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Gardiner intrusion, an ultramafic complex at Kangerdlugssuaq, East Greenland

by

Wolfgang Frisch and Hansrudolf Keusen

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Gardiner intrusion, an ultramafic complex at Kangerdlugssuaq, East Greenland

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Abstract

The Gardiner intrusion is an ultramafic complex in the inner region of Kangerdlugssuaq fjord, forming part of the East Greenland Tertiary Igneous Province.

The rocks of the intrusion can be placed into three categories. (1) An older sequence is composed of dunites, pyroxenites, and a narrow marginal zone of alkali rich rocks. The rocks of the marginal zone consist of melteigite where the bordering country rock is plateau basalt, and of contaminated rocks where the country rock is the basement gneisses. The bordering gneisses have a narrow fenitized zone. (2) A strongly alkaline and undersaturated dyke sequence comprises amphibole pyroxenites, tawites, urtites, and sodalite, nepheline and alkali-feldspar syenites. (3) A younger sequence consists of uncompahgrites (intrusive melilite rich rocks) and calcite carbonatite dykes. Parts of the uncompahgrite show layered accumulations of magnetite, perovskite and apatite on the one hand, and melilite on the other. Massive aggregate concentrations of perovskite and magnetite are also recorded. The intrusion of uncompahgrite and carbonatite has resulted in intense alkali metasomatism of the rocks of the older and the dyke sequences.

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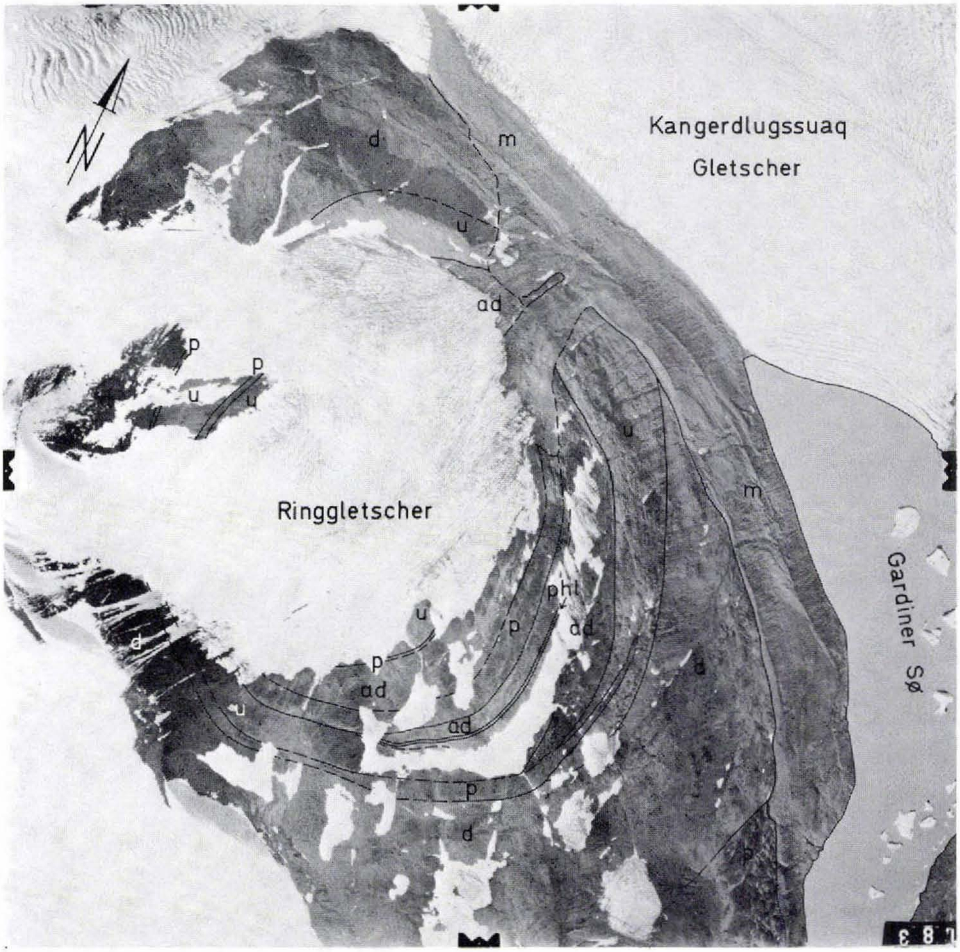

Fig. 1. Aerial photograph of the central part of the Gardiner intrusion. d = dunite, p = pyroxenite, ad = altered dunite and pyroxenite, phl = phlogopite zone, u = uncompahgrite, m = moraine (cf. plate 1). Scale ~ 1:30000. Copyright Geodetic Institute, Denmark. (Published with permission A. 649/72).

INTRODUCTION

A previously unknown intrusion was discovered in 1971 by K. Vohryzka while engaged in prospecting work for Nordisk Mineselskab. It was identified during a reconnaissance flight into the innermost parts of Kangerdlugssuaq, a large fjord on the east Greenland coast at latitude 68° N.

The intrusion is circular in shape and has a diameter of about 6 km. It is situated between Gardiner Sø and Gardiner Plateau, a glacier plateau, at the south-western edge of Kangerdlugssuaq Gletscher. It is exposed on the northern and eastern slopes of the nunatak Anorerssuaq (2040 m), the last major nunatak against the inland ice cap. The intrusion has been named Gardiner intrusion.

There is only a brief mention in the literature of the extraordinary ultramafic rock types at Gardiner Plateau. Wager (1947) describes "a remarkable magnetite-tremolite rock" which he considers as belonging to the Archaean basement, but which without doubt originated within the intrusion.

The Gardiner intrusion belongs to the East Greenland Tertiary Igneous Province. It is unique in the area, being composed predominantly of ultramafic rocks with later intrusions of uncompahgrite and carbonatite.

The field work was carried out by the authors, with the assistance of G. Malecki (Vienna).

Because of the short time available for field work, and the relatively poor topographic control, the geological map presented must be considered a preliminary one, and the description of the rock types merely a first characterization.

The first information about the Gardiner intrusion was given in a lecture presented at the 49th annual meeting of the Schweizerische Mineralogische und Petrographische Gesellschaft in Neuchâtel (Switzerland), October 1974 (Frisch & Keusen, 1975).

GEOLOGICAL REVIEW OF THE EAST GREENLAND TERTIARY IGNEOUS PROVINCE

The Gardiner intrusion is one of several plutonic complexes occurring between latitude 66° and 73° N, and forming part of the East Greenland Tertiary Igneous Province. Plateau basalts of Lower Tertiary age cover much of the area between latitude 68° and 71° N, and the Gardiner intrusion occurs near their southern termination (fig. 2).

A brief summary characterizing the intrusions of the East Greenland Tertiary

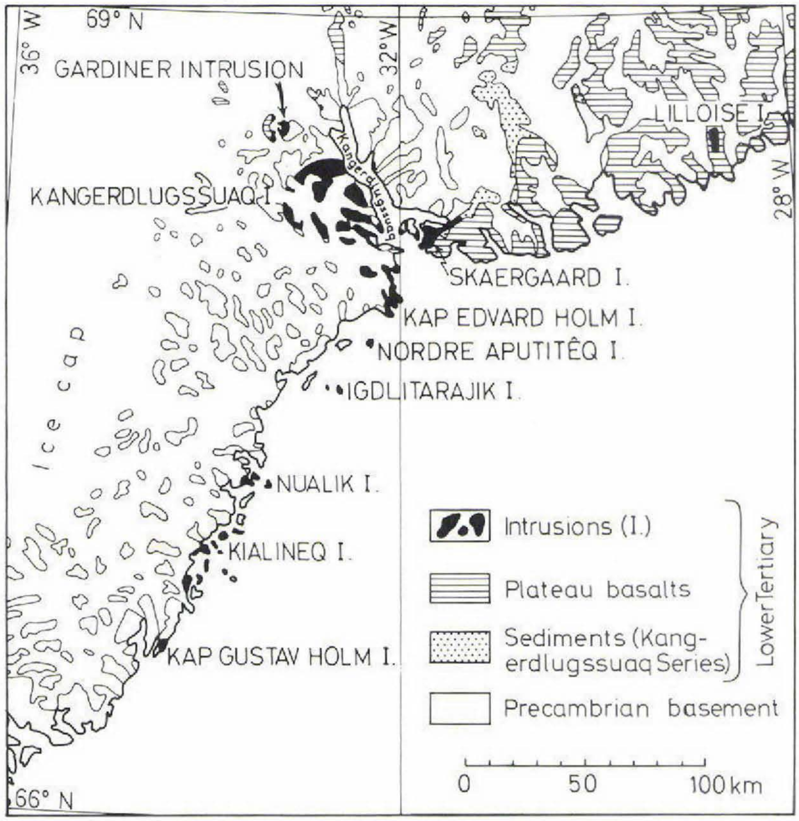

Fig. 2. Geological sketch map showing the southern part of the East Greenland Tertiary Igneous Province between 66° N and 69° N, and the position of the Gardiner intrusion. After Tectonic/ Geological Map of Greenland (1970).

Igneous Province is given by Haller (1971). Detailed studies were made on the Kangerdlugssuaq intrusion (Kempe, Deer & Wager, 1970; Kempe & Deer, 1970), the Skaergaard intrusion (Wager & Deer, 1939), the Werner Bjerge intrusion (Bearth, 1959), and the subvolcanics east of the Werner Bjerge (Kapp, 1960). The age of these intrusions is Lower Tertiary (Beckinsale, Brooks & Rex, 1970) and several of the intrusions cut the Lower Tertiary plateau basalts.

The basement in the Kangerdlugssuaq region is made up of granitic to granodioritic gneisses which belong to the Nagssugtoqidian mobile belt (1800–1650 m.y.; Wager & Hamilton, 1964).

GEOLOGICAL SURVEY OF THE GARDINER INTRUSION

The rock sequences

The intrusion is ring shaped with a diameter of about 6 km (plate 1). On the aerial photograph (fig. 1) showing the central part of the intrusion, the circular outline of the rocks can be clearly seen.

The intrusion is made up of ultramafic rocks with the exception of a narrow marginal zone, and the majority of the dykes. The rocks can be divided into three sequences, i.e. an older sequence followed by a related dyke sequence, and a younger sequence (fig. 3).

The alkaline character of the intrusion is apparent in the rocks of the marginal zone and the adjacent fenites, in the rocks of the dyke sequence, and in alkaline metasomatism in the contact zones of the uncompahgrite bodies.

The rocks of the *older sequence* make up the greater part of the intrusion. They are disposed circularly, particularly near the centre of the intrusion where several dunite and pyroxenite bodies form concentric rings. The outermost pyroxenite zone and the contact of the intrusion against the country rocks appear to be disordered in places. In the north-western part of the intrusion where the outcrops are poor and most of the contact is covered with ice, the outermost pyroxenite zone could not be found.

At the contact of the intrusion with the basaltic country rocks there is a marginal zone a few metres thick made up of melteigite. At the contact with the gneissic country rocks of the basement, the rocks of the marginal zone are contaminated, and the adjacent basement rocks display a narrow zone of fenitization.

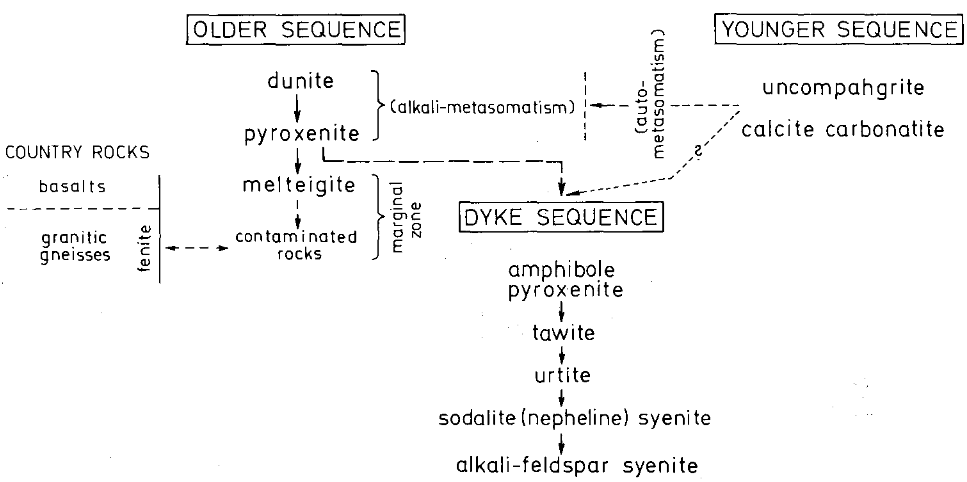

Fig. 3. Scheme of the rock sequences of the Gardiner intrusion (cf. plate 1).

The *dyke sequence* intrudes the rocks of the older sequence, and in places cuts the contacts with the country rocks and intrudes a short distance into them. The dykes are arranged concentrically or radially with respect to the centre of the intrusion. Most of the dykes dip very steeply but some relatively flat lying concentric dykes dip 30–50° away from the centre. The large sodalite syenite dyke within the outer pyroxenite zone in the south-eastern part of the intrusion, is an example of this type.

In composition the dykes range from ultramafic rocks to strongly alkaline and undersaturated leucocratic syenites.

