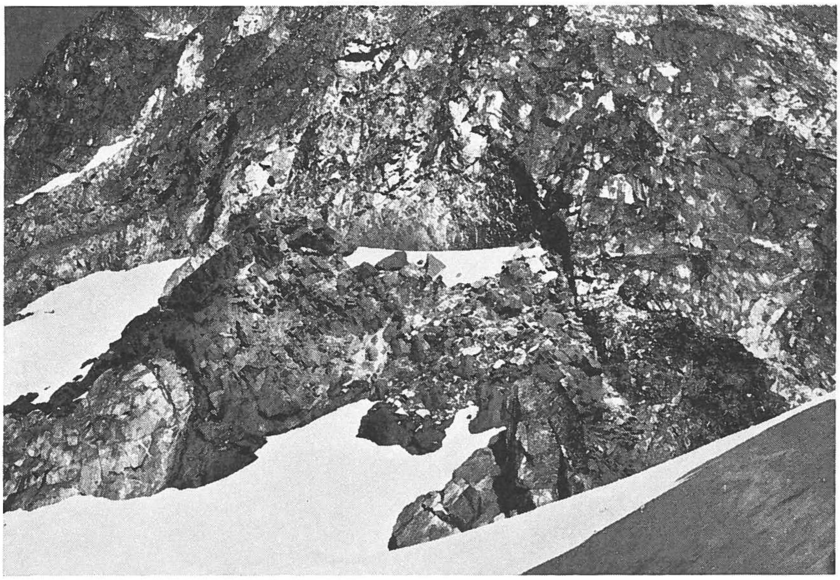

Fig. 4. A swell at the northeast end of the Sarqâ pluton. Note the outward dipping contact.

322 m measured at a mean gradient of 32°. At the north-east end it strikes into the corrie glacier and is presumed to continue for another 500 to 600 m in the same direction before making a 90° bend and striking south-east across the 1050 m ridge between Qingârssûp qâqâ and the 1246 m summit (figs. 1 and 5). This portion of the body is inaccessible and could only be studied where it meets the corrie glacier. It is *c.* 4–10 m wide, pinches and swells, has faint rhythmic layering and is formed of the same rocks as the mapped portion. At its south-west end this pluton is at an altitude of 769 m, it was mapped over a vertical height of 200 m to 969 m but the inaccessible portion is exposed for another 100 m of altitude.

A composite picture of the two plutons shows that there is a tendency for them to become narrower with increasing altitude. Plate 1 shows that the Amitsoq body which was mapped at 1:400 is much wider than the Sarqâ one which was mapped at 1:200.

An examination of aerial photographs shows that the country rocks on Angmalortoq and Amitsoq are traversed by two sets of steeply dipping fractures or joints trending respectively east and north-east (fig. 5). The east-trending set has apparently governed the attitude of the Amitsoq and Angmalortoq bodies and it also seems probable that the swell of the upper part of the Amitsoq pluton was facilitated by the intersection of an east with a north-east trending fracture at this locality. Snow hides the joint pattern on the mainland around the Sarqâ pluton.

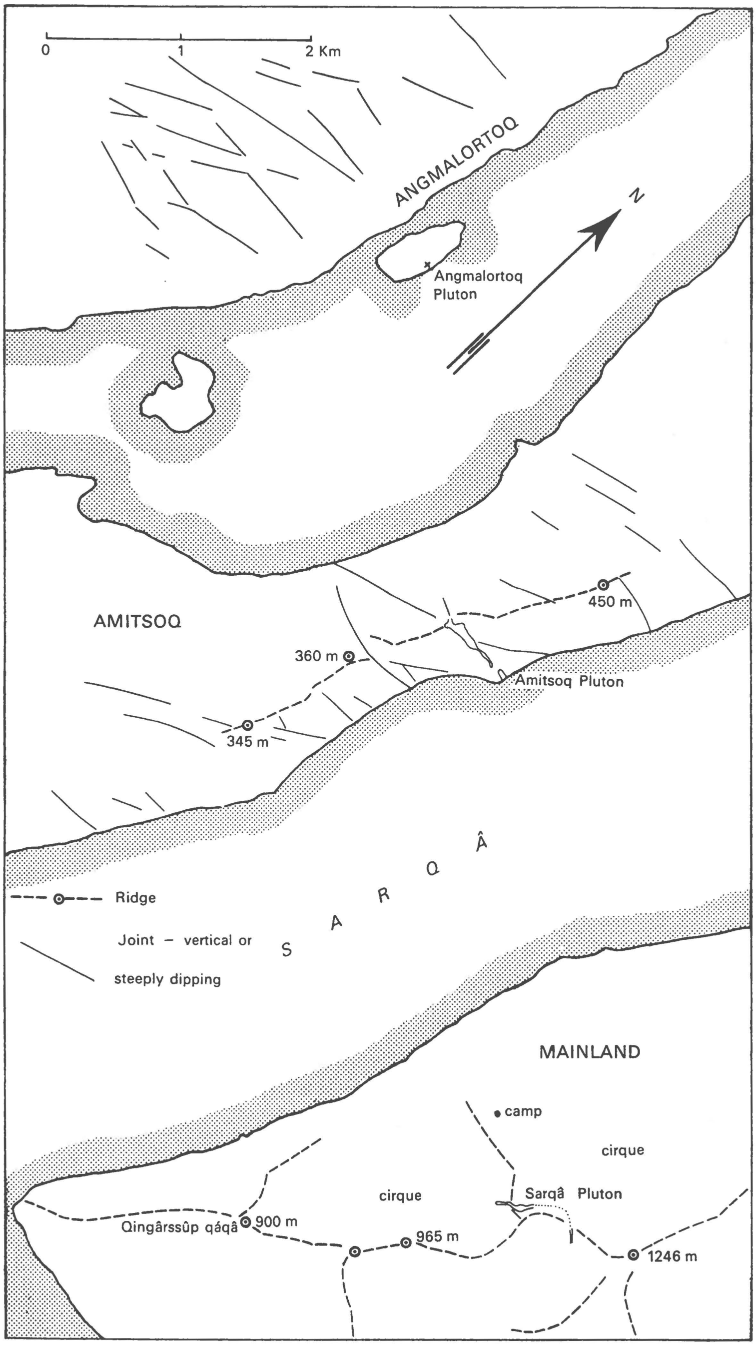

Fig. 5. Sketch map showing the location of the ultramafic plutons and the control on their attitude exercised by joints.

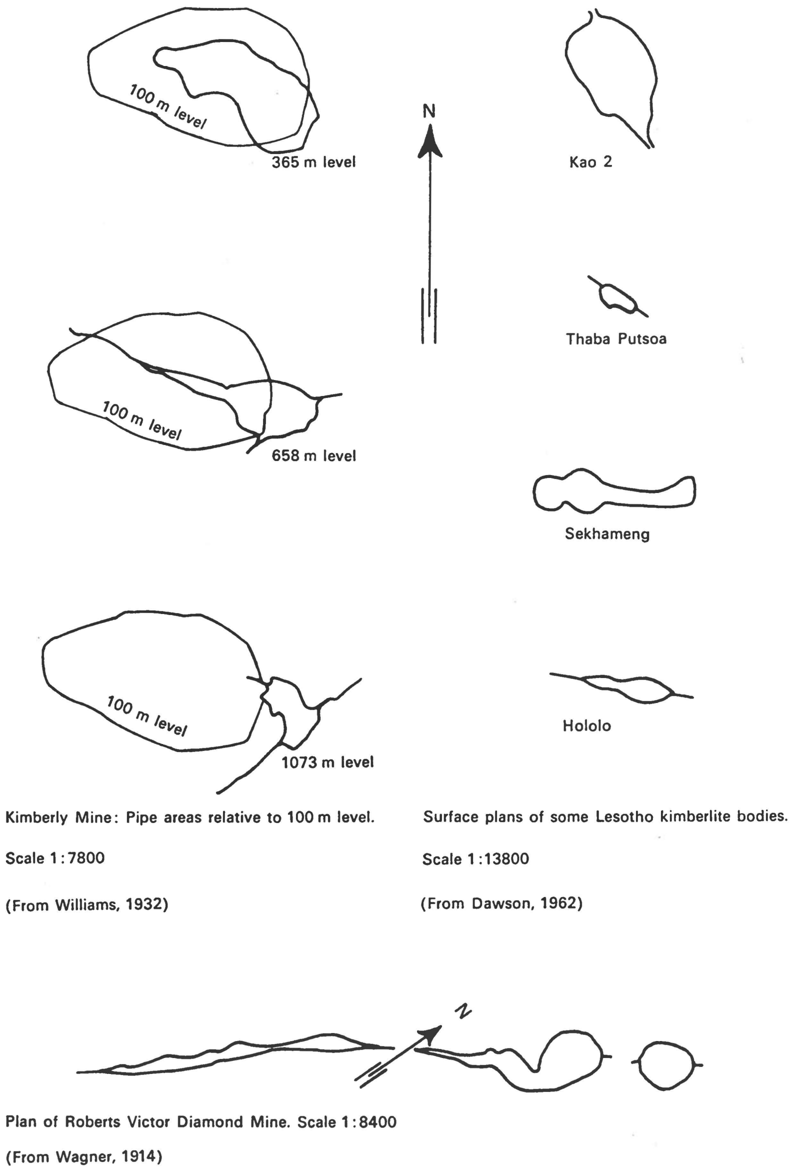

Fig. 6. Plans of some South African kimberlite plutons.

It is difficult to reconcile the shape of the plutons with the relatively simple mechanism of intrusion of magma into tension fractures. A comparison of the shape of the plutons with that of other igneous bodies elsewhere in the world shows that they closely resemble kimberlite bodies as can be seen by comparing Plate 1 with fig. 6. Kimberlite occurs in pipes or diatremes, and dykes that in some examples pinch and swell.

In many cases there is conclusive evidence that the pipes are local enlargements of the dykes (DAWSON, 1967, p. 242; DAWSON, 1962, p. 548; WILLIAMS, 1932, pp. 112–120). Mining has shown that the diatreme in a kimberlite body can be simply a local enlargement on a single fissure or enlargement at the intersection of two or more fissures as is the case with the swells in the upper part of the Amitsoq pluton.

Current opinion regards kimberlite pipes as having formed at the intersection of preferred planes of weakness by emplacement of fluidised gas-charged kimberlite (DAWSON, 1967, p. 246). There is no direct evidence to support emplacement of the Sarqâ-Amitsoq plutons by fluidisation although such a mechanism would help explain features such as the pinch-and-swell form and the virtual absence of contact metamorphism. It is thought that the unusual shape and many other features of the bodies can best be explained as follows:

It is known that cooling contraction cracks can form at relatively high temperatures (above red heat) which allowing for latent heat is between 600° and 700° C. (JAEGER, 1961). This is the basis for suggesting that the joints formed in the granitic country rock at a time when it was still hot and slightly plastic, i. e. before it was completely "dead".

A hydrous magma charged with olivine was rapidly and forcibly injected up into these joints in still hot and plastic country rock. Some of the swells were localised at the intersection of joints and possibly by local choking of the dykes with crystalline material which would have caused a local build-up of the vapour pressure.

The Sydprøven granite has semicontemporaneous noritic gabbro associated with it, the field relations being such that the gabbros intrude, and are intruded and hybridised by, the granite (BRIDGWATER, 1963, p. 176). In the case of the Sarqâ-Amitsoq plutons there is definitely no hybridisation and this fact would seem to rule against the concept that the plutons were emplaced into hot plastic granite. However the granite around the Sarqâ-Amitsoq plutons could have been less mobile at the time of their intrusion than was the Sydprøven granite at the time when its associated gabbros were formed. Moreover, mixing of semicontemporaneous acid and basic magmas is not bound to occur, as can be shown by studies on net-veined intrusions (WINDLEY, 1965a, 1965b).

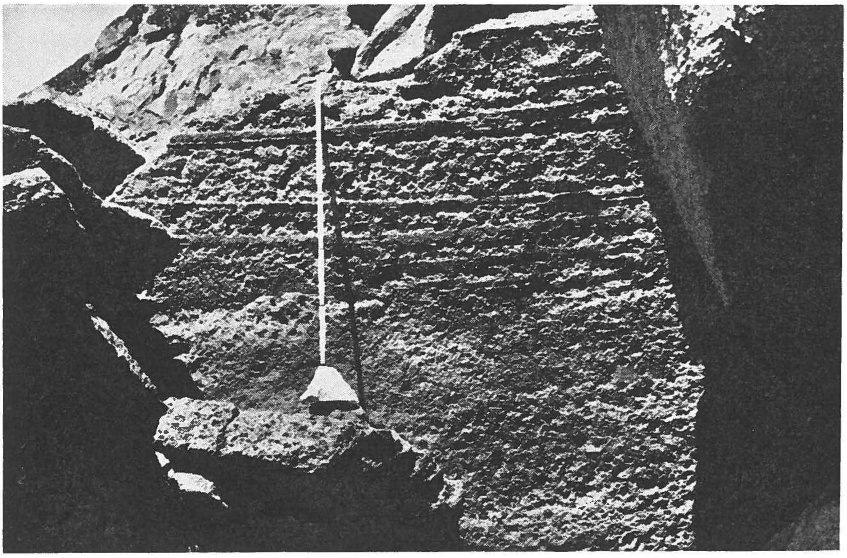

Fig. 7. Rhythmically layered hornblende peridotite overlying massive hornblende peridotite at 920 m, Sarqâ pluton. Scale is 100 cm long.

V. PETROLOGY

1. Internal structures

Both plutons exhibit rhythmic layering produced by variations in the relative proportions and size of both cumulus and postcumulus minerals. This layering is visible on many outcrops over the entire vertical interval covered by the two bodies and is picked out by differential resistance to erosion of the layers.

The layering is generally horizontal or gently dipping in the medial parts of the plutons (figs. 7–12) and inward dipping near the margins (fig. 13), thereby describing open synclinal and/or basin structures. In rounded chambers or swells such as are well developed at the north-east end of the Sarqâ pluton, the layered structure can be likened to that produced by the piling of numerous saucers one on top of another, the diameter of these plates at first increasing, and then decreasing as the top of the swell is approached. Dips of between 20° and 45° have been measured in the middle parts of the Amitsoq pluton but in most cases these steep dips can be related to the nearby granite floor which is exposed within the pluton.

Figures 7–13 show the most common types of layering encountered. There is appreciable variation in the thickness of the constituent layers from one outcrop to the next. In places (fig. 7) the individual layers are only a few cm thick and are regularly repeated. This type resembles the "inch-scale layering" at the Stillwater Complex (HESS, 1960). Elsewhere (fig. 8) 25–40 cm thick layers alternate regularly with 2–3 cm thick layers. In other places there are thin (< 3 cm thick), discontinuous,

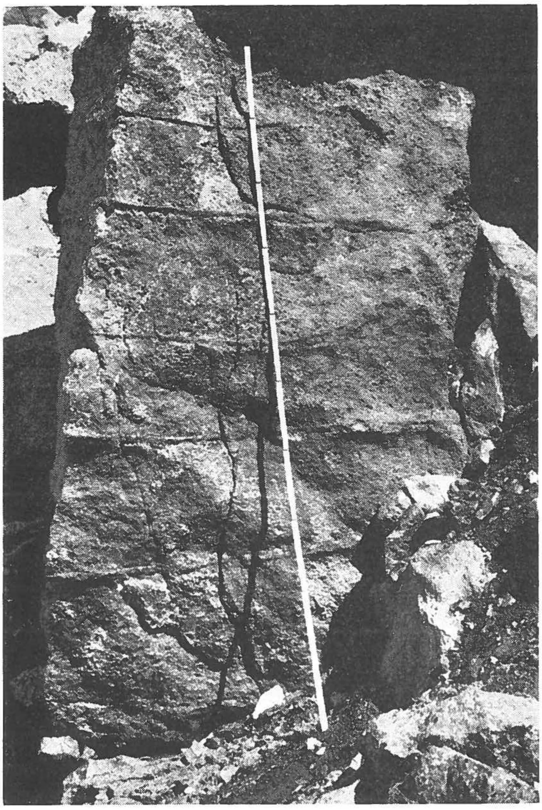

Fig. 8. Rhythmic layering at 945 m, Sarqâ pluton. Scale is 200 cm long.

tapering brown hornblende-rich layers, some of which bifurcate (figs. 11 and 12).

The rhythmic layering is picked out on outcrops by subtle colour variations and by relative differences in resistance to weathering of the individual layers. These features reflect subtle differences in the proportions of both the cumulus olivine and the postcumulus minerals, as illustrated by modal analyses (presented below and each based on 1000 points) of a greenish-grey and a greenish-black layer illustrated in figures 9 and 10. It was also noted that the olivine crystals in the pale layers are generally larger than those in the dark layers.