The *younger sequence* confined to the centre of the intrusion consists of uncompahgrite (plutonic rock mainly made up of melilite; Larsen & Hunter, 1914). This material forms two ring shaped bodies, the inner one being largely covered by ice. The uncompahgrite affects the rocks of the older sequence and the dyke group by causing intense alkali-metasomatism.

Genetically connected with the uncompahgrite are carbonatite (sövite, i.e. calcite carbonatite) dykes. These are rare and found only within the rocks of the older sequence.

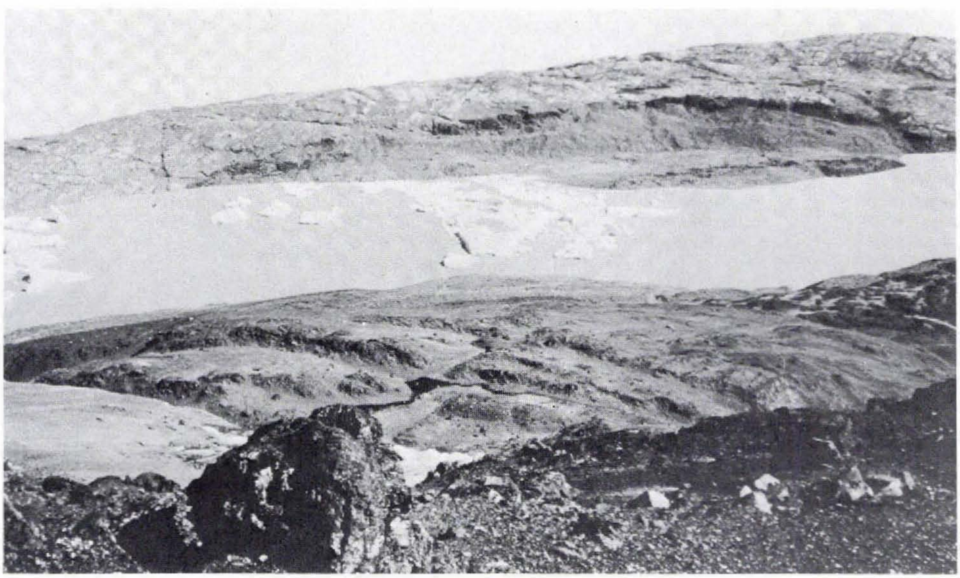

Fig. 4. View of the north-eastern part of the Gardiner intrusion. The contact of the intrusion is well developed on the far side of Gardiner Sø. In front of Gardiner Sø dunite borders against pyroxenite (black) (at the right hand edge of the picture). In the foreground is auto-metasomatically influenced uncompahgrite.

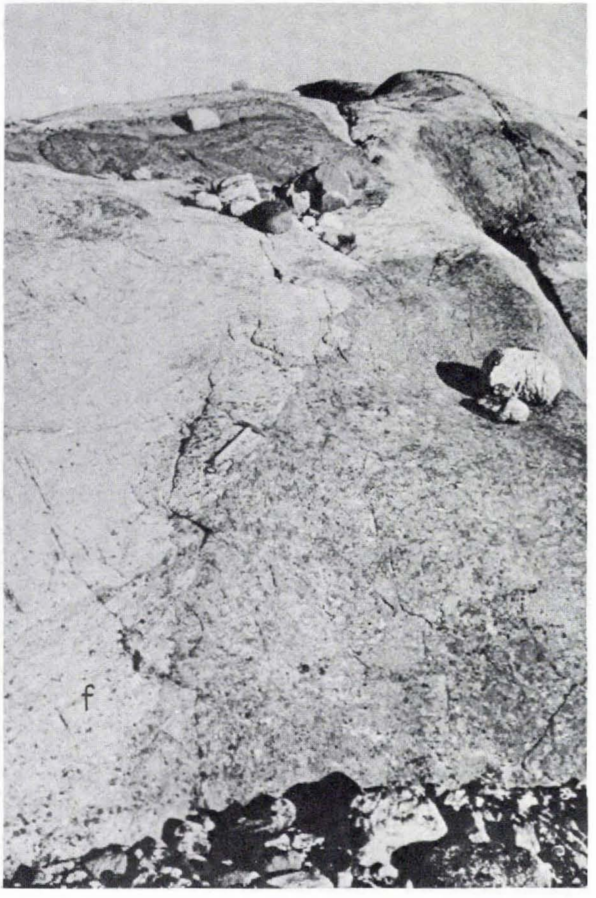

Fig. 5. Sharp contact of melanocratic contaminated marginal zone rock against fenitized gneissic country rock. The fenite zone (f) is narrow and grades into unaffected gneissic material. Locality: contact east of Gardiner Sø (fig. 4). Length of hammer: 30 cm.

The contacts of the intrusion with the country rocks

The contacts of the intrusion are vertical in the region of Anorerssuaq. At all other exposed localities the dip of the contact is away from the centre at angles of about 35–50°.

The contact with the Tertiary basalts, which appear unaffected by the intrusion, can be seen at Anorerssuaq. The contact with the Archaean gneisses can be studied east of Gardiner Sø (figs 4 and 5).

Generally the zone of fenitization in the gneisses around the intrusion is narrow. Here, however, the fenitization is macroscopically recognizable in the gneisses for a distance of 0.5–1 m from the contact, by the growth of aegirine-augite, amphibole, biotite, calcite, and albite.

The reason that the contacts of the intrusion generally dip outward is possibly

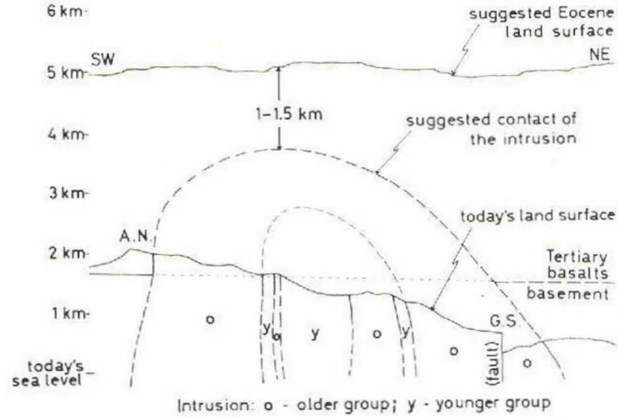

Fig. 6. Reconstruction of the Gardiner intrusion subsequent to emplacement.

that today's land surface cuts the intrusion at a high level (fig. 6). It is suggested that the land surface which developed on the Tertiary basalts was approximately 5000 m above today's sea level, the total thickness of the basalts in the Gardiner area being between 3000 and 4000 m (Wager, 1947, p. 37). Drawing a schematic diagram of the intrusion and placing it in relation to the suggested land surface during the time of emplacement, gives an intrusion depth of between 1 and 1.5 km. Today's erosion surface in the centre of the intrusion would thus be 2–2.5 km beneath the culmination point of the intrusion cupola.

The age of the Gardiner intrusion

Although it cuts the Lower Tertiary plateau basalts, the intrusion itself is cut by younger doleritic and ultramafic dykes. As the age of the younger dykes is not known, the intrusion can only be dated as post-basaltic.

The syenitic intrusions of the Kangerdlugssuaq region post-date the formation of the coastal flexure and its dykes at least in part and are therefore younger than the basic Skaergaard intrusion which pre-dates the coastal dyke swarm but post-dates the plateau basalts (Haller, 1971). Biotite from the syenitic Kangerdlugssuaq intrusion yielded a Rb-Sr age of 49 ± 2 m.y. (Hamilton, 1966) which is early Eocene. If the acid plutons are considered to mark the end of the Tertiary igneous activity as suggested by Haller (1971), the Gardiner intrusion can be assumed to have been emplaced about lower Eocene or upper Paleocene time.

Structural relations

The Kangerdlugssuaq region is marked by a NNW–SSE striking fault system running parallel to the fjord (Brooks, 1973) and at approximately right angles to the northern part of the coastal flexure which bends at the mouth of Kangerdlugssuaq (fig. 7). The majority of intrusions so far known in the southern part of the East Greenland Tertiary Igneous Province are restricted to the immediate vicinity of the coastal flexure or, like the Gardiner intrusion, to the Kangerdlugssuaq fault system. Several important intrusions, i.e. the Kangerdlugssuaq intrusion, the Kap Edvard Holm intrusion, and the Skaergaard intrusion, are situated in the area where the coastal flexure bends and where the Kangerdlugssuaq fault system joins it (fig. 7). Both the coastal flexure and the Kangerdlugssuaq fault system have been active in Lower Tertiary time. There is a clear relation in space and in time between the tectonic and the igneous activity.

The Gardiner intrusion itself is cut by a major fault traced by the long axis of the Gardiner Sø (plate 1). This fault strikes in a NNW–SSE direction and raises the eastern part of the intrusion, or displaces it to the south. Although it has been active since the intrusion was emplaced, it probably predates the intrusion. The existence of the fault is inferred because of the incompatibility of the geology to the east and west of Gardiner Sø. At the south-east end of the lake, the continuation of the fault is indicated by a shattered zone some 10 m in thickness within the Archaean basement rocks.

The Gardiner Sø fault strikes 150° or 160°. Its theoretical continuation to the south-south-east would meet the contact of the Kangerdlugssuaq intrusion west of Kangerdlugssuaq Tinde. It should be noted that there is a dyke swarm running parallel to the Gardiner Sø fault and cutting the rocks of the Kangerdlugssuaq intrusion (Wager, 1947, p. 43). These dykes run at right angles to the coastal dyke swarm and parallel to the fjord Kangerdlugssuaq.

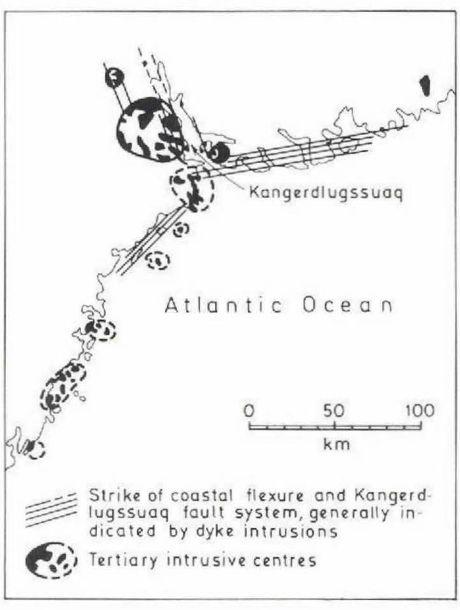

Fig. 7. Sketch showing the structural relations in the Kangerdlugssuaq region. Coastal flexure and dyke swarm after Wager (1947).

Apparent displacement of the contact rocks in the southern part of the Gardiner intrusion suggests the presence of a second fault. This fault, hidden beneath the glacier, may well be responsible for the country rock – dunite contact in the north-western part of the intrusion. This fault would strike parallel to the Gardiner Sø fault, and to the Kangerdlugssuaq fault system.

THE PETROGRAPHY OF THE GARDINER INTRUSION

The rocks of the older sequence

Dunite

The dunites are the oldest rock type of the intrusion and comprise the greater part of it (plate 1). In the central part of the intrusion there are two or three concentric pyroxenite rings alternating with the dunites. Most of the central dunites have been replaced or metasomatically altered by the uncompahgrites.

The dunites show little variation throughout the whole series, except where metasomatically altered.

Table 1. Modal analyses of dunites of the Gardiner intrusion

Sample no.	2535*	2534	2512	2551^{+}	2531*	2530	2529	2528*	2527	2501^{+}	2547^{+}
Olivine (forsterite)	70	77–88	64	97	86	93	91	82	82	86	94
Crysotile-α	–	+	30	–	1	–	1	–	–	4	–
Diopside	1	4–12	1	+	2	–	2	10	10	4	+
Amphibole	1	+	–	–	3	–	+	+	1	–	–
Phlogopite	8	2–3	2	–	2	1	1	1	2	–	–
Magnetite	18	5–10	3	3	4	5	3	4	4	6	6
Magnetite as oriented intergrowths	+	~1	–	–	~1	~1	~2	~2	~1	–	–
Perovskite	2	≦1	–	–	+	–	–	1	+	–	–
Calcite	–	–	+	–	1	–	–	–	+	–	–
Apatite	–	–	–	–	+	–	–	–	–	–	–
Melilite	–	–	–	–	–	–	–	–	+	–	–
	central part				of dunite zone					marginal part	

Modal analyses in volume per cent

$^{+}$ rocks unaffected by contact metasomatism

* chemical analysis available in table 19

Sample 2534 shows the modal range of three samples

The composition of the *olivine* is strongly forsteritic. From whole rock compositions, and universal stage measurements, values of $Fo_{90\text{-}92}$ have been established. X-ray determination of 26 olivine samples after the method of Yoder & Sahama (1957) yielded no change in olivine composition in the dunites throughout the intrusion.

Serpentinization has been weak. Only one sample (2512*; table 1) could be found showing considerable amounts of pale green chrysotile with a typical mesh-texture. The serpentinization begins along cracks showing a preferred orientation, and does not correlate with the intensity of alkali.metasomatic alteration caused by the younger uncompahgrite intrusion (see later).