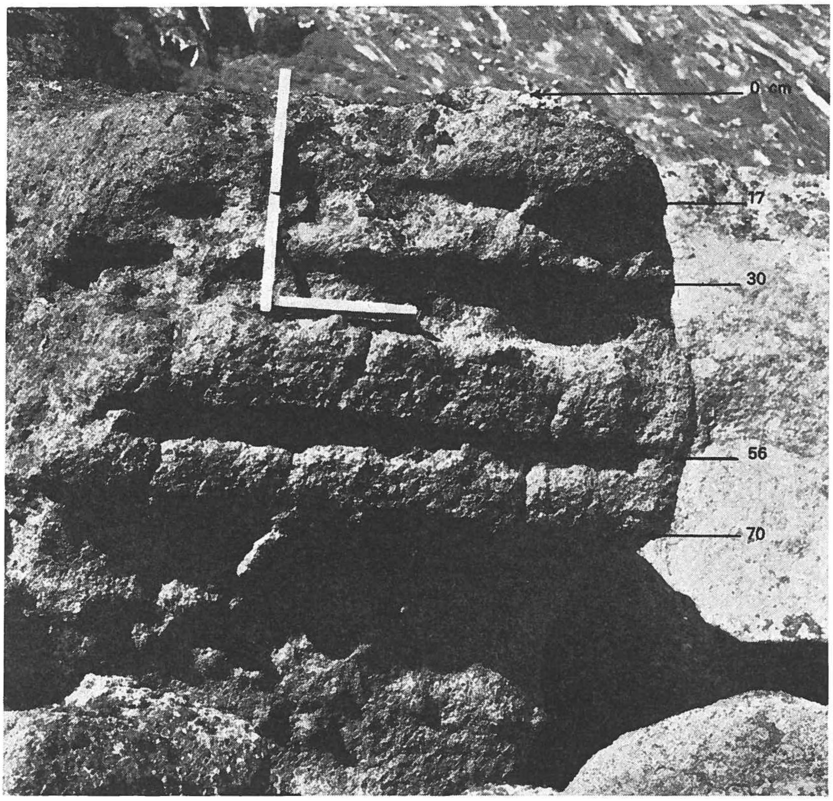

Fig. 9. Rhythmic layering at 13 m, Amitsoq pluton. Fig. 10 for details. Scale segments 22 cm long.

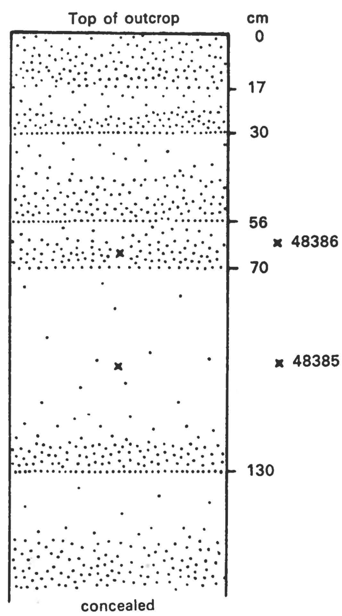

Fig. 10. Measured columnar section of the rhythmic layering shown in fig. 9. Greenish-black layers heavily stippled, greenish-grey layers lightly stippled.

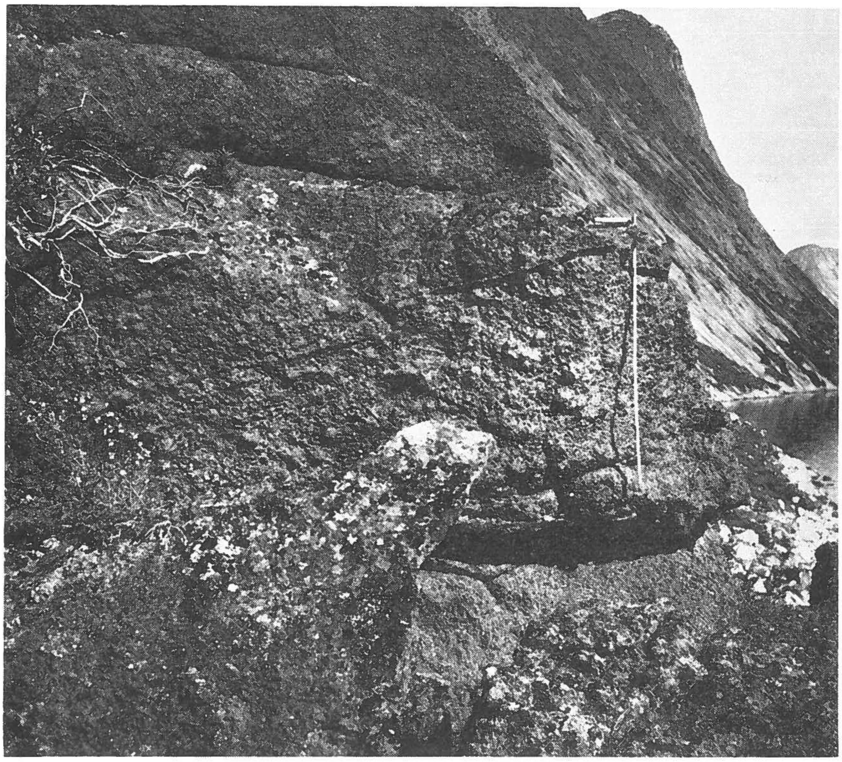

Fig. 11. Impersistent rhythmic layering dipping 20°, 20 m Amitsoq pluton.

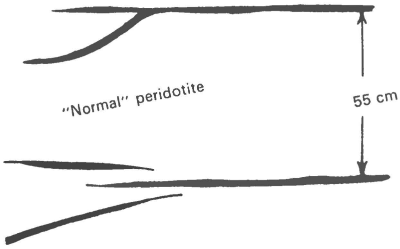

Fig. 12. Field sketch of discontinuous and bifurcating rhythmic layering at 91 m Amitsoq pluton. Hornblende-rich layers, 1–2 cm wide, black.

	Greenish-grey layer GGU 48385	Greenish-black layer GGU 48386
Olivine	25 %	35 %
Opaque oxide	2 -	2 -
Hypersthene	10 -	4 -
Amphibole	29 -	26 -
Phlogopite	7 -	2 -
Autometamorphic minerals	27 -	31 -

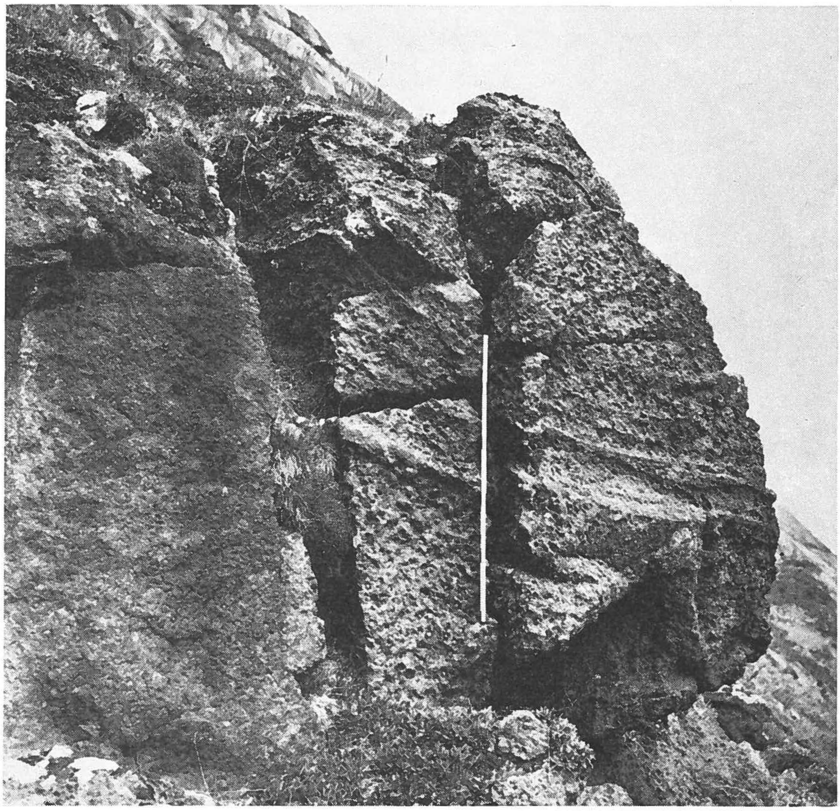

Fig. 13. Curviplanar rhythmic layering adjacent to the granite contact at 205 m Amitsoq pluton. Scale 100 cm long.

At a few localities primary subhorizontal rhythmic layering is cut by sets of nearly vertical compositional banding. Figure 14 shows vertical compositional banding in which bands, *c.* 10 cm wide, relatively rich in brown hornblende alternate with bands, 15–50 cm thick, richer in secondary minerals. This vertical structure "cuts" across (no relative age seen or implied) vague primary rhythmic layering that dips gently from right to left. In the Amitsoq pluton a similar sort of feature—very steeply dipping brown hornblende-rich bands 1–2 cm thick cut gently dipping primary rhythmic layering developed in peridotite about one metre away from the contact.

The explanation for this cross-cutting structure is thought to be as follows: It is known that cooling contraction cracks can form at relatively high temperatures (above red heat) which allowing for latent heat is between 600° and 700° (Jaeger, 1961). It is suggested that cooling cracks formed after the formation of the primary rhythmic layering but before the plutons had completely solidified and at a time when they

Fig. 14. Vertical compositional banding, in hornblende peridotite, cutting vague subhorizontal rhythmic layering trending obliquely from lower left to upper right. 911 m Sarqâ pluton.

could have had a temperature in excess of 600° C. These cracks formed low pressure zones towards which intercumulus liquid diffused and crystallised out as brown hornblende.

The vertical hornblende-rich bands shown in figure 14 form furrows instead of ridges as is normally the case with layers enriched in brown hornblende. This is probably due to further contraction and opening of the cracks after the crystallisation of the brown hornblende, and subsequent promotion of weathering along these joints.

Around 158 m in the Amitsoq pluton rhythmically layered peridotite (dip 5°) is cut by vertical veinlets, 1–3 cm wide, of pale grey cross-fibre asbestos. These asbestos veins are also thought to have originated by diffusion of material into low pressure contraction cracks but in this case the cracks formed later than those now filled with brown hornblende which is earlier in the paragenetic sequence (see next chapter).

2. Petrography

The two plutons have a similar lithology, the only difference being that the Amitsoq body has more hypersthene and correspondingly less brown hornblende. Coarse-grained hornblende peridotite is by far the most common rock comprising at least 95 $^0/_0$ of the total volume. Rhythmic layering in the peridotite is due to slight variations in both grain size and the relative proportions of the constituent minerals, but these differences are seldom pronounced enough to give rise to different rock types classified on either a modal or a cumulus basis (cf. JACKSON, 1967). It is doubtful whether a chemical classification would show the existence of different types in this layered series which chemically are picrites.

Fig. 15. Weathered surface of very coarse-grained hornblende peridotite. Individual hornblende crystals are shown as white (schillerising) and dark patches. 940 m Sarqâ pluton. Brunton compass 7 × 15 cm.

The layered series contain a few cognate inclusions of hornblendite. The marginal rocks of the plutons (i.e. within a metre of the contacts) are finer grained, appreciably less basic and slightly less mafic, there being a small amount of plagioclase present. Modally these rocks are mica hornblendites and chemically they vary from picrite to syenogabbro. Plagioclase-rich hornblende gabbro occurs as residual pockets and dykelets in the peridotites and as a veneer along part of the contacts. It is quantitatively insignificant and only forms a fraction of one per cent of the total bulk of the plutons.

The hornblende periodites of the layered series are seen in outcrops to be greenish-black to greenish-grey, coarse- to very coarse-grained rocks composed essentially of large poikilitic hornblende crystals containing tiny olivines. The hornblendes are commonly 2 cm and not uncommonly 5 cm in diameter (fig. 15). They tend to weather to knobs and the schillerising reflection of light off cleavage planes helps identify individuals. The paler greenish-grey material between the large hornblendes mainly comprises autometamorphic amphibole and phyllosilicates. No directional fabric is visible.

Thin sections show that the peridotites contain cumulus opaque oxide and olivine; postcumulus hypersthene, brown hornblende and phlogopite; and autometamorphic cummingtonite, antigorite, talc, chlorite, calcite and opaque oxide. The postcumulus minerals all have the same poikilitic relationship towards the cumulus opaque and olivine, whereas the autometamorphic minerals give the impression of filling spaces between or replacing minerals of these two earlier groups.

Opaque oxide occurs in accessory amounts as tiny euhedral cumulus crystals scattered through the slides and poikilitically enclosed in the later minerals.

Olivine (84–74 $^0/_0$ Fo) is the chief cumulus mineral and it forms subhedral to euhedral crystals scattered throughout the slides and poikilitically enclosed by the postcumulus minerals. It has a brownish-red colour and is slightly pleochronic. Zoning is absent, reaction rims are rare and replacement by autometamorphic minerals generally slight. It varies in amount from an estimated 20 $^0/_0$ to 50 $^0/_0$.

Hypersthene is found in some slides and not in others. In the Sarqâ body it is commonly absent and never comprises more than 5 $^0/_0$ of any sample. It may originally have been more plentiful as is suggested by the fact that it commonly occurs as corroded remnants more or less replaced by later amphiboles etc. It is more abundant in the Amitsoq pluton which contains layers of hornblende-hypersthene peridotite; one layer was found to be harzburgite consisting essentially of olivine and hypersthene. The hypersthene-rich rocks have less brown hornblende (and vice versa) and in these it forms relatively large poikilitic crystals containing inclusions of, and being moulded around, the olivine and cumulus opaques. The hypersthene is strongly pleochroic (α = clear red, γ = very pale green).

Brown hornblende characteristically forms large poikilitic crystals enclosing or moulded around opaque oxide and olivine. This hornblende is commonly zoned and has olive-green margins. In some samples the olive-green variety predominates. It has a large extinction angle ($\gamma : c = 30°$). Brown hornblende is one of the most abundant constituents and is estimated to comprise between 20 $^0/_0$ and 40 $^0/_0$ of different specimens.

		CUMULUS PHASE	POSTCUMULUS PHASE	AUTOMETAMOR - PHIC PHASE
CUMULUS MINERALS	Opaque oxide	--		
	Olivine	-------		
POSTCUMULUS MINERALS	Hypersthene		------	
	Brown hornblende		------	
	Phlogopite		------	
POSTCUMULUS & AUTOMETAMOR - PHIC MINERALS	Neutral amphibole		-----	--- ---
AUTOMETAMOR - PHIC MINERALS	Antigorite			---
	Talc			---
	Chlorite			---
	Calcite			---
	Opaque oxide			---

Fig. 16. Diagrammatic representation of crystallisation sequence in the plutons.

Phlogopite is another essential constituent. It is either neutral or pale brown in colour and commonly has undulose extinction indicative of slight post-crystallisation strain. The larger crystals are poikilitic towards the olivine and opaques.

Neutral amphibole occurs grown around and in optical continuity with the brown hornblende, but it is definitely a discrete younger mineral. It also forms prismatic and/or fibrous crystals intergrown with the secondary minerals. Cummingtonite ($\gamma : c = 18–20°$) has been tentatively identified but there could be more than one type and generation of neutral amphibole which apparently belongs to both the postcumulus and autometamorphic paragenetic phases. It is an essential constituent of the peridotites.

Autometamorphic minerals which at least in part have formed by replacement of the earlier minerals are abundant. Antigorite occurs pseudomorphing olivine or as irregular masses and veinlets, and secondary opaque oxide occurs as tiny granules associated with this serpentinisation. Talc, chlorite and calcite complete the list of autometamorphic minerals so far identified.

The mutual textural relationships shown by the constituent minerals suggest the paragenetic sequence in the crystallisation of the plutons shown in fig. 16.

Cognate inclusions of hornblendite are found near the eastern end of the Sarqâ pluton at 963 m (fig. 17). These inclusions occur as steeply inclined lenses in normal peridotites and there is no reaction zone around them. They are greenish-black, medium-grained hornblendite which in thin section is seen to consist of large hornblende crystals ($\gamma : c = 32°$,

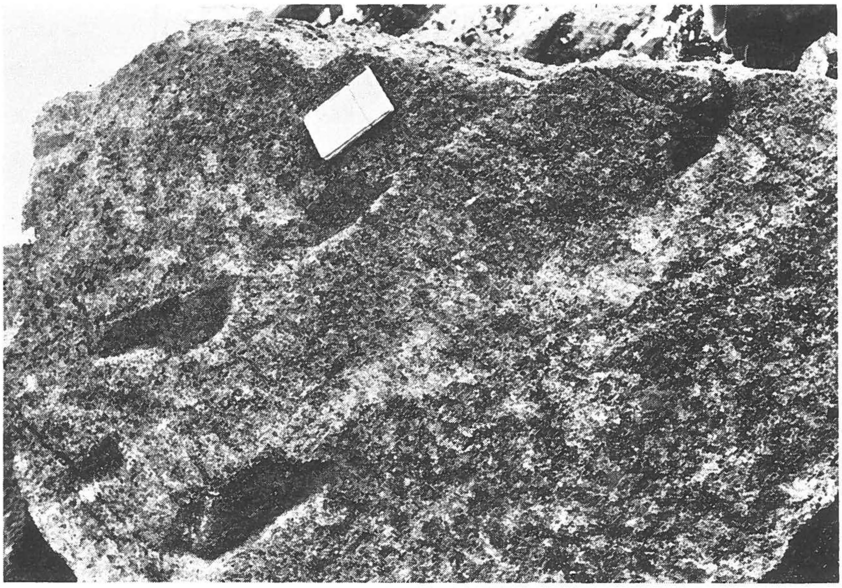

Fig. 17. Cognate inclusions of hornblendite in hornblende peridotite at 963 m Sarqâ pluton. Notebook 12 × 17 cm.

pleochroic from light to dark brown) 1–2 cm in diameter set in a groundmass of second generation finer grained hornblende ($\gamma : c = 30°$, pleochroic from yellow to clear green) together with accessory talc, phlogopite and calcite. The large brown hornblendes have margins of the green variety and are in fact phenocrysts in a hypidomorphic granular groundmass of green hornblende.

There is a more profound difference between the rocks of the layered series and those of the border group, than between various facies within the layered series which vary only from hornblende peridotites through hornblende-hypersthene peridotites to rare harzburgite. At a distance of about one metre from the contacts, the peridotites of the layered series merge into a variable group comprising rocks, difficult to classify modally, that have been called hypersthene-olivine and mica hornblendites. Chemically these are less basic and vary from picrite to syenogabbro. It will be seen that the hornblendites of the border group have many features in common with the greenish-grey hornblende peridotite of the layered series. As it is the differences between the hornblende peridotites and the hornblendites that are of petrogenetic significance, the emphasis will be on a description of these contrasts, rather than a straightforward account of the border group types.