Clinopyroxene may form up to 10 per cent of the dunites, and partly replaces olivine. The pyroxene is a diopside similar to that encountered in the pyroxenites (see next section). Universal stage measurements on a zoned sample are given below.

Innermost core (only partly developed)	$2V_\gamma = 53°$
Coloured core	$2V_\gamma = \pm 58°$
Colourless rim	$2V_\gamma = 60–62°$

The coloured core with a larger extinction angle (γ:c) appears to be a little richer in Fe^{+2} than the rim.

In several thin sections some accessory *amphibole* has been identified showing euhedral to subhedral outlines. It is restricted to the vicinity of magnetite and pyroxene and replaces olivine and pyroxene. The colour of the amphibole is reddish brown of medium intensity in the core and pale yellowish or greenish brown to colourless (transitions) in the rim. It has a large axial angle ($2V_\alpha \sim 80°$), and is considered to be kaersutite or titanian hornblende in the cores with a transition to titanium-free varieties in the colourless rims. The amphibole present in both dunites and pyroxenites shows no correlation with alkali-metasomatism, and is hence thought to be primary. Only the pale rims may have been subject to metasomatic alteration.

Alkali-metasomatized dunites in the contact zone of uncompahgrite

In the contact zone around the uncompahgrites the dunites are affected by alkali-metasomatism. Alteration has been particularly strong in the zone between the central and the outer uncompahgrite bodies. The metasomatic solutions have apparently used the pre-uncompahgritic dykes as channels of ascent thereby altering dunites in the outer parts of the intrusion, e.g. north-north-west and west of the great bay of Gardiner Sø.

* Sample numbers are those used in the field. For localities, see fig. 35. A representative collection is held by the Geological Survey of Greenland.

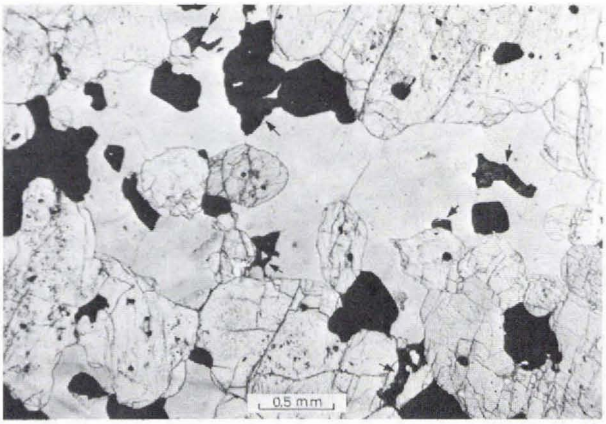

Fig. 8. Large phlogopite flakes replacing olivine in metasomatically influenced dunite. Black: magnetite, and some perovskite (arrows). Thin section of sample 2535, parallel nicols.

The rock types considered in this section are only dunites which have remained dunites in spite of alteration. Between the two uncompahgrite bodies there are in addition many rocks in which the original mineral assemblage is partly or completely destroyed and replaced by other minerals.

The alkali-metasomatically altered rocks are characterized by an abundance of accessory minerals. The presence of perovskite, calcite, and in one case melilite, indicates that the intrusion of the uncompahgrite is responsible for the alteration process. The overall appearance of phlogopite in the altered rocks underlines the alkaline character of the metasomatic process.

Only three of the investigated samples listed in table 1 (2501, 2547, 2551) have remained unaffected by the metasomatic processes (see also table 2).

Phlogopite is the most sensitive mineral to the metasomatic effects. It rims magnetite and grows at the expense of olivine, diopside and amphibole. It may occasionally form large poikiloblasts (samples 2534, 2535) (fig. 8).

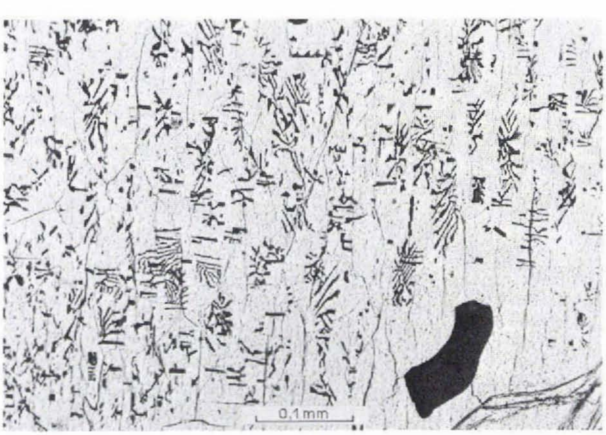

Fig. 9. Dendritic magnetite within olivine (forsterite). Black: magnetite. Metasomatically slightly influenced dunite. Thin section of sample 2527, parallel nicols.

Table 2. Several alkali-metasomatic alteration degrees deduced from the mineral assemblages in the dunites

Sample no.	Minerals grown due to alkali-metasomatic alteration				alteration degree
	Phlogopite	Additional magnetite	Perovskite	Amphibole (pale to colourless variety)	
2501					no metasomatic alteration
2547					
2551					
2512	+				beginning to
2529	+	(+) dr		(+)	slight metasomatic alteration
2530	+	(+) dr			
2528	+	(+) dr	+	(+)	
2527	+	(+) dr	+	+	
2531	+	(+) dr	+	++	
2534	+(+)	+ r	+	(+)	increasing alteration
2535	++	++ (r)	++	+	

(+) = slight, + = medium, ++ = strong increase (relative)
Magnetite: besides intergranular magnetite some intragranular magnetite occurs as: d dentritic intergrowths, r oriented rods in olivine

The phlogopite varies in the intensity of its colour from sample to sample, and may have colourless rims, probably poorer in iron than the typical pale yellow-brown cores. A pale green low birefringent variety was recorded in some samples.

With increasing metasomatic influence in the dunites, the amount of *magnetite* increases. In the unaltered dunite patches or octahedra of magnetite occur.

In slightly altered dunite (samples 2527–31) additional magnetite occurs as oriented intergrowths within olivine. This may be either as dendritic intergrowths (fig. 9) or as rods 0.02–0.04 mm in length and oriented parallel to the *b* and *c* crystallographic directions in the (001) and (100) planes respectively.

The magnetite intergrowths could be considered as exsolution products formed during cooling of the olivine (Deer, Howie & Zussman, 1964, pp. 1–6). It is more likely, in view of their absence from unmetasomatized rocks, that they have been formed by oxidation processes associated with the alkali metasomatism.

In the more strongly affected dunites (samples 2534, 2535) the magnetite crystallizes to coarser patches. The strong increase in the proportion of intergranular magnetite to 15–20 volume per cent can only be explained by the introduction of iron during metasomatic alteration.

The occurrence of *perovskite* in the metasomatically influenced dunites represents a somewhat higher degree of alteration. It always accompanies magnetite as narrow seams and forms anhedral or subhedral grains with typical polysynthetic twinning.

In one sample a large grain of *melilite* was found (sample 2527) and in another *apatite* was noted (sample 2531). Some *calcite* may also be present. These minerals are considered as a product of metasomatism.

With the beginnings of metasomatic alteration in the dunites, recrystallization occurs. The grain size of olivines (and pyroxenes) increases from 0.5–3 mm to 5–20 mm. In more strongly affected rocks (samples 2534, 2535) replacement of olivine by secondary minerals results in a decrease in grain size (fig. 8), although many small crystals are frequently in optical continuity indicating an originally larger crystal. Table 2 summarizes the effect of increasing degrees of alteration on the dunites.

Pyroxenite

Pyroxenite occurs in the outer parts of the intrusion, where it is strongly developed in the south-east, weakly in the south and south-west, and apparently absent in the north-west. It also occurs in the centre of the intrusion as two or three concentric rings partly replaced by uncompahgrite.

The boundaries between pyroxenite and dunite are in all cases sharp on a macroscopic scale although in certain samples there is an increase of diopside in the dunites and of olivine in the pyroxenites (up to 10 vol. %) as the boundary is approached (tables 1 and 3). In most pyroxenites olivine is absent or occurs as an accessory phase.

Table 3. Modal analyses of pyroxenites

Sample no.	2546	2516	2496	2484*
Diopside	91	83	85	94
Olivine (forsterite)	–	3	10	1
Amphibole	+	2	+	+
Biotite	+	–	–	–
Magnetite	8	10	3	5
Magnetite as rods in diopside	~1	~2	~2	+
	central	part of intrusion		marginal

* For chemical analysis see table 19.

Table 4. Wet chemical analysis of diopside of the pyroxenite

	wt. %	number of cations on the basis of 6 oxygens			
SiO_2	51.90				
TiO_2	0.90				
Al_2O_3	2.56	Si	1.91		2.00
Fe_2O_3	1.90	Al	0.09		
FeO	4.85	Al	0.02		
MnO	0.13	Ti	0.02		
MgO	15.80	Fe^{+3}	0.05	1.11	
CaO	21.25	Fe^{+2}	0.15		
Na_2O	0.46	Mg	0.87		1.98
K_2O	0.01	Ca	0.84	0.87	
P_2O_5	0.06	Na	0.03		
H_2O^+	0.17				
	99.99				

Sample 2484
Analyst: W. Frisch

The main constituent of the pyroxenite is a very pale greenish yellow *diopside*. The diopside shows twinning on (100) and may show slight compositional zoning.

A chemical analysis of a typical pyroxene is given in table 4. The composition is in close agreement with that estimated from the optic axial angle (table 5).

Recalculating this analysis gives a pyroxene of the following composition (magnetite impurity eliminated):

$(Na_{0.03}\ Ca_{0.85})_{0.88}\ (Mg_{0.87}\ Fe^{+2}_{0.14}\ Fe^{+3}_{0.03}\ Al_{0.03}\ Ti_{0.02})_{1.09}\ [(Si_{1.92}\ Al_{0.08})_{2.00}\ O_6]$,

i.e.	En	45.3 mol. %	or (without acmite):	En 46.8 mol.%
	Fs	7.3 mol. %		Fs 7.5 mol. %
	Wo	44.3 mol. %		Wo 45.7 mol. %
	Ac	3.1 mol. %		

Olivine occurs as subhedral to euhedral grains, enclosed and partly replaced by poikilitic pyroxene. The composition of the olivine is identical to that of the olivine from the dunites.

Amphibole is ubiquitous as an accessory phase, forming up to 2 per cent of the rock. It patchily replaces the cores of pyroxene, and grows with the same orienta-

Table 5. Axial angles $2V_\gamma$ of diopside of the pyroxenite

Sample no.	$2V_\gamma$	$2V_\gamma$ in rim of zoned crystals
2516	53–54°	–
2496	53–54°	56–57°
2484	51–52°	53–54°

Universal stage measurements

tion as the host. The amphibole is a dark reddish brown with a large axial angle ($2V_\alpha \sim 80°$) and is probably kaersutite with less intensely coloured, titanium-poorer rims.

Magnetite (3–10 vol. %) forms euhedra within the diopside grains or, more commonly, it is interstitial. The bulk of the magnetite has grown after the pyroxene.

The replacive nature of much of the magnetite, and the higher magnetite content of the rocks of the central part of the intrusion, suggest that, as with the dunites, much of the magnetite has been formed under metasomatic conditions. Reaction 'seams' of amphibole and anatase, between metasomatic magnetite and magmatic olivine suggest disequilibrium. Magnetite also occurs as rods within the diopside. These rods are oriented along the *c* axis of the host in the (110) plane and along the *a* axis in the (001) plane (fig. 10). As with the dunites, the magnetite rods are considered to be the product of oxidation and alteration of the primary diopside caused by a metasomatic process, rods being rare in the unaffected rocks. A narrow rim of magnetite free pyroxene occurs, a feature also noticed in the olivine of the dunites.

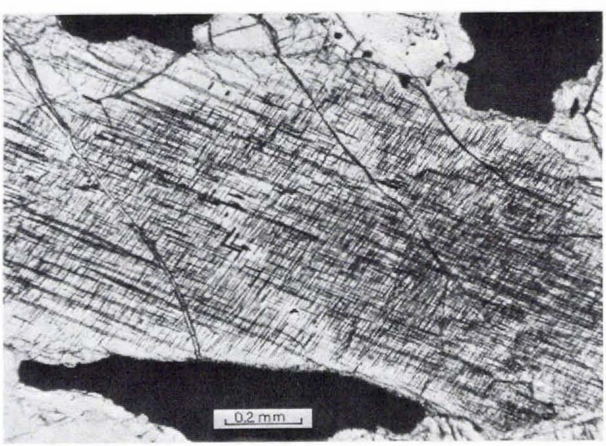

Fig. 10. Magnetite rods within diopside. Black: magnetite. Metasomatically slightly influenced pyroxenite. Thin section of sample 2516, parallel nicols.

Apart from the occurrence of increased amounts of magnetite, and a certain amount of recrystallization, there is little mineralogical evidence for metasomatism. The pyroxenites are obviously less prone to alteration than the dunites.

The marginal zone

Between the outer pyroxenite zone and the country rocks a narrow marginal zone is developed. This zone is made up of melteigites where the adjacent rocks are the Tertiary plateau basalts. The rocks change their composition due to contamination where the zone borders against the basement gneisses. The gneisses are themselves weakly fenitized.

In the field, the rocks of the marginal zone are recognizable by the presence of felsic minerals, the dominant mafic mineral being pyroxene.