The hornblendites are generally greenish-grey, and medium-grained in outcrop, this reflecting their greater relative proportion of secondary amphibole plus phyllosilicates and less intercumulus brown hornblende as compared with the peridotites. The cumulus minerals (opaque oxide and olivine) are less abundant than in the peridotites and are completely absent from many samples taken within 30 cm of the contact. There is never more than 10 % olivine. Between one and three metres in from the contact the olivine generally has a composition approximating Fo 75 %. There is an abrupt change in composition at about the one metre mark to olivine containing only 30 % Fo. The border group olivines are much more altered than those in the layered series. The alteration products are also different—brownish iddingsite plus opaques rather than antigorite and opaques. Although some slides have no hypersthene, others contain up to about 10 %, and some samples taken directly adjacent to the contacts contain augite ($\gamma : c = 39°$) instead of orthopyroxene. The pyroxenes generally occur as highly corroded, relatively large remnants. The brown hornblende ($\gamma : c = 32°$), so characteristic of the peridotites, is less abundant (< 25 %) and forms smaller crystals. Phlogopite is abundant and many comprise up to 25 % of the minerals present. The secondary amphibole, (cummingtonite?) also appears to have the same optical properties ($\gamma : c = 18°$) as that in the peridotites. Autometamorphic minerals including cummingtonite, talc, antigorite, iddingsite, chlorite, calcite and opaque oxides are much more abundant in the border group and many comprise up to 40 % of the rock. One of the augite-bearing samples from next to the contact contains appreciable amounts of microcline and an unidentified feldspar. These are the so-called syenogabbros. Although the mineral paragenesis is the same in both the layered series and the border group, the presence of fayalitic olivine and the greater proportion of autometamorphic minerals in the hornblendites indicates that they crystallised after the peridotites and are not a simple fine-grained chill facies.

Plagioclase-rich hornblende gabbros occur as residual pockets (fig. 18) and 2–5 cm wide dykelets in the peridotite, and as a veneer up to 20 cm wide along part of the contacts. They are quantitatively insignificant and only form a fraction of one per cent of the total bulk of the plutons. These are the only rocks that are not ultramafic. They consist essentially of calcic plagioclase and brown and/or green hornblende in varying proportions. The plagioclase is zoned but in one case was found to be labradorite (An_{48}). It is as a rule considerably altered to calcite, sericite and/or scapolite. The hornblende forms long euhedral prisms that are indicative of crystallisation in a volatile environment and has the same extinction angle ($\gamma : c = 32°$) as that found in the ultramafites. Other mafic minerals occuring sporadically in these gabbros include neutral amphibole, brown biotite and hypersthene. Some have essential quartz and myrmekite. Opaque oxide, sphene, apatite,epidote and anal-

Fig. 18. Pocket of residual hornblende gabbro in peridotite at 945 m Sarqâ pluton. Lens cap *c.* 3 cm in diameter.

cite are accessory minerals of erratic distribution. The presence of analcite in the plagioclase-rich late differentiate of picritic magmas is quite characteristic elsewhere in the world (Drever & Johnston, 1967a). The texture is generally medium- to coarse-grained hypidiomorphic.

It is clear that the hornblende gabbros represent a feldspathic residual differentiate of the ultramafites trapped in or cutting the solidified parent rock. The fact that much of the hornblende gabbro occurs as a veneer along the contacts between the mica hornblendites and the granite is a further indication that the fine-grained border group is itself a late differentiate and not a chilled margin.

3. Olivine

As most samples contain appreciable quantities of cumulus olivine its composition was determined in order to see whether there is any cryptic layering in the two plutons. The X-ray technique described by Yoder & Sahama (1957) was used for this purpose. This method is only suitable for olivine containing more than 95 % Fo + Fa, in which case it has an error of 3–4 %. When considering the results it should be borne in mind that as many of the olivines have a brownish-red colour in thin sections they may contain appreciable amounts of the manganese end member of the olivine series. Against this is the fact that silicate analyses did not show the ultramafites to be particularly rich in manganese

Table 2. *Composition of olivine from various levels in the Amitsoq and Sarqâ plutons.*

GGU No.	Mol. % MgO	Alt. m	Remarks	
			AMITSOQ PLUTON	
48380	81	1	Massive c-gr. peridotite	
48385	79.5	13	Layered " "	Olivine from two contrasting
48386	83	13	Layered " "	layers see Figs. 9 & 10
48387	78.5	25	Massive " "	
48388	81	45	Massive " "	
48421	78	90	Layered " "	
48404	78.5	108	Massive " "	
48425	82	160	Layered " "	
48427	81	185	Layered " "	
48431	77	237	Layered " "	2 m from contact
48432	81	240	Massive " "	
48445	75	260	Layered " "	3 m from floor of pluton
48417	80	285	Massive " "	
48448	82	285	Massive " "	
48449	78	302	Massive " "	
48455	78	328	Layered " "	
48454	79.5	332	Layered " "	
			SARQÂ PLUTON	
24124	81	769	Massive c-gr. peridotite	
24125Y	79	795	Layered " "	Olivines from two contrasting
24125Z	76.5	795	Layered " "	layers on same sample
24095[1]	31.5	827	Massive m-gr. "	0.35 m from the contact
24097[1]	82.5	828	Massive c-gr. "	From centre of pluton
24098	80	847	Massive " "	
48467	80	851	Massive " "	
24100	76.5	874	Layered " "	
24127	76.5	874	Layered " "	
24131	81.5	886	Massive " "	
24109	81	894	Massive " "	
24113	84	911	Layered " "	
24123	28	915	Layered m-gr. "	Less than 1.0 m from contact
48469	31	921	Massive m-gr. "	Directly adjacent contact
48470	77	923	Layered c-gr. "	
24115	76.5	939	Massive " "	
48468A	81.5	945	Layered " "	Olivines from two contrasting
48468B	78	945	Layered " "	layers on same sample
24118	83	945	Layered " "	
48466	78	965	Massive " "	
24121	75	966	Massive " "	3.5 m from the contact
24119	74	969	Massive m-gr. "	1.0 m " " "

[1]) Samples for which silicate analysis of the rock is available, see Table 3.

(0.14–0.18 % MnO). Allowing for this possibility of error, the X-ray results presented in Table 2 illustrate some significant features:

(1) All the olivine from the hornblende peridotites of the layered series is chrysolite (84–74 mol. % Fo) and as such corresponds well with the remarkable uniformity in composition of olivine from picrites elsewhere (DREVER & JOHNSTON, 1967a, p. 59; 1967b, p. 77).

(2) Olivines from contrasting layers on the same sample or outcrop have no difference in composition detectable by the method used.

(3) In three samples the olivines are ferrohortonolites (31–28 mol. % Fo). These ferrohortonolites are from samples of the finer grained border group at, or less than 100 cm from, the contacts. Most of the less magnesian chrysolites, i.e. those with a composition of 77–74 mol. % Fo, are from within three metres of the contacts.

(4) No olivine was found intermediate in composition between Fo_{74} and Fo_{31}.

(5) Although no cryptic layering has so far been detected there is an abrupt change in composition between olivines found in the hornblende peridotites of the layered series and those occurring in the hornblendites of the border group.

4. Chemistry

A chemical investigation of the Sarqâ-Amitsoq plutons was undertaken for three reasons: (a) to determine whether they have chemical affinities with other ultrabasic and basic rocks in South Greenland (Sanerutian vs Gardar affinites), (b) to classify the rocks on a chemical basis as the extensive alteration made modal classification difficult, (c) to trace magmatic differentiation trends and thereby decipher the petrogenesis of the plutons. Although numerous samples have been collected for analysis, to date it has only been possible to analyse three of them. These specimens all come from about the same level (828 m) in the Sarqâ pluton, are fresh, large and representative of the outcrops from which they were taken.

A comparison of the Sarqâ analyses (Table 3, columns 1, 2 and 3) with all analyses from the Gardar igneous province available to Nov. 1965 (WATT, 1966) shows that there is no chemical affinity between them. For example, the relatively high alumina, titania, sodium and calcium, and low magnesium in Gardar rocks of similar silica content contrasts markedly with the Sarqâ rocks. This is additional evidence against a Gardar age for the Sarqâ-Amitsoq plutons.

As it has been suggested (WALTON, 1967) that the plutons have affinities with the Sanerutian appinitic rocks north of Narssarssuaq, the most closely comparable analysis from this suite has been included in the table (column 9). Although there is a much greater similarity between this Sanerutian rock compared with those from Sarqâ as compared with the Gardar intrusives, there are nevertheless marked differences. All that can be said is that the chemistry is not incompatible with a Sanerutian age.