The marginal zone has been found north-east and south-east of Anorerssuaq, and on both sides of Gardiner Sø. Thickness varies from less than 1 m to several metres. Locally, lenses of melteigite occur a few metres or, occasionally, some distance from the contact of the intrusion within the outer pyroxenite zone. These lenses are up to a few metres thick.

Generally, the rocks of the marginal zone (including the melteigite lenses) grade into the bordering pyroxenites.

The relationships between the composition of the marginal zone rocks and the adjacent country rocks is shown in table 6 where the modes of eleven samples taken from six different localities are displayed.

Melteigites and contaminated marginal zone rocks will be described separately. The most conspicuous differences between the two groups is the presence of two pyroxenes, one of which is aegirine-augite, in the melteigites, and the presence of feldspar (and quartz) instead of sodalite and nepheline in the contaminated rocks.

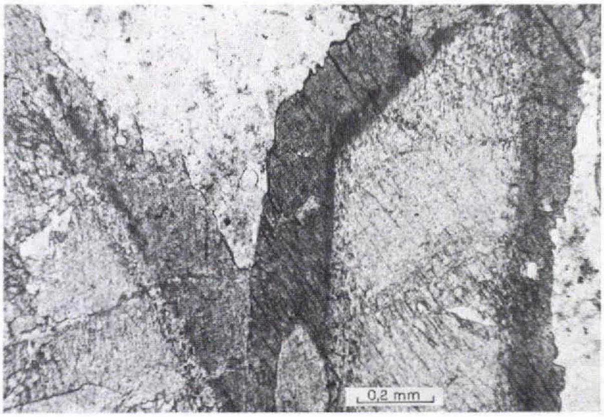

Fig. 11. Zoned pyroxene with diopside core and aegirine-augite rim, the inner part of the rim (dark) being richer in the acmite component than the outer part. Zeolite and one apatite crystal. Melteigite. Thin section of sample 2485, parallel nicols.

Table 6. Modal analyses, colour indices, and relationships to the country rocks of the different rock types comprising the marginal zone

	Melteigites					Contaminated marginal zone rocks					
Sample no.	2485–1	2485–2	2504–1	2504–2	2500*	2490–1	2490–2	2569–1	2569–2	2498*–1	2498–2
Diopside	24.5	32	49	40	0.5	56	49	12.5	28	8	6
Aegirine-augite	39	29	18	19	45	–	–	–	–	(+)	–
Amphibole	10.5	–	–	–	18.5	9	4.5	38	17	18.5	7.5
Biotite	+	5.5	7.5	8	+	5.5	3.5	+	3.5	0.5	1
Chlorite and biotite alterations	–	–	–	–	–	–	–	1.5	1.5	–	–
Sphene	9.5	4.5	–	+	1	–	1	11.5	2.5	1.5	0.5
Magnetite	+	3	5.5	4.5	+	16.5	11	16.5	13	6	4.5
Apatite	2.5	1	1	3	2	2	0.5	1.5	2	1	0.5
Calcite	–	–	–	–	3	–	–	0.5	–	–	(+)
Sodalite	6	6	–	–	14	–	–	–	–	+	0.5
Nepheline	–	15.5	14	14	8	–	–	–	–	–	+
Natrolite and other zeolites (secondary)	8	3.5	5	11.5	8	–	–	–	–	–	0.5
Plagioclase	–	–	–	–	(+)	11	30	18	24	64.5	79
Quartz	–	–	–	–	–	–	0.5	–	8.5	–	–
Colour index	86	75	81	74.5	70	89	69.5	82	67.5	35.5	20
Mafic silicates omitting sphene	74	66.5	74.5	67	64	70.5	57	52	50	27	14.5
Bordering country rock	Pyroxenite of intrusion		Plateau basalts		/	Weakly fenitized gneisses					

* For chemical analyses see table 19

Sample 2485. Lens within pyroxenite some distance from contact of intrusion
Sample 2504. Marginal zone in contact with plateau basalt of Anorerssuaq
Sample 2500. Marginal zone in contact with plateau basalt and bordering gneisses south-east of Anorerssuaq
Sample 2490. Marginal zone in contact with gneisses, west of large bay in Gardiner Sø
Sample 2569. Marginal zone in contact with gneisses, east of Gardiner Sø
Sample 2498. Marginal zone in contact with gneisses, at the southernmost tip of the intrusion

Table 7. Acmitic portion of the pyroxenes in melteigite

Sample no.	2485	2504	2500
Core (diopside)	~5	~5	(~5)
Outer core	(10–15)	–	–
Transitional zone (frequently narrow)	30–40	(10–20)	25–30
Inner rim (narrow)	(60–70)	–	–
Rim or whole crystals	50–65	30–40	30–45

Optical determination of $\alpha:c$ and 2V
Values in parentheses are of zones which may not always be developed
Mol. % acmite

Melteigite

The primary *pyroxene*, diopside, similar to that in the pyroxenites, has been rimmed by aegirine-augite forming phenocrysts some 10 mm in length (fig. 11). Discrete, smaller crystals of aegirine-augite are also frequently present. The aegirine-augite rims of the phenocrysts are themselves zoned, and may possess a narrow inner zone more acmitic than the bordering outer zone (fig. 11). Samples taken from a lens within pyroxenite (e.g. sample 2485) show a higher acmite component in their rims (table 7).

Amphibole, where present, is of different composition to the amphiboles of the contaminated rocks. The amphiboles exhibit strong zoning obvious from their colour and the optic axial angle (table 8).

From the optical data (colour, 2V, $\alpha:c$, Δ), the amphibole is an arfvedsonite with a high $MgFe^{+3}/Fe^{+2}$ Fe^{+3} ratio (magnesio-arfvedsonite) decreasing towards the rims.

Except for a few sporadic flakes of *biotite* when amphibole is present, these two minerals are mutually exclusive in the melteigites. The titanium content of the biotite depends on the presence of sphene. In rocks containing sphene (sample 2485) the biotites possess olive-brown colours (γ) indicating a high Fe^{+3}/Ti ratio, whereas biotites of rocks containing no sphene (samples 2504, 2500) have an intense brownish red colour indicating a high Ti content.

Amphibole and biotite replace both pyroxenes. At the reaction borders of biotite with aegirine-augite small granules of magnetite/hematite may be present as a result of excess Fe^{+3} originating from the acmitic pyroxene.

Apatite, magnetite, and at least a part of the *sphene* are early formed phases. Around large magnetite patches included in the pyroxene, the diopside has been altered to aegirine-augite.

The wedges between the mafic minerals are filled by *sodalite, nepheline,* and secondary *natrolite*. Sodalite contains numerous fine unidentifiable particles pro-

Table 8. Absorption colours and optic axial angles of amphiboles from melteigites

	Colour parallel to			
Sample 2485–1	α	β	γ	$2V_\alpha$
Core	light yellowish brown	dark greyish brown to purplish grey	brownish green	60–70°
Rim	pale yellowish brown	(bluish) green	(bluish) green	similar
Sample 2500				
Core	light yellowish brown	yellowish brown to purplish brown	brownish green	62°
Rim	pale brownish grey to nearly colourless	dark brownish grey	green	38°
Outermost rim (narrow)		colourless		50–60°(?)

bably derived from unmixing. Parts of the sodalite and nepheline are altered to natrolite.

The felsic minerals are the youngest components and react with apatite, aegirine-augite, amphibole, biotite, and in part, sphene and magnetite.

The melteigite with its complex mineral assemblage is the product of a residual fraction of the magma. The early crystallization of diopside, the replacement by alkali pyroxenes and amphiboles, and the transitional borders to the pyroxenites indicate that the melteigites represent a part of the pyroxenite zone in which the volatile-rich, highly oxidized and alkaline residue of the dunite and pyroxenite producing magma has become concentrated.

Contaminated marginal zone rocks

Contaminated marginal zone rocks occur at all contacts with the gneisses of the basement. They range from melanocratic to leucocratic types (table 6), the leucocratic types being the more acid and more strongly contaminated.

The contaminated marginal zone rocks exhibit essential differences in chemistry and mineralogy to the melteigites as the result of an exchange of elements with the gneissic country rocks, which themselves are fenitized within a narrow zone. Despite this the contact between marginal zone rocks and gneisses is a sharp one (fig. 5).

The principal differences between the contaminated marginal zone rocks and the melteigites are: (a) there is no aegirine-augite in the contaminated rocks; (b) the amphibole is not arfvedsonite but hastingsite or kaersutite; (c) there is a higher proportion of magnetite in the contaminated rocks; (d) the felsic minerals of the contaminated rocks are plagioclase and, in places, quartz (for modal compositions see table 6).

Diopside is present in the contaminated marginal zone rocks as long prismatic phenocrysts exhibiting euhedral to subhedral outlines against plagioclase and quartz. At times it shows patchy extinction, lowered birefringence and anhedral outlines, suggesting that it is out of equilibrium with its surroundings.

The composition of the *amphibole* depends on the presence of sphene. Where sphene is absent or present as an accessory mineral only (samples 2490 and 2498), a brown amphibole rich in Ti occurs: kaersutite. In the presence of sphene (sample 2569), it is a green variety poor in Ti: hastingsite, the cores of many crystals having a somewhat higher titanium content than the rims.

Homoaxial intergrowths of relic diopside with amphibole are frequent, but are more common with hastingsite than with kaersutite.

As with the amphibole, the Ti contents of the *biotite* is variable. A dark reddish brown (γ) Ti-rich biotite occurs with kaersutite, whereas a dark brown to olive Ti-poor biotite occurs with hastingsite.

Magnetite is present as small crystals within diopside or, more frequently, as large aggregates in wedges between diopside crystals. A remarkably high proportion of magnetite occurs in samples 2490 and 2569 (10–17 vol. %).

Sphene occurs as 'seams' around magnetite but only where it is in contact with later formed amphibole. There are also large poikiloblasts of sphene in sample 2569 intimately associated with both magnetite and amphibole. Where amphibole and biotite are Ti-rich sphene is an accessory phase or absent.

Plagioclase occurs as large poikilitic crystals 5 mm across surrounding all mafic minerals (samples 2490 and 2569). In sample 2498 plagioclase forms large tabular or thick prismatic crystals.

The plagioclase is an oligo-andesine (An_{28-33}) zoning to oligoclase rims (An_{25-27}). Twinning is common after the albite, Carlsbad, Roc Tourné, and occasionally the pericline laws.

Plagioclase and quartz have reacted with all of the mafic minerals and preferentially replace diopside and amphibole. *Quartz,* found in two thin sections, frequently occurs together with biotite and replaces it intensely. It may also replace plagioclase.

Fenite

Fenites are found in a narrow zone in the gneissic country rocks at the margins of the intrusion. From field observations this zone would appear to be restricted to a thickness of 0.5–1 m (fig. 5).

The unaltered country rocks are granitic or granodioritic gneisses with about a quarter to a third quartz in the mode. Plagioclase is oligoclase to andesine, orthoclase is converted to microcline. Mafic minerals constitute about 10 per cent of the rock. An analysis of a similar granodioritic gneiss is given by Wager & Deer (1939) from the vicinity of the Skaergaard intrusion. This analysis is listed in table 19, and the rock is plotted in figs 27–31.

The fenites are characterized by the growth of aegirine-augite, Na-Mg-amphibole, biotite, calcite, and albite, and by the disappearance of quartz. Albite grows at the expense of quartz, alkali feldspar (chessboard albitization), and plagioclase.

The minerals which grew during the fenitization process are arranged in clusters, bundles and aggregates.

Without doubt, an exchange of elements has taken place between the intrusive body and the country rocks.

The contamination process

The variations in the composition of the rocks of the marginal zone are dependent on the composition of the adjacent country rock.

From the chemical analyses (table 19) and the modes of the marginal zone rocks and fenites, some conclusions can be made concerning the exchange of elements. Both Si and Al have been introduced into the marginal zone from the bordering gneisses and there is significant migration of Ca, Mg, and Na into the fenitization zone of the country rocks.

Comparing the modal analyses of the majority of contaminated marginal zone rocks with those of the melteigites, it can be seen that there is a general decrease in Na in the contaminated rocks. There is strong evidence for the introduction of Na into the country rocks, both from the compositions of the minerals formed during fenitization, and the high Na content of the fenites (8 wt. % Na_2O).

In general it can be established that the process:

aegirine-augite + nepheline (sodalite) + Al_2O_3 + SiO_2 $\rightarrow$ plagioclase $_{An\pm 30}$ (+ quartz) + magnetite + Na_2O + CaO + MgO

is valid for the formation of the contaminated rocks. The left hand side of this equation represents a partial mineralogy of the melteigites, plus the elements which have been introduced into the marginal zone by contamination (Al, Si). The right hand side represents a partial mineralogy of the contaminated marginal zone rocks, plus the elements which have migrated into the gneissic country rocks and caused fenitization (Na, Ca, Mg, and some of the Fe).

The equation is derived from the mineralogical observations in the marginal zone rocks and the fenites, and is confirmed by the chemical analyses (table 19). The right hand side reflects the mineralogical characteristics of samples 2490 and 2569: lack of aegirine-augite, presence of plagioclase (oligo-andesine), some quartz, and abundance of magnetite. For sample 2498 which is extremely rich in plagioclase but does not bear free quartz, introduction of greater amounts of SiO_2 and Al_2O_3 is necessary which is in accord with the chemical analysis of this sample when compared with that of the melteigite (table 19).

The process of exchange of elements occurred as a reaction between the still liquid residual fraction of melteigitic composition (diopside probably being already crystallized) and the gneissic country rocks. The exchange of elements only occurred over distances of the order of a few metres.

The rocks of the dyke sequence

A variety of dykes cut the rocks of the older sequence, and some cut the contacts of the intrusion with the country rock, as seen in the south and south-east of the intrusion. Nearly all the dykes are either concentric or radial.

There are both melanocratic and leucocratic types of dykes. The melanocratic dykes are amphibole pyroxenites and tawites, and the leucocratic ones are urtites, sodalite (and nepheline) syenites, and alkali-feldspar syenites. These leucocratic dykes together with parts of the contaminated marginal zone are the only leucocratic rocks of the intrusion.

The dykes are characterized by the predominance of sodium over potassium.

Amphibole pyroxenite dykes

These are three parallel radial amphibole rich pyroxenite dykes south-east of Ringgletscher within the dunite zone. They stand out clearly on aerial photographs and in the field are nearly black in colour. Their continuation to the north-north-west into the second pyroxenite ring is uncertain.

The dykes are composed of diopside, brown amphibole, and minor amounts of magnetite (table 9).

Diopside corresponds in its optical properties to that observed in the pyroxenite of the older sequence. The crystals are prismatic and up to 1 cm in length.

Brown *amphibole* ($\gamma = \beta$ = yellowish brown, α = pale yellowish brown) occurs as euhedral

Table 9. Modal analysis of amphibole pyroxenite

	Sample 2537
Diopside	48 vol. %
Amphibole	38
Biotite	+
Magnetite	12
Apatite	2

crystals. It appears to replace diopside, replacement occasionally occurring in the cores of the diopside grains.

Biotite, an accessory phase, occurs in association with magnetite. It replaces bordering diopside and amphibole. Some biotites show zonation with light reddish brown cores grading through a yellowish brown transition zone into nearly colourless rims.

Magnetite occurs as inclusions in diopside and amphibole. Large clusters of anhedral magnetite occur in the interstices of the rock.

Apatite, which seems to have crystallized after diopside, is present as prisms, mostly fractured, up to 1 mm in length.

Tawite dykes

Several tawite dykes cut the rocks of the older sequence near its centre. All the tawite dykes have been found within the dunite zone, but it is possible that the dark tawites have been overlooked within the dark pyroxenite. (The same may be true for amphibole pyroxenite dykes.)

The dykes are about 1 m in thickness. Two concentric dykes west of Ringgletscher dip away from the centre, whereas south-south-east of Ringgletscher parallel concentric dykes of tawite dip steeply towards the centre.

The tawites are fine-grained and of dark grey colour stippled with sodalite, the only light constituent.

In thin section, the mafic minerals occur embedded in minerals of the sodalite group. Pyroxene and amphibole show a preferred orientation, probably as a result of flow during intrusion of the dyke. The modal compositions of two tawites are listed in table 10. The rock differs somewhat from the original tawite from the Tavaiok valley, Kola Peninsula (Tröger, 1969, p. 260). The main difference is that the tawites of the Gardiner intrusion contain pyroxene less sodic in composition. Nevertheless, the name is considered to be applicable to the rock in question.

Pyroxene, the main mafic constituent, is a pale yellowish green diopside or diopsidic augite. The grain size of the pyroxenes tends to be less than 1 mm in length, and due to replacement by other minerals they rarely show euhedral outline.

Table 10. Modal analyses of tawite dykes

Sample no.	2511	2522*
Pyroxene	26 vol. %	30 vol. %
Amphibole	17.5	3.5
Biotite	2.5	9.5
Apatite	3	1
Magnetite	9	8
Sphene	(+)	14
Sodalite	41.5	34
Zeolite	0.5	(+)

* For chemical analysis see table 19

Amphibole (γ greyish brown, β dark greyish brown, α pale yellowish brown) tends to partly replace pyroxene. It occurs as crystals, up to 3 mm in length, including drop-like pyroxenes, apatite and magnetite (e.g. sample 2511). Amphibole itself may be extensively replaced by sodalite, and has a skeletal appearance (e.g. sample 2522).

Biotite partly replaces amphibole. Its colour is an intense yellowish brown in thin section with a distinct tinge of red. Some crystals have nearly colourless, possibly phlogopitic rims. In certain of the biotites the reddish core contains sagenite needles.

Sphene is a major constituent of sample 2522 (14 vol. %) where it occurs as subhedral poikilitic crystals of about 1 mm in length. It may also form narrow continuous 'seams' around magnetite. It is interesting that sample 2511 contains no sphene (only some negligible leucoxene). Titanium is restricted to amphibole and biotite in this rock.

Magnetite forms aggregates with partly euhedral outlines. It may be included in pyroxene, either rarely as single crystals, or very rarely, as oriented rods.

Minerals of the *sodalite* group are the youngest constituents and fill the intergranular space. In sample 2522, two generations can be distinguished both in thin section and by X-ray diffractometry. The powder diagram shows well developed peaks close to the values of pure nosean or haüyne with a minor shift towards the sodalite component. Less intense peaks correspond to sodalite proper. In thin section, clear grains with some tendency to euhedral outlines are surrounded by a variety filled with numerous microliths. It is suggested that the clear grains are almost pure sodalite (older generation), while the microlithic variety is close to nosean or haüyne (younger generation). This is supported by the refractive indices. In sample 2511, the sodalite is decomposed to minerals of the zeolite group.

The tawite dykes are mineralogically related to the ultramafic amphibole pyroxenite dykes described above. The most obvious difference between them is the major occurrence of sodalite in the tawites, and their much higher content of Ti. Pyroxene and amphibole are of similar composition in both rock types.

Urtite dykes

The urtite dykes are the most common in the Gardiner intrusion. Nearly all of them are disposed concentrically or radially, and most of them dip steeply. In certain areas of the intrusion a dense network of urtite dykes is found, e.g. south-west of Ringgletscher within dunite, and west of the great bay in Gardiner Sø within pyroxenite. The thickness of the dykes ranges from decimetres to metres, and they can be traced for several hundred metres along their length.

Table 11. Range of modal composition of urtite dykes

Aegirine-augite	8–30 vol. %
Nepheline	55–90
Sodalite	2–15
Albite	0–12
Apatite	≦2
Sphene and decomposed sphene	0–1

Samples 2481, 2482 and 2483 from south-south-east of Ringgletscher

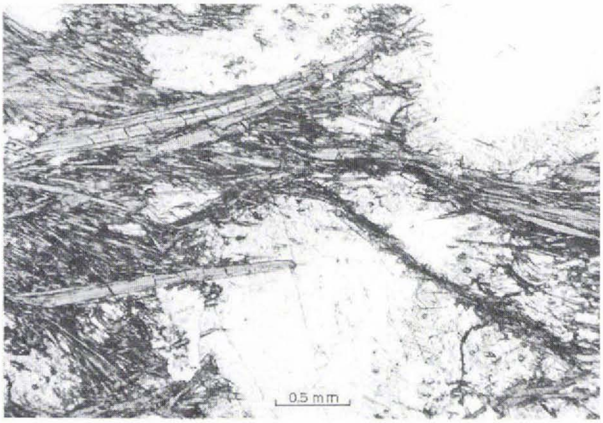

Fig. 12. Bundles of aegirine-augite needles within large nepheline crystals. Urtite dyke. Thin section of sample 2481, parallel nicols.

The urtite dykes are characterized by their leucocratic nature and are composed mainly of nepheline and aegirine-augite, with some sodalite.

The coarse grain size of the constituent minerals, and their irregular distribution, makes it difficult to fix the modal composition of the urtites. The point counting of several thin sections supported by estimation in hand specimens resulted in the modal composition ranges given in table 11.

Aegirine and *aegirine-augite* are the major mafic minerals of the urtites and are pale or dark bluish green in colour (α). They form either thick prisms or fine needles. Whereas the prisms occur as single, well-shaped crystals, the needles form bundles or rosettes enclosed by later albite (shorter needles) or nepheline (fig. 12). Frequently, the needles of pyroxene are oriented within the nepheline, parallel to its *c* axis.

From the extinction angles, $\alpha{:}c$, the aegirines and aegirine-augites range from Ac_{40} to Ac_{90}. Most crystals show slight zoning with the cores being up to 15 mol. per cent richer in the acmite component than the rims. Both hourglass and oscillatory zoning have also been recorded.

Albite is present in some of the urtite dykes, but only occurs together with very sodic pyroxene. The less sodic pyroxenes are restricted to albite-free rocks. Albite is either included in younger nepheline, or forms aggregates of subparallel laths with aegirine suggesting flow structure. The long aegirine crystals are warped and fractured by the flow of the crystal mush (fig. 13a, b). Tiny needles of aegirine either fill the interstices between the albite laths, or are included in them.

A few per cent of thick prismatic chessboard albite may be present. This represents an earlier alkali feldspar which has become replaced by the action of solutions rich in soda. The chessboard albite is itself replaced by nepheline whereas primary albite is replaced by nepheline to only a small extent, if at all. The sequence of crystallization has been: albite laths (flow structure) – alkali feldspar – nepheline, and albitization of alkali feldspar.

Nepheline is the main constituent of all the rocks dealt with in this section. It occurs as large euhedral crystals several centimentres in length or, more commonly, anhedral crystals several millimetres in diameter, with fine-grained nepheline in the intergranular space.

Sodalite shows irregular distribution and replaces nepheline and albite. Microchemical experiments with nitric acid and calcium chloride indicated the presence of appreciable amounts of SO_3, in the sodalite. Both the haüyne and the nosean component have been identified. This is in agreement with the X-ray powder data and with the refractive index determinations ($n \sim 1.490$ which is too high for pure sodalite).

a

b

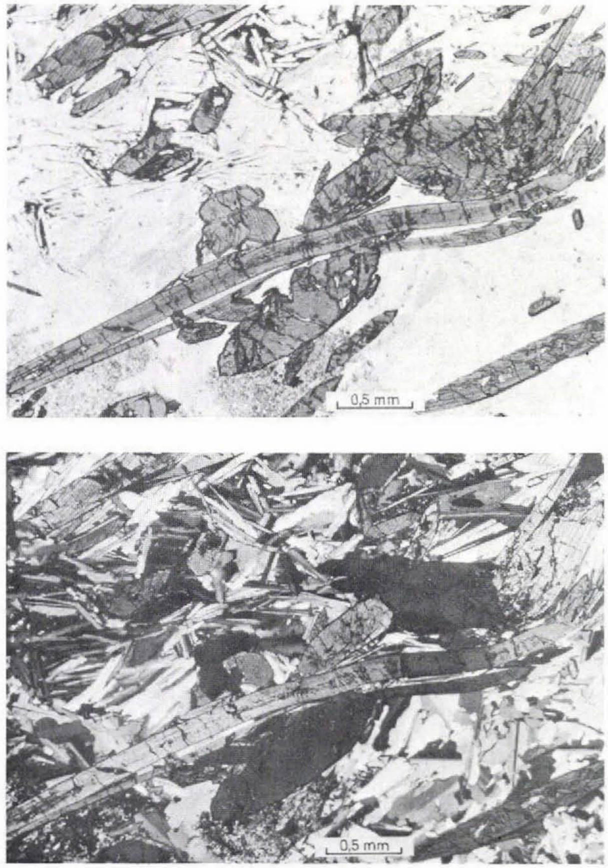

Fig. 13. Warped and fractured aegirine-augite crystals within an albite matrix indicating flow, by the parallel alignment of the laths. Urtite dyke. Thin section of sample 2532, *a* parallel nicols and *b* crossed nicols.

Apatite, a late crystallizing phase, forms large, anhedral patches. *Sphene* is occasionally present, and may be decomposed to leucoxene + anatase + rutile. A cubic mineral with a deep reddish brown colour, probably a member of the pyrochlore group, is a rare accessory.

Cancrinite may replace both nepheline and sodalite. The amount of replacement is usually small and restricted to fractures, but sample 2483 shows extensive replacement by a cancrinite, which, from optical data, contains 40 per cent of the vishnevite molecule.

The appearance of cancrinite replacing the feldspathoids together with accessory calcite, indicates the possibility of metasomatic influence caused by the later intrusion of uncompahgrite and carbonatite.

Sodalite (nepheline) syenite dykes

Among the leucocratic dykes are several sodalite syenites, composed mainly of alkali feldspar and sodalite, and with the mafic minerals forming only about 5 per cent of the rock.

Table 12. Modal analysis of sodalite syenite dyke

Aegirine-augite	3 vol. %
Amphibole	0.5
Biotite	+
Sphene	1.5
Alkali feldspar	75–80
Sodalite	15–20

Sample 2493 from the thick dyke in the south-eastern part of the intrusion. For chemical analysis see table 19

A conspicuous sodalite syenite dyke of this type, lying within pyroxenite, occurs in the south-eastern part of the intrusion. It is concentric, 6–8 m thick, and dips at a rather shallow angle. The dyke's modal analysis is given in table 12. It resembles 'foyaites' described from the central part of the Kangerdlugssuaq intrusion by Kempe, Deer & Wager (1970).