Table 3. *Chemical analyses of Sarqâ ultramafic rocks and comparisons with ultrabasic and basic rocks from other regions.*

	1	2	3	4	5	6	7	8	9
SiO_2	52.00	46.55	40.30	40.50	40.30	46.59	40.27	42.43	49.83
TiO_2	0.25	0.24	0.29	0.67	1.28	1.83	1.30	0.96	0.94
Al_2O_3	6.43	7.40	6.08	7.87	6.30	7.69	7.29	5.50	10.80
Fe_2O_3	0.84	1.74	2.89	2.08	4.12	2.20	4.28	2.62	4.10
FeO	7.59	9.12	8.27	12.00	10.83	10.46	9.08	9.90	7.95
MnO	0.14	0.18	0.16	0.25	0.35	0.18	0.25	–	0.19
MgO	21.32	23.62	28.80	27.19	24.95	21.79	24.31	30.79	10.38
CaO	3.00	3.00	3.79	5.36	3.99	7.41	7.15	4.78	8.53
Na_2O	0.84	0.59	0.53	1.20	1.52	1.33	1.06	0.81	2.30
K_2O	3.20	1.52	0.64	0.16	0.80	0.28	0.62	0.44	1.53
P_2O_5	0.11	0.10	0.06	0.15	0.07	0.11	0.38	0.08	0.58
CO_2	–	–	tr	–	–	–	0.34	–	0.00
H_2O^+	3.80	5.46	7.02	1.83	4.08	0.37	3.67	1.69	2.98
H_2O^-.....	0.22	0.27	0.41	0.74	1.44	0.04	–	–	–
Cr_2O_3	0.12	0.14	0.17	–	–	–	–	–	–
Other.....	–	–	–	–	0.02	0.25	–	–	0.15
Sum......	99.86	99.93	99.41	100.00	100.05	100.53	100.00	100.00	99.36

	1	2	3
$\frac{100\cdot(FeO + Fe_2O_3 + MnO)}{(MnO + FeO + Fe_2O_3 + MgO)}$	28.67	31.85	28.22
$\frac{100\cdot Fe_2O_3}{(Fe_2O_3 + FeO)}$	9.96	16.02	25.90
$\frac{(Na_2O + K_2O)}{CaO}$	1.30	0.70	0.30
$\frac{100\cdot Na_2O}{(Na_2O + K_2O)}$	21	28	45

(continued)

Table 3 (continued)

C. I. P. W. Norms.	1		2		3	
or	18.91	30.34	8.98	27.02	3.78	20.58
ab	7.11		4.99		4.48	
an	4.32		13.05		12.32	
wo di	4.11	7.83	0.49	0.93	2.54	4.82
en di	2.99		0.35		1.94	
fs di	0.73		0.09		0.34	
en hy	30.90	38.46	28.61	35.97	9.36	10.99
fs hy	7.56		7.36		1.63	
fo ol	13.46	17.09	20.93	26.86	42.34	50.45
fa ol	3.63		5.93		8.11	
mt	1.22		2.52		4.19	
cm	0.18		0.21		0.25	
ilm	0.47		0.46		0.55	
ap	0.25		0.23		0.14	
others	4.02		5.73		7.43	
Sum	99.86		99.93		99.40	
Normative Ab	62.18		27.66		26.69	
Normative An	37.82		72.34		73.31	

No. 1 Mica hornblendite from adjacent contact Sarqâ pluton 828 m, GGU No. 24093. Analyst: B. I. BORGEN.

No. 2 Hypersthene-olivine hornblendite 30–40 cm in from contact Sarqâ pluton 827 m, GGU No. 24095. Analyst: B. I. BORGEN.

No. 3 Hornblende peridotite from near centre of Sarqâ pluton 828 m, GGU No. 24097. Analyst: B. I. BORGEN.

No. 4[1]) Gabbroic picrite, Shiant Isles. Average of three analyses. Analysts: E. G. RADLEY (WALKER, 1930), and E. J. MURRAY.

No. 5[1]) Picrite at 323 feet, Nebo No. 6 bore. Analyst: G. C. CARLOS (EDWARDS, 1953).

No. 6[1]) Picrite, Uwekahuna, Hawaii. Analyst: G. STEIGER (DALY, 1911) (MURATA & RICHTER, 1961).

No. 7 Alkali peridotite, average of twelve analyses, (NOCKOLDS, 1954).

No. 8 Hornblende peridotite, average of five analyses, (NOCKOLDS, 1954).

No. 9 Noritic gabbro, Nordgletscher, GGU No. 55189. Analyst: B. I. BORGEN (WALTON, 1965).

[1]) Data from DREVER & JOHNSTON, (1967a).

The mica hornblendite (Table 3, column 1) comes from directly adjacent to the granite contact and may have been contaminated by diffusion of material in from the country rock. It contains essential K-feldspar, augite, brown hornblende, phlogopite, cummingtonite, talc and opaque oxide. Chemically the rock is a monzonite (bordering syenite) with affinites to the syenogabbro kentallenite. It is of interest that kentallenite is also associated with hornblende picrite in Argyllshire (Hatch, Wells & Wells, 1949).

The hypersthene-olivine hornblendite (Table 3, column 2) comes from the border group at a point 30–40 cm from the contact. It contains essential olivine (31.5 % Fo) (5 % estimated), hypersthene (10 %), brown hornblende (20 %), phlogopite (20 %) and autometamorphic minerals (45 %) including cummingtonite, iddingsite, talc, antigorite, chlorite, calcite and opaques. Chemically the rock is a picrite as indicated by the high magnesia content and its similarity with picrite shown in column 6.

The hornblende peridotite (Table 3, column 3) comes from near the centre of the Sarqâ pluton. It contains essential olivine (82.5 % Fo) (40 % estimated), brown hornblende (20 %), phlogopite (5 %) and autometamorphic minerals (35 %) including cummingtonite, antigorite, calcite and opaques. Chemically the rock is a picrite as indicated by the high magnesia content and its similarity with the picrites shown in columns 4 and 5.

A comparison of the analyses of the Sarqâ picrites with picrites, alkali peridotites and hornblende peridotites from other regions (columns 4–8) shows that the Sarqâ rocks are relatively low in titania, calcium and sodium but appreciably richer in water.

The fine-grained margins of the two plutons were originally sampled for chemical analysis in the belief that they would provide an indication as to the original composition of the parent magma prior to differentiation. However, subsequent petrographic study has shown that the margins are enriched in those minerals crystallising late in the paragenesis and are impoverished in olivine which, furthermore, is an iron-rich variety. Both petrological and chemical evidence supports the theory that the plutons underwent flowage differentiation (Simkin, 1967; Bhattacharji, 1967) which brought about mechanical segregation of the suspended olivine crystals away from the walls of the plutons due to the rapid upward movement of the magma. As a result, the lateral mineralogical (and chemical?) variation is more profound than the vertical variations produced by magmatic differentiation and gravitative settling. The hornblende peridotites of the layered series in the medial portions of the plutons had largely crystallised prior to solidification of the finer grained rocks of the border group and represent the composition of the parent magma more closely. The various lines of evidence supporting this theory of evolution will be assembled in the section on petrogenesis; at this stage we are only concerned to see what support is afforded by the chemistry of the rocks concerned.

A comparison of columns 1, 2 and 3 (Table 3) shows that from the centre to the margins there is progressive enrichment in silica, sodium and potassium, depletion in magnesium and total iron, and that the ratio

$(Na_2O + K_2O)/CaO$ increases whilst the ratio $100 \times Na_2O/(Na_2O + K_2O)$ decreases, just as would be expected if the border group represents a relatively late differentiate. A comparison of the norms also supports this concept. The total salic normative minerals increase and the olivine decreases whilst the proportion of normative Ab increases relative to An.

5. Petrogenesis

Between 1700 and 1335 million years ago, during the second episode of Ketilidian plutonism (= Sanerutian) that is characterised by reactivation of the pre-existing plutonites and intrusion of a wide variety of rocks varying from ultrabasic to intermediate, a magnesia-rich magma of picritic composition was developed, probably by partial fusion of an ultrabasic source in the mantle (cf. DREVER & JOHNSTON, 1967b).

Cooling contraction cracks developed in the overlying granite that was at sufficient depth and temperature to still be relatively plastic. The picritic magma was injected under great pressure and at a considerable velocity into these fractures. By the time it had arrived at the present day erosion level this was a water-rich magma charged with crystals of olivine (Fo_{80}) so that its temperature was probably in the order of 1200° C. The relatively low temperature (for an ultrabasic melt) of the magma and the fact that only a limited volume of it was intruded at a great velocity accounts for the relatively low degree of contact metamorphism – albite-epidote hornfels facies. The suggestion that only a limited amount of magma was injected, and that the plutons are not feeders along which large volumes of magma moved slowly up towards a high-level pluton, is deduced from their tendency to become narrower with increase in altitude. The high velocity (or low viscosity, or both) of the intrusion is indicated by the fact that they have undergone flowage differentiation—the mechanical segregation of the suspended olivine crystals away from the contacts. Flowage differentiation is indicated by the fact that the margins of the plutons are impoverished in cumulus olivine. The formation of swells in the primitive dykes was facilitated by intersecting joints in still plastic country rock and by the high vapour pressure of the magma.