Other sodalite syenite dykes occur in the same areas as the urtite dykes, but are less common than them. Not all are shown on the geological map.

The pyroxene is *aegirine* or *aegirine-augite* forming long prisms or needles and having intense bluish green cores with narrow green rims. The pyroxene is apparently unstable and is replaced by feldspar.

Pyroxene is associated with an arfvedsonite type *amphibole* which exhibits anomalous interference colours and the following pleochroic scheme: α yellowish green; β dark brownish grey; γ grass-green. It forms micrographic intergrowths with sodalite.

Some yellowish brown *biotite* has replaced aegirine, but primary biotite is also present, either orange-red (titanium biotite) or brownish black in thin section. Biotite may be accompanied by *vermiculite*. *Sphene* forms subhedral rhombs and is partly decomposed to leucoxene.

The *alkali feldspar* is an anorthoclase-microperthite developed as vein perthite or, more commonly, as patch perthite grading into chessboard albite. The bulk composition of the alkali feldspar from norm

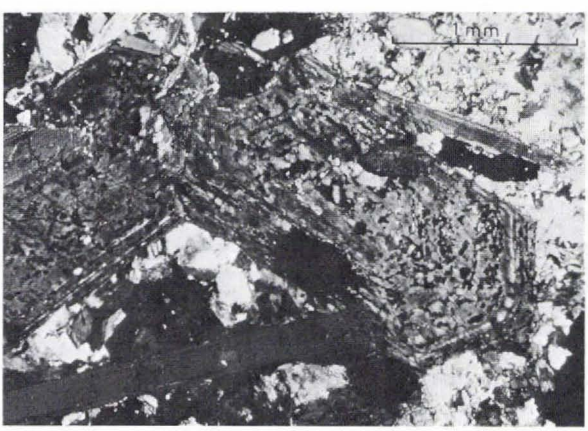

Fig. 14. Euhedral eudialyte crystals with oscillatory zoning in a nepheline syenite dyke. Thin section of sample 2497, crossed nicols.

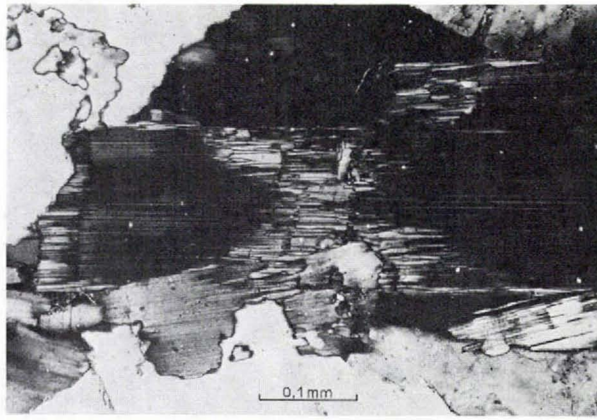

Fig. 15. Alkali feldspar showing a kind of 'hourglass' texture. Alkali-feldspar syenite dyke. Thin section of sample 2520, crossed nicols.

calculations is Or_{25} Ab_{75}. Generally, the feldspar possesses the thick prismatic orthoclase habit, but some individuals have the tabular habit of sanidine. Carlsbad twinning is common, and the axial angle $2V_{\alpha}$ ranges between 90° and 95°, the optical character therefore being positive.

Sodalite shows irregular distribution and similar composition to that in the urtites. Sodalite has formed after feldspar, and shows a tendency to decompose to natrolite and calcite.

An interesting nepheline syenite dyke occurs at the southern tip of the intrusion, cutting the contact with the Archaean rocks. It is unique in the area, containing eudialyte and verly large amphibole prisms, and for this reason is mentioned separately.

The *pyroxene* is a deep blue-green colour, and very rich in the acmite component (70–90 mol. % Ac).

The large *amphibole* crystals post-date the pyroxene. They may show brown cores of kaersutite, but are dominantly amphiboles which, from their optical properties, appear to be magnesium-rich members of the arfvedsonite group (α yellowish green, β dark brownish grey, γ grass-green).

Red *eudialyte* is a conspicuous accessory mineral. It shows oscillatory zoning (fig. 14) and is optically positive. The minerals have a variable birefringence, parts being almost isotropic.

Alkali feldspar (anorthoclase), and large irregularly distributed *nepheline* crystals are the other major phases present.

Well developed *sphene* crystals have been found, and *apatite* occurs as an accessory.

Large interstitial areas are filled with fine-grained albitic alkali feldspar, together with minor aegirine and sphene. The areas resemble the alkali-feldspar syenites described in the next section.

Alkali-feldspar syenite dykes

Alkali-feldspar syenite dykes (for nomenclature see Streckeisen, 1974) have been found together with intensely metasomatically altered rocks of the older sequence. They occur in the central uncompahgrite at the eastern edge of Ringgletscher, and within the metasomatically altered zone at the northern edge of the same glacier.

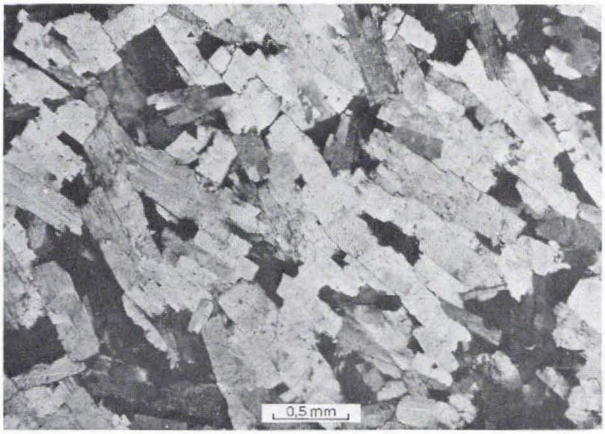

Fig. 16. Flow structure indicated by parallel alignment of tabular alkali feldspar crystals. Alkali-feldsparsyenitedyke. Thin section of sample 2520, crossed nicols.

The dyke east of Ringgletscher (sample 2520) is almost entirely made up of *albite* or *anorthoclase* (2V= ± 90°) exhibiting tabular habit. The crystals have very wavy extinction and show albite and Carlsbad twinning. Chessboard texture is common in parts of the crystals.

Many of the feldspars possess an 'hourglass' texture (fig. 15). Inside the 'hourglass' the mineral is free of twinning lamellae or contains only indistinct fine lamellae whereas outside the 'hourglass' there is distinct albite twinning, often combined with chessboard texture. Parts of some crystals are finely cross-hatched after the microcline law.

A preferred orientation of the tabular feldspar suggests flow structure in the rock (fig. 16).

Some calcite and opaque minerals, mostly decomposed, occur as accessories (less than 1%).

One dyke (sample 2562) contains thick prismatic *albite* crystals. The crystals are twinned after the albite, Carlsbad and Roc Tourné laws.

Variable amounts of *calcite* occur. This forms intact and sometimes zoned crystals in the interstices, and may partly replace albite. Accessories are *pyrite*, *chalcopyrite* (both in clusters), and decomposed Fe-Ti oxides. An olive-green, zoned mineral of the perovskite-dysanalyte group has been observed.

The presence of calcite together with sulphides and perovskite or dysanalyte suggests that these minerals formed during metasomatic processes associated with the intrusion of the rocks of the younger sequence (uncompahgrite–carbonatite). This is supported by the position of the dykes, occurring as they do within the metasomatically affected zone.

The rocks of the younger sequence

Uncompahgrite

Uncompahgrites are plutonic ultramafic rocks with melilite as the dominant constituent, and lesser amounts of diopsidic pyroxene, magnetite, perovskite, and apatite.

The uncompahgrites are some of the youngest rocks of the Gardiner intrusion (fig. 17) and form two distinct bodies. One occupies the core of the intrusion (central uncompahgrite body), and the other forms a nearly concentric ring (outer uncompahgrite body or uncompahgrite ring). The distance between the two uncompahgrite bodies ranges from less than 100 m in the west to several 100 m in the east (plate 1).

The central uncompahgrite body has a diameter of 1100–1300 m. Much of the body is covered by the Ringgletscher, hence there is no proof that the uncompahgrite occupies all the area indicated in the profiles (plate 2). In the two places where the border of the central uncompahgrite body is exposed, it is conformable with the bordering pyroxenite ring.

The outer uncompahgrite, ranging in thickness from 150–250 m, is not conformable with the second and third pyroxenite rings and hence is not exactly concentric (plate 1).

The dunite and pyroxenite both between the uncompahgrite bodies and near the outer contact of the uncompahgrite ring are metasomatically altered (see later).

Within the uncompahgrites are bodies of strongly altered dunite or pyroxenite, showing transitional boundaries with the uncompahgrite. Parts of the uncompahgrite appear to have suffered auto-metasomatism.

Fig. 17. Uncompahgrite area, outer uncompahgrite body west of Ringgletscher. Note the weathering of the uncompahgrite which is poorly exposed. Light spots are from reflecting, loose phlogopite crystals.

Table 13. Modal analyses (vol. %) of uncompahgrites

	2518*	2538*	2566	2563*-1	2563-2	Type loc. 1*	Type loc. 2*
Melilite	75–83	78	63	54	45	72	64
Pyroxene	2–4	5	1.5	3.5	+	9	15
Amphibole	2–3	–	2	–	–	–	–
Phlogopite	0.5–1	1.5	0.5	5.5	9	1	2
Magnetite	6–8	7.5	11.5	18	21	7	13
Perovskite	2–5	6.5	11.5	6	4.5	–	4
Apatite	4–5	1.5	10	13	20.5	1	1
Calcite	0.5–1	(+)	+	–	–	2	1
Melanite	–	–	–	–	–	8	–

* For chemical analyses see table 19

Sample 2518: typical uncompahgrites from east-south-east of Ringgletscher, central body
Sample 2538: typical uncompahgrite with long pyroxene needles from south of Ringgletscher, outer body
Sample 2566: uncompahgrite rich in magnetite-perovskite-apatite aggregates from north of Ringgletscher, outer body
Sample 2563: layered magnetite-perovskite-apatite uncompahgrites from north-north-east of Ringgletscher, outer body
Type loc. 1 and 2: uncompahgrites from type locality, Iron Hill, Uncompahgre Valley, Colorado (Larsen, 1942, p. 13).

The uncompahgrite of the Gardiner intrusion corresponds very well to that of the type locality at Iron Hill with respect to both modal and chemical composition (tables 13 and 19).

Besides the 'normal' uncompahgrites there occur types enriched in magnetite, perovskite, apatite, and phlogopite and correspondingly depleted in melilite. The

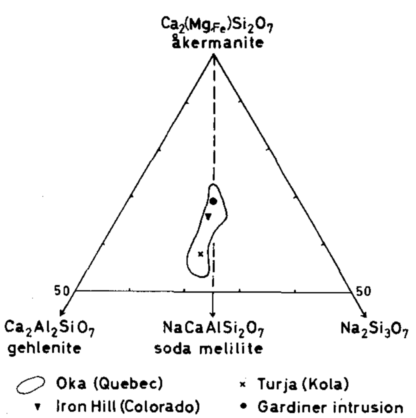

Fig. 18. Composition of melilites from intrusive rocks (after Watkinson, 1972).

Table 14. Wet chemical analysis of melilite from uncompahgrite

	wt. %		number of cations on the basis of 7 oxygens	
SiO_2	44.70	Si	2.06	3.03
TiO_2	0.14	Al	0.31	
Al_2O_3	5.75	Mg	0.60	
Fe_2O_3	0.58	Fe^{+2}	0.06	
FeO	1.85	Na	0.30	1.90
MnO	0.07	Ca	1.60	
MgO	8.75			
CaO	32.80		(impurities of magnetite, perovskite, apatite and calcite eliminated)	
Na_2O	3.36			
K_2O	0.07			
P_2O_5	0.05			
H_2O^+	0.28			
CO_2	0.21			
	98.61			

Sample 2538 (outer body)
Analyst: W. Frisch

enrichment in magnetite, perovskite and apatite occurs in clusters (sample 2566) or in compositional layers (sample 2563).

The 'normal' uncompahgrites of the central and the outer bodies (samples 2518 and 2538 respectively) are identical. They are massive, very tough, solid rocks. The melilite weathers to give a distinctive brownish yellow colour.

Melilite makes up more than three quarters by volume of the 'normal' uncompahgrites of the Gardiner intrusion. It forms anhedral crystals up to 1 cm in diameter and shows the typical bluish interference colours which make it easily distinguishable from apatite in thin section. Locally, patchy melilite is altered to a fine felt of calcite + diopsidic pyroxene probably by auto-metasomatism.

The melilite of sample 2538 has been separated and analyzed (table 14). The formula of the analyzed melilite is:

$(Na_{0.30}Ca_{1.60})_{1.90}(Mg_{0.60}Fe^{+2}_{0.06}Al_{0.31})_{0.97}[Si_{2.06}O_7]$,

that is 69 mol. % $Ca_2(Mg, Fe)Si_2O_7$ (åkermanite)
15 mol. % $Ca_2Al_2SiO_7$ (gehlenite)
16 mol. % $Na_2Si_3O_7$

or 69 mol. % $Ca_2(Mg, Fe)Si_2O_7$ (åkermanite)
31 mol. % $NaCaAlSi_2O_7$ (soda melilite),

and corresponds well with other melilites from intrusive rocks. Watkinson (1972) pointed out that the melilites from jacupirangite, okaite, and melilite carbonatite from the Oka complex (Quebec, Canada) remain within a limited range when they are plotted onto the system $Ca_2MgSi_2O_7$ (åkermanite) – $Ca_2Al_2SiO_7$ (gehlenite) – $Na_2Si_3O_7$, and that they are approximately restricted to the line $Ca_2MgSi_2O_7$ (åkermanite) – $NaCaAlSi_2O_7$ (soda melilite) on which the ratio Si:O equals 2:7. Fig. 18 shows the plot of several melilites from intrusive rocks, including that from the Gardiner uncompahgrite.

Diopsidic pyroxene of pale greenish yellow colour occurs as zoned prismatic needles up to 5 cm in length (sample 2538) and 1–3 mm width. The crystals show marginal replacement or are poikilitically enclosed by melilite. Frequently, only skeletons of previously large crystals are preserved, the rest being replaced by the melilite. Remnant pyroxene may also show replacement by amphibole (samples 2518, 2566) or phlogopite.

The non-silicates, apatite, magnetite and perovskite have the tendency to form clusters and aggregates (cumulus texture).

Apatite is early formed, enclosed by the other phases, and may be partly replaced by melilite.

Magnetite is present as single crystals or, more often, as large aggregates. In some cases magnetite rods have been observed as inclusions in the (001) plane of melilite. The crystals are homogeneous in reflected light.

Perovskite occurs either rimming the magnetite aggregates, or as large euhedral to subhedral crystals intimately associated with magnetite. The perovskite is easily recognizable by its polysynthetic twinning in two mutually perpendicular directions. The twinning is orientated 45° to the crystal faces and the extinction. Generally, the perovskite is a light purplish brown, although large crystals possess a reddish brown core (fig. 19). Narrow rims of perovskite around magnetite and aggregates or single crystals of perovskite may be pale yellowish brown (for chemical analysis of a perovskite see table 16).

Melanite-schorlomite occurs sporadically together with perovskite (see later).

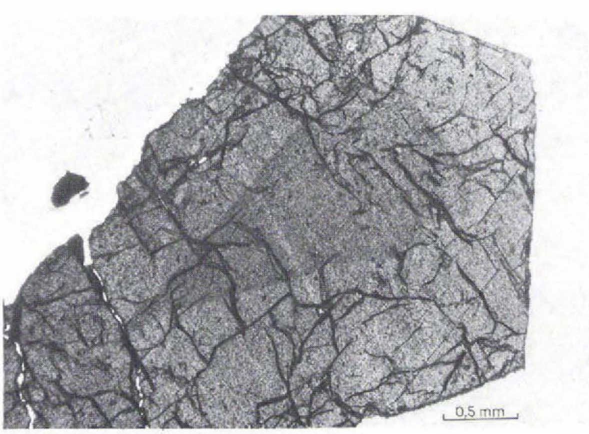

Fig. 19. Zoned perovskite crystal with reddish brown core and purplish brown rim. Uncompahgrite. Thin section of sample 2567, parallel nicols.

Amphibole only occurs as a replacement mineral after pyroxene. It has light greyish green to yellowish green colour. From the optical data the amphibole is possibly an eckermannite.

Phlogopite is generally rare in the uncompahgrites, but may be important locally. In the northern half of the outer uncompahgrite body it forms euhedral flakes several centimetres in diameter. It is a pale yellowish brown parallel to γ with colourless or green zones and patches.

Amphibole and the great part of the phlogopite in the phlogopite-rich rocks are the product of intense auto-metasomatic alteration, particularly near the eastern contact of the central uncompahgrite body, and in the northern segment of the uncompahgrite ring.

Uncompahgrites rich in magnetite, perovskite and apatite have been found in several places both in the central uncompahgrite body and in the northern and north-eastern parts of the outer uncompahgrite body. These minerals occur in

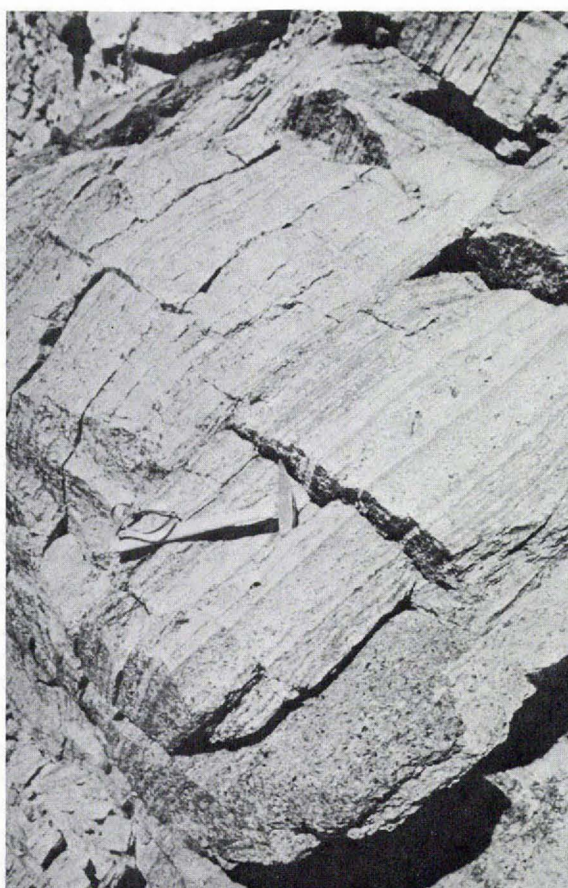

Fig. 20. Layered magnetite-perovskite-apatite rich uncompahgrite dipping *c*. 55° to the centre of the intrusion. Light layers consist mainly of melilite, dark layers of magnetite, perovskite and apatite. Outer uncompahgrite body north-north-east of Ringgletscher. Length of hammer: 30 cm.

Fig. 21. Hand specimen of layered uncompahgrite. Same locality as in fig. 20.

clusters and may be accompanied by melanite or schorlomite. They occur in rocks containing a relatively high proportion of phlogopite (5–10 vol. %).

A remarkable rock type showing a layered concentration of these minerals occurs in the northern part of the outer uncompahgrite body (see profile 2, plate 2). The layers strike parallel to the ring and dip with a medium angle (55°) towards the centre of the intrusion. This is not conformable with the outer contact of the uncompahgrite which is dipping 80° away from the centre.

The layering is caused by an accumulation of apatite, magnetite and perovskite (black layers), and of melilite (dark greyish layers). The melilite weathers to an intense yellowish brown colour making the layering easy to distinguish. The thickness of the layers ranges from 1 to 10 cm (figs 20 and 21).

The borders between the apatite-magnetite-perovskite layers and the melilite layers may be sharp or transitional (fig. 21). Sharp borders between the layers have been observed both at the upper and particularly the lower boundary of the black layers.

There is strong evidence that the layering of the uncompahgrite has been formed *in situ* and with the present day inclined attitude. Thus the undisturbed, parallel layering is primary and is considered as evidence for an uncompahgritic magma.

Massive perovskite concentrations

Massive perovskite and magnetite concentrations occur in a separate zone at most a few metres thick at the contact of the inner uncompahgrite body (plate 1). They can also occur in rocks strongly affected by, and adjacent to, the uncom-

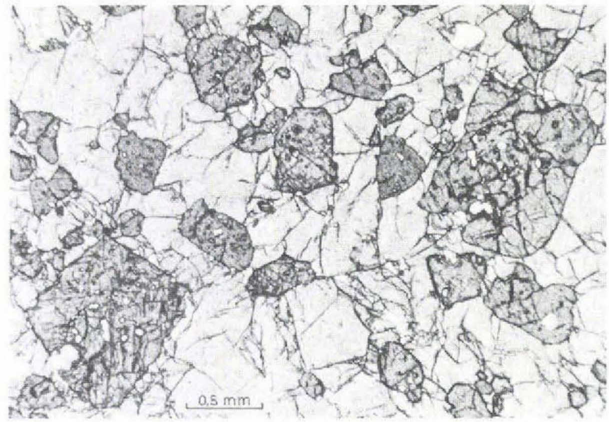

Fig. 22. Perovskite crystals within a large single melanite crystal. Light: calcite. Perovskite-melanite rock. Thin section of sample 2540, parallel nicols.

pahgrite intrusion. It is likely that the zone continues around the inner uncompahgrite body under the ice of Ringgletscher.

The zone contains varying amounts of magnetite, perovskite, and melanite as the major constituents.

Magnetite is frequently an important constituent. In the southern part of the outcrops east of Ringgletscher, a magnetite layer 2 m thick was observed, containing only small amounts of perovskite, which forms narrow rims to the magnetite. The magnetite crystals are homogeneous in reflected light. The Cr content examined by semiquantitative spectral analysis is low (c. 200–2000 ppm).

In other parts, *perovskite* makes up 50 per cent or more of the whole rock. The perovskite is usually the light purplish brown variety described as the dominant type in the uncompahgrites.

Melanite to *schorlomite* (Ti-andradite) occurs sporadically, particularly east of Ringgletscher. It forms aggregates several decimetres across in which the large melanite-schorlomite crystals occur together with euhedral perovskite (samples 2540, 44 and 45; fig. 22). The TiO_2 content of two schorlomites has been investigated by the method of Howie & Woolley (1968). The determined values of $a_0 = 12.12 \pm 0.05$ and $n = 1.90–1.92$ correspond with TiO_2 contents of 8–9 per cent.

Apatite, *calcite*, and *phlogopite* may be present as minor or accessory constituents. Calcite which is considered to be primary, occurs as drop-like inclusions within perovskite or between perovskite crystals.

Other concentrations of perovskite, forming clots several decimetres in diameter or lenses several metres in length, are situated within the marginal parts of the uncompahgrites or within the alteration zone between the two uncompahgrite bodies. Several melanite (schorlomite)-perovskite occurrences have been found north and east of Ringgletscher (e.g. sample 2540).

West of the moraine leading from Ringgletscher to Kangerdlugssuaq Gletscher there is a limited occurrence of a layered zone within the outer uncompahgrite body. It is composed of magnetite-perovskite-apatite-phlogopite layers, which are separated by thin, nearly pure, apatite layers, and in which melilite is lacking (table 15).

Perovskite from a melanite (schorlomite)-perovskite rock taken from the zone of concentration east of Ringgletscher, has been separated and analyzed (table

Table 15. Average modal analysis of layered magnetite-perovskite-apatite rock

	Sample 2568
Magnetite	30 vol. %
Perovskite	18
Apatite	25
Phlogopite	27

For chemical analysis see table 19

16). Remnants of dunite, strongly altered, occur at the contact of the melanite-perovskite zone at this locality. The perovskite is the light purplish brown variety. Its specific gravity is 4.15 ± 0.05.

The formula of the analyzed perovskite is:

$(Ca_{0.90}\,Fe^{+2}_{0.01}\,Na_{0.02}\,Ce_{0.03}\,La_{0.02}\,Nd_{0.01})_{0.99}\,(Ti_{0.97}\,Nb_{0.02})_{0.99}\,O_3$.

Table 16. Chemical analysis of perovskite from melanite-perovskite rock, east of Ringgletscher

	wt. %	number of cations on the basis of 24 oxygens		
SiO_2	–			
TiO_2	53.80	Ti	7.76	7.98
Nb_2O_5	2.23	Nb	0.19	
Ta_2O_5	0.01	Al	0.01	
Al_2O_3	0.04	Fe^{+3}	0.02	
Fe_2O_3	0.15			
Ce_2O_3	2.93	Ca	7.17	7.90
La_2O_3	2.32	Fe^{+2}	0.06	
Eu_2O_3	0.01	Na	0.18	
Nd_2O_3	1.52	Ce	0.20	
Pr_2O_3	0.32	La	0.16	
FeO	0.37	Nd	0.11	
MnO	0.01	Pr	0.02	
MgO	–			
CaO	35.40			
Na_2O	0.51			
K_2O	0.01			
	99.63			

Sample 2545
Analysts: Analyx SA (Genève) and H. Keusen

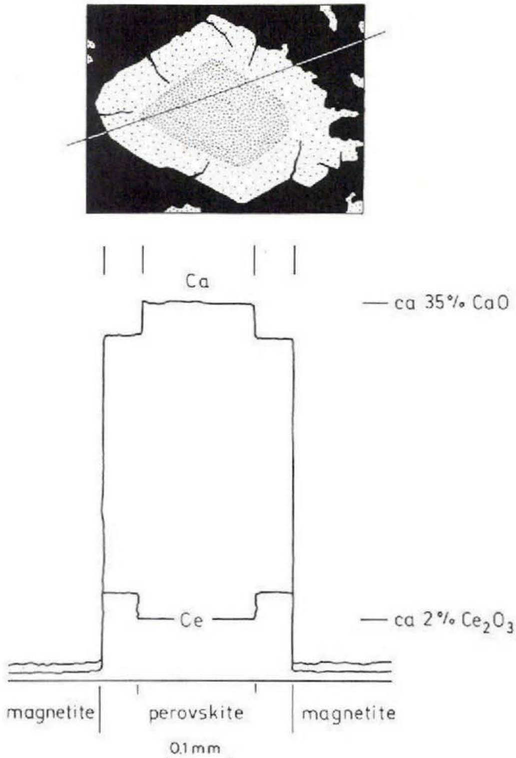

Fig. 23. Microprobe profile through a zoned perovskite crystal from uncompahgrite. Locality near the inner contact of the outer uncompahgrite body north of Ringgletscher (sample 2567).