After intrusion of a magma containing crystals of olivine and opaque oxides, layering was initiated by sorting of the olivine into layers according to size, ascribed to differential rates of sinking in the several magma chambers. This incipient layering was further accentuated during crystallisation of the postcumulus material by restrictions of the free movement of the intercumulus liquid imposed by the partially solid olivine layers which hindered diffusion and caused variations in the concentrations volatile elements. Differences between the various rhythmic layers are subtle and due to variations in the relative proportions of cumulus olivine, postcumulus hypersthene, brown hornblende and phlogopite, and autometamorphic amphiboles and phyllosilicates. Hypersthene is more abundant in the Amitsoq as compared with the Sarqâ pluton, and whereas the former body has layers of hornblende peridotite, hornblende-hypersthene peridotite and even harzburgite, the latter has only hornblende peridotite of varying mineral composition.

The layered series was largely crystalline by the time the rocks of the border group solidified as is shown by: (a) the preponderance of postcumulus and secondary minerals in the border group, (b) the chemical trends, (c) the composition of the olivine which is chrysolite in the layered series but ferrohortonolite in the border group. The ferrohortonolite must have either crystallised after the chrysolite or been remade. The border group mostly comprises hypersthene-olivine and mica hornblendites that vary chemically from picrite to monzonite with affinites to kentallenite.

Plagioclase-rich hornblende gabbros, some of which contain analcite, occur in residual pockets, dykelets and as a veneer along the contacts. These gabbros were the final differentiate of the picritic magma.

VI. ECONOMIC GEOLOGY

Sparsely disseminated iron, copper and nickel sulphides with associated platinoids, gold and silver are found throughout much of the Angmalortoq, Amitsoq and Sarqâ plutons, and four relatively well mineralised zones have been mapped in the two larger bodies.

The Angmalortoq pluton contains sulphides in three habits:

(i) As patchy or erratically disseminated aggregates, less than 10 cm across, in ordinary hornblende peridotite.

(ii) Disseminated in narrow (< 10 cm wide) dykelets of hornblende gabbro.

(iii) Finely disseminated in inclusions of semipelitic schist.

There is less than 0.1 per cent sulphides in the body as a whole.

The Amitsoq pluton generally contains more sulphides than Sarqâ and it is not uncommon to find peridotite boulders with patches up to 15 cm across containing as much as 5 $^0/_0$ sulphides. Due to the steep slopes it is impossible to determine whether these boulders come from a single zone or from several localities. No sulphides were found in the lower section below the 45 m survey point. Near the top, between 300 and 335 m altitude, there is an elongated gossan zone (fig. 19) containing an average of 4 $^0/_0$ sulphides but locally as much as 7 $^0/_0$. Field relations show that this zone directly overlies the granite floor outcropping nearby, that its average width is *c.* 6 m and that it is probably not more than two metres thick. As such, there would be insufficient tonnage to make ore even if it were exceptionally rich in noble and other elements.

There are three mineralised zones in the Sarqâ pluton:

(i) The lowermost, at 874 m, is an 80 cm wide layer of hornblende peridotite dipping back into the mountain at 15°. Although not exposed for the entire width of the pluton it is reasonable to suppose that it extends across the width—here 19 m. The zone is rather richer (*c.* 2 $^0/_0$) in disseminated sulphides than the normal peridotite, and sulphate bloom has formed on the surface of the outcrop.

(ii) At 894 m there is a 50 cm wide zone that is also rather richer in sulphides than is normally the case.

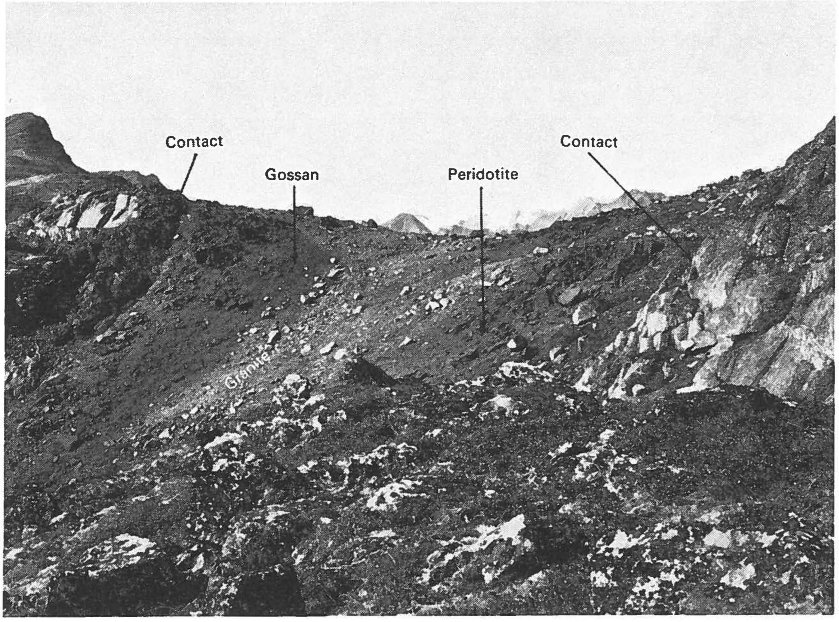

Fig. 19. The topmost swell in the Amitsoq pluton. Note the gossan (dark grey) adjacent to the granite floor (white) and the hornblende peridotite (medium grey) on the right.

(iii) The topmost zone is in the form of a mineralised horizontal layer, 100–150 cm wide, exposed on the north-facing slopes of a large bulge in the pluton. It is overlain by peridotite of rather variable composition and pockets of hornblende gabbro. There is an average of 1–3 $^0/_0$ sulphides but locally the tenor goes up and they are sufficiently abundant to form a ramifying network interstitial to the silicates. This might be called massive ore.

The following minerals were identified in a preliminary examination of polished sections of the mineralised samples: chalcopyrite, cubanite, pentlandite, valleriite, pyrrhotite, bravoite, sphalerite and magnetite surrounded by maghemite. The chalcopyrite occurs both as subhedral crystals and as veinlets cutting the pyrrhotite. It has exsolved cubanite in the form of fine lamelli or more equant blebs. The pentlandite and pyrrhotite have undergone partial bravoitisation with the associated development of skeletal valleriite. The sphalerite is of minor importance. The sulphides as a rule form aggregates a couple of millimetres across, although here and there samples containing masses up to 15 mm in diameter are seen. In the Amitsoq pluton the sulphides locally form lensoid grains whose orientation is parallel to the rhythmic layering. Samples split parallel to the layering therefore appear to

Table 4. *Trace element analyses from*

	GGU No.	Pt		Pd		Ir	Rh	Au		Ag	Cr
		GGU[2])	FB	GGU[2])	FB	GGU[2])	FB	GGU[2])	FB	FB	GGU[1])
AMITSOQ PLUTON	48397	0.1	..	tr	..	..	..	tr	..	..	..
	48399	0.1	..	< 0.1	..	..	..	tr	..	..	..
	48391	0.1	..	0.2	..	..	..	0.3	..	..	..
	48393	0.5	..	0.5	..	..	..	0.3	..	..	..
	48394	< 0.1	..	0.1	..	..	..	0.1	..	..	..
	48407	0.1	..	0.1	..	..	..	0.2	..	..	..
	48409	0.2	..	0.6	..	..	..	< 0.1	..	..	..
	48419	0.8	..	0.8	..	..	..	0.8	..	..	..
	48415	0.2	..	0.6	..	..	..	< 0.1	..	..	..
	48420	0.2	0.3	0.3	0.4	..	< 0.1	0.1	0.1	2.0	..
	48433	< 0.1	..	0.1	..	..	..	–	..	..	..
	48451	0.2	..	0.5	..	..	..	tr	..	..	..
	48435	tr	..	0.1	..	..	..	–	..	..	..
	48436	–	0.1	0.3	0.6	..	< 0.1	–	0.2	7.0	..
	48438	0.1	0.4	0.5	0.4	..	< 0.1	0.1	0.1	2.0	..
	48440	0.2	0.3	0.2	0.2	..	< 0.2	< 0.1	< 0.2	4.0	..
	48442	0.2	0.4	0.5	0.4	..	< 0.1	tr	0.1	3.0	..
	48453	0.2	0.2	0.1	0.2	..	< 0.1	0.1	0.1	3.0	..
	48457	tr	< 0.1	–	< 0.1	..	< 0.1	tr	< 0.1	3.0	..
SARQÂ PLUTON	24090	–	< 0.6	–	< 0.6	< 0.2	< 0.6	–	< 0.6	7.0	1000
	24091	0.6	..	1.0–5.0	..	< 0.2	..	≤ 0.2	..	..	1000
	24092	–	..	0.3	..	< 0.2	..	–	..	..	2000
	24096	–	< 0.6	tr	< 0.6	–	< 0.6	–	< 0.6	7.0	1000
	24099	tr	< 0.7	0.2	< 0.7	–	< 0.7	–	< 0.7	2.0	2000
	24101	0.2[1])	0.2	0.4[1])	0.4	?	< 0.1	< 0.1[1])	0.1	5.0	3000
	24103	0.1[1])	0.3	0.6[1])	0.5	< 0.2	< 0.1	0.2[1])	0.1	3.0	> 5000
	24104	0.1[1])	0.4	0.5[1])	0.5	–	< 0.1	0.2[1])	0.1	4.0	~ 10000
	24126	0.2[1])	0.5	0.8[1])	0.6	?< 0.5	< 0.1	< 0.1[1])	0.1	5.0	> 5000
	24128	0.3	1.0	0.7	0.8	0.2	< 0.6	0.5	< 0.6	20.0	> 5000
	24105	0.2	..	0.2	..	–	..	0.2	..	..	200
	24106	0.2	..	0.5	..	< 0.2	..	0.2	..	..	5000
	24110	0.2	< 0.7	0.5	< 0.7	–	< 0.7	0.2	< 0.7	< 7.0	5000
	24111	0.5	< 0.6	0.5	< 0.6	–	< 0.6	0.5	< 0.6	7.0	2000
	24132	–	< 0.8	0.5	< 0.8	< 0.2	< 0.8	–	< 0.8	< 8.0	~ 10000
	24134	≤ 0.2	< 0.6	0.5	< 0.6	< 0.2	< 0.6	–	< 0.6	5.0	> 5000
	24116	0.5	< 0.8	tr	< 0.8	–	< 0.8	–	< 0.8	21.0	1000
	24136	0.2	< 0.5	0.5	< 0.5	< 0.2	< 0.5	tr	< 0.5	20.0	1000
	24139	0.7	< 0.7	5.0–10.0	3.0	0.2	< 0.7	1.0	0.8	19.0	~ 3000
	24142	0.2[1])	0.3	0.6[1])	0.5	< 0.2	0.1	< 0.1[1])	0.1	3.0	–
SARQÂ collected by LORÉTAN	46367	0.2	< 0.5	0.5	< 0.5	0.2	< 0.5	0.5–1.0	< 0.5	24.0	1000
	46368	< 0.1[1])	0.5	0.1[1])	0.8	?	< 0.1	tr	0.2	8.0	3000
	46369A	~ 1.0	2.0	0.5–1.0	< 0.6	–	< 0.6	≤ 0.8	< 0.6	15.0	2000
	46369B	0.2	< 0.7	0.2	0.9	–	< 0.7	0.2	< 0.7	12.0	3000
	46377A	0.1[1])	< 1.0	0.6[1])	1.0	0.2	< 1.0	–	< 1.0	64.0	100
	46377B	–	10.0	< 0.1[1])	0.8	?	0.1	–	0.2	22.0	~ 10000
	46377C	0.5[1])	0.7	0.6[1])	0.6	–	0.1	0.2[1])	0.2	14.0	~ 10000
Goles average		0.2		0.12				~ 0.009		0.05	2400

All figures in parts per million.

1) Quantitative spectrographic analyses, possible error 10–25 %.
2) Semi-quantitative spectrographic analyses, possible error 50–100 %, unless otherwise indicated.
3) Colormetric analyses.

GGU Analyses done by the Mineralogical-Geological Institute of the University of Copenhagen.
FB Analyses done by the Metallurgical Laboratories of Falconbridge Nickel Mines Ltd.

the Sarqâ and Amitsoq plutons.

Co GGU[1])	Co GGU[3])	Ni GGU[1])	Cu GGU[1])	Cu GGU[3])	Pb GGU[3])	Zn GGU[3])	Altit. m	Remarks	
..	..	..	..	..	..	..	49	s f	
..	..	..	..	..	..	..	61	s f	
..	..	..	..	..	..	..	74	r f	
..	..	..	..	..	..	..	74	r f	
..	..	..	..	..	..	..	74	r f	
..	..	..	..	..	..	..	113	r f	
..	..	..	..	..	..	..	136	r f	
..	..	..	..	..	..	..	275	s f	
..	..	..	..	..	..	..	280	r f	
..	..	..	..	..	..	..	280	r p	
..	..	..	..	..	..	..	290	s f	
..	..	..	..	..	..	..	312	r f	gossan zone
..	..	..	..	..	..	..	315	s f	
..	..	..	..	..	..	..	316	s f	
..	..	..	..	..	..	..	316	r p	
..	..	..	..	..	..	..	316	r p	
..	..	..	..	..	..	..	316	s p	
..	..	..	..	..	..	..	321	r p	
..	..	..	..	..	..	..	328	r p	
100	–	1000	–	100	25	100	802	r p	
100	200	1000	10000	8000	–	300	810	r f	
100	–	1000	500	200	–	100	813	r f	
100	–	1000	300	100	–	100	824	s p	
100	–	1000	3000	150	–	50	847	s p	
100	–	2000	4000	750	–	150	874	r p	874 m mineralised layer
100	–	2000	4000	1250	–	150	874	r p	
200	175	2000	3000	4000	25	250	874	r p	
100	–	2000	4000	1000	–	200	874	s p	
200	225	3000	3000	2000	100	150	874	s p	
200	–	2000	5000	1750	125	200	880	s f	
200	–	2000	5000	750	–	150	881	s f	
200	–	2000	5000	150	–	50	894	s p	894 m mineralised layer
100	–	1000	4000	1000	–	150	894	s p	
100	200	1000	4000	1500	–	100	894	s p	
100	–	1000	2000	1500	–	150	894	s p	
200	–	1000	4000	1250	–	200	940	r p	
200	200	1000	4000	1500	–	150	940	s p	
100	400	> 10000	6000	3000	50	250	945	s p	945 m mineralised layer
–	–	–	–	14000	–	350	945	r p	
300	..	~ 10000	15000	..	..	..	..	s f	
200	..	2000	4000	..	..	..	..	s f	
200	..	2000	10000	..	..	..	..	s f	
400	..	~ 10000	13000	..	..	..	..	s f	
1000	..	⩾ 10000	10000	..	..	..	..	s f	
500	..	> 10000	60000	..	..	..	..	s f	
700	..	> 10000	7000	..	..	..	..	s f	
110		~ 1500	30		~ 0.05	40	..	Estimates of abundances in "average" ultramafic rocks (Goles, 1967)	

– Not detected.
tr Trace.
s Selected sample.
r Representative sample.
p Sample in place.
f Float.

be richer in sulphides than is actually the case. Most of the sulphides are thought to be early magmatic segregations although there are indications that some of the sulphides may be of later replacement origin but nevertheless syngenetic. In general the mineralisation resembles the "cubanite ore" from Insizwa, South Africa, and the "offset ores" at Sudbury.

Table 4 gives the results of analysis, of both representative and selected samples, for the platinoids, gold, silver, chromium, cobalt, nickel, copper, lead and zinc, as well as the average abundances of these elements in ultramafic rocks according to GOLES (1967). A comparison of analyses for the platinoids, gold and silver made by the Mineralogical-Geological Institute of the University of Copenhagen with those done by the Metallurgical Laboratories of Falconbridge Nickel Mines Ltd. shows considerable discrepancies between the two sets of figures. This suggests analytical inaccuracies or that the samples were too small—Falconbridge expressed the view that the samples submitted to them were not sufficiently large.

If GOLES's mean figures for the various elements are compared with the analytical results, it is apparent that within the two plutons there are layers considerably enriched in the platinoids, gold, silver, chromium, copper and nickel. There is slight enrichment in zinc, but only normal amounts of cobalt and lead. The table also shows that most of the samples rich in the various elements concerned are selected, and as such represent the best mineralisation of a given outcrop or mineralised layer. This makes the results less interesting from an economic viewpoint.

It can be concluded that:

(1) The plutons as a whole contain above average amounts of the platinoids, gold, silver, chromium, copper and nickel, and that certain layers are considerably enriched in these elements.

(2) As these layers are narrow (< 2 m) and of limited lateral extent, it seems unlikely that they would constitute ore.

(3) Outcrop is sufficiently extensive and the sampling and analysis programme has been adequate enough for it to be concluded that further surface investigation will not yield more promising results. If it were decided to undertake further work this should be an electromagnetic survey to try to find hidden zones of conducting sulphides.

(4) The narrow asbestos veinlets (page 22) are much too small to be of economic interest.

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Institute of Geological Sciences,
Photogeological Unit,
5, Princes Gate,
London, S.W. 7

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDDELELSER OM GRØNLAND BD. 192 NR. 1 (J. P. BERRANGÉ)

PLATE 1

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDDELELSER OM GRØNLAND BD. 192 NR. 1 (J. P. BERRANGÉ)

PLATE 2