As described in the foregoing section, large perovskite crystals in the uncompahgrites possess cores of reddish brown colour in thin section coated by the light purplish brown variety (fig. 19). To study the distribution of Ca and Ce, a microprobe profile (fig. 23) was obtained through a well developed zoned crystal which derives from the outer uncompahgrite body. A sharp and distinct break between core and rim can be seen. The profile (fig. 23) clearly shows substitution of Ca by Ce. The Ce_2O_3-value of the core is about 2 wt. per cent, that of the rim about 3 wt. per cent.

Alkali-metasomatic alteration zones

Around the uncompahgrites, particularly in the area between the two uncompahgrite bodies, the rocks of the older sequence are alkali-metasomatically altered by hydrothermal solutions originating from the uncompahgrite-carbonatite magma (fig. 24). The dunites are strongly altered or even replaced whereas the pyroxenites are generally more resistant to the hydrothermal solutions.

Alkali-metasomatic alteration has also taken place some distance from the uncompahgrite where urtite and syenite dykes are common. The hydrothermal solu-

Fig. 24. Screens of dunite which became replaced metasomatically by solutions from the uncompahgrite. Zone of altered dunites between the two uncompahgrite bodies north of Ringgletscher.

tions of the uncompahgritic magma seem to have used certain of the dykes as access channels.

Potassium clearly predominates over sodium in the altered zones as is shown by the ubiquity of phlogopite. A degree of *auto-metasomatism* has been noticed in the uncompahgrites themselves. The strongest alteration has been found in the outer uncompahgrite body north, north-east and east of Ringgletscher, and in the central body east-south-east of Ringgletscher. The melilites are particularly susceptible, large crystals being replaced by a fine felt of diopsidic pyroxene (determination by X-ray powder diagram) or calcite or both. The pyroxene is developed as fine brown needles which are arranged as rosettes, and calcite forms minute grains (<0.001 mm) which may be accompanied by some colourless mica.

Primary diopsidic pyroxene and apatite are only partly corroded. Pale brown phlogopite grows in large flakes up to several centimetres in diameter (fig. 25) and may be rimmed by colourless mica. Some amphibole, brownish green in colour, becomes replaced by a fine calcite-mica-pyroxene(?) felt.

In the section on the dunites, alkali-metasomatic influences were described resulting in an increase in the magnetite proportion and growth of phlogopite, perovskite, calcite, and amphibole.

In the following, *metasomatized dunites and pyroxenites* are described which are altered so intensely that they can no longer be described as dunites and pyroxenites. The stippled areas on the geological map (plate 1) indicate the alteration zones (strongly altered rocks). Less altered material may occur in juxtaposition.

The alteration zones tend to be characterized by the very coarse grain size of most of the minerals. The characteristic new minerals of the alteration zones are described briefly.

Diopsidic pyroxene occurs in prisms up to 30 cm in length (near the inner contact of the outer uncompahgrite body east-south-east of Ringgletscher). Newly formed colourless diopside grains of microscopic size are common.

Apatite occurs in prisms up to 10 cm in length of light green colour, frequently together with *natrolite*.

Melanite and *schorlomite* in crystals up to several centimetres in diameter are present, sometimes forming aggregates up to decimetre-size. The melanite colour varies patchily from dark reddish brown (titanium-rich varieties: schorlomite) to brownish yellow. As the melanite forms aggregates, euhedral crystals are rare. In one case a specimen with well developed crystals was found in a natrolite matrix and showed (110) and (211) faces.

In addition to melanite-schorlomite, grains of another garnet of the 'grandite' group occur in sample 2556. This garnet is colourless in thin section and has patches showing a very low birefringence ($\leqq 0.001$) with anomalous interference colours.

The melanites (schorlomites) frequently are interspersed with numerous *perov-*

Fig. 25. Auto-metasomatically influenced uncompahgrite with large phlogopite flakes bordering against strongly altered zones. Near inner contact of outer uncompahgrite body, north-north-east of Ringgletscher.

skite crystals in the same way as in the massive perovskite concentrations. They are distributed regularly within parts of the melanite crystals, although zones, particularly the rims, remain perovskite free. The perovskite again is a light purplish brown colour in thin section, with only the larger crystals having a reddish brown core.

Discrete perovskite octahedra up to 2 cm in diameter also occur, demonstrating that perovskite may be an important constituent of the altered rocks.

In one sample zoned *vesuvianite* was found accompanying melanite and perovskite. The vesuvianite is anomalously biaxial with positive optical character ('wiluite').

Phlogopite is the commonest mineral of the alteration zones and indicates potassium metasomatism. It forms large flakes and thick books. There is a conspicuous phlogopite zone south-east, east and north-east of Ringgletscher running concentrically a short distance from the inner contact of the outer uncompahgrite body (plate 1). The phlogopite zone averages about 6–8 m in thickness and contains phlogopite books up to several decimetres in diameter and thickness (fig. 26). The phlogopite is accompanied by huge magnetite crystals (see below). Microprobe investigation (partial analysis) showed the phlogopite to contain 15–18 mol. per cent iron-biotite.

Besides phlogopite, light mica of microscopic size is to be found in several samples of the alteration zone.

An optically positive *chlorite*, grochauite, is present as an accessory in some thin sections.

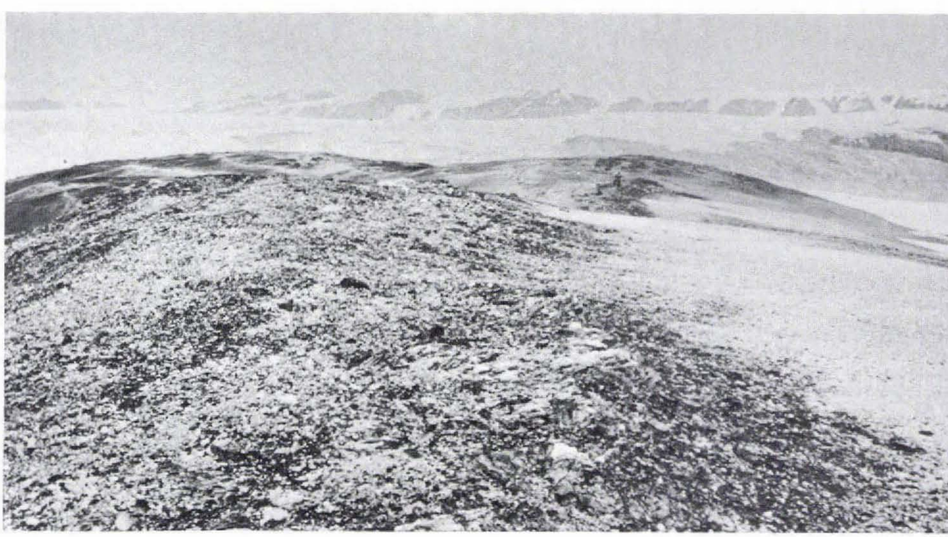

Fig. 26. Phlogopite zone east of Ringgletscher. To the right, weathered uncompahgrite and replaced dunite.

Magnetite has also been formed by the metasomatic processes. It becomes conspicuous as huge, well-developed octahedra several centimetres across. In many cases the octahedra are rounded. Crystals of this size have been found in altered dunite beyond the outer uncompahgrite zone south and south-west of Ringgletscher, and within the phlogopite zone.

Calcite fills wedges between the calcium-bearing constituents, and fine needles of *aegirine* may be found growing in it.

Occurring within the alteration zones are altered dykes, mainly of urtite. Nepheline has been transformed into *natrolite* which is present either as euhedral crystals, radial aggregates up to several centimetres in length, or as pseudomorphs which possess the outlines of the hexagonal nepheline, the prisms being up to 10 cm in length. Accessory phases are other zeolites (rare), aegirine (rosettes of fine needles), aegirine-augite (huge zoned crystals), calcite, baryte (single crystals, very rare), apatite and sphene (long prisms up to nearly 10 cm in length, rare).

Carbonatite dykes

Carbonatite appears as dykes within the rocks of the older sequence, and it appears likely that it is genetically related to the uncompahgrites. By comparison with similar intrusions (Iron Hill and Oka) it is probable that a larger carbonatite body is to be expected at a shallow depth beneath the centre of the intrusion (plate 2).

Four carbonatite dykes have been found. The largest one, 50–60 cm in thickness, is a concentric dyke and runs parallel to the sodalite-syenite dyke in the south-eastern part of the intrusion. There is a reaction zone in the bordering pyroxenite. Another concentric dyke lies within dunite, north-east of Anorerssuaq in the south-western part of the intrusion. In the southern part two radial dykes occur both within dunite.

The carbonatite is a *calcite carbonatite (sövite)* (calcite 99 vol. %). Accessories are melilite and apatite. The rock exhibits a slight parallel structure conformable to the dyke walls.

Most of the *calcite* is present as anhedral grains 0.5–3 mm in diameter. It shows slightly undulating extinction, and the rarely developed twinning lamellae are slightly warped. The proportion of Mg and Fe is negligible (see table 19). The calcite grains are elongated parallel to the contact of the dyke.

Melilite occurs both intergranularly and intragranularly, either as single crystals or small aggregates.

Apatite forms irregularly distributed aggregates.

The carbonatite dyke which cuts pyroxenite in the south-eastern part of the intrusion has caused a brown weathering reaction zone 0.5–1 m thick, in the pyroxenite. The pyroxenite has been replaced along cracks by chlorite, and as a whole by a probably dolomitic carbonate.

The accessory minerals (melilite, apatite), as well as the minor elements (0.60 wt. % Sr, 0.17 wt. % Ba, 0.03 wt. % La) and the reaction with the pyroxenite are evidence that the dykes are in fact carbonatite dykes and not hydrothermal calcite veins.

GEOCHEMISTRY

Main elements

Table 19 shows chemical analyses of the main rock types of the Gardiner intrusion together with their Niggli values and the base norm values after Niggli.

A considerable variety of rock types is present in the intrusion, ranging from ultrabasic through basic to intermediate. A part of the marginal zone rocks, and probably the sodalite syenite of the dyke rocks have suffered contamination by the adjacent granitic to granodioritic country rocks.

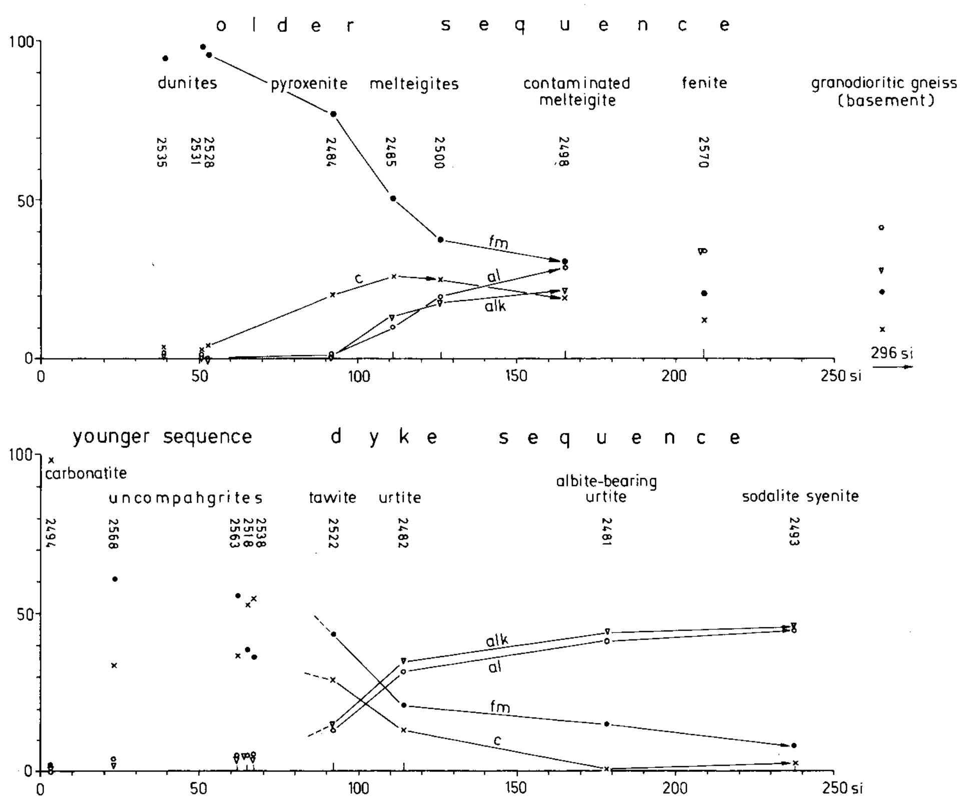

Fig. 27. Variation diagram for the rocks of the Gardiner intrusion, and one granodioritic basement gneiss after Wager & Deer (1939). For sample localities see fig. 35, for chemical analyses see table 19.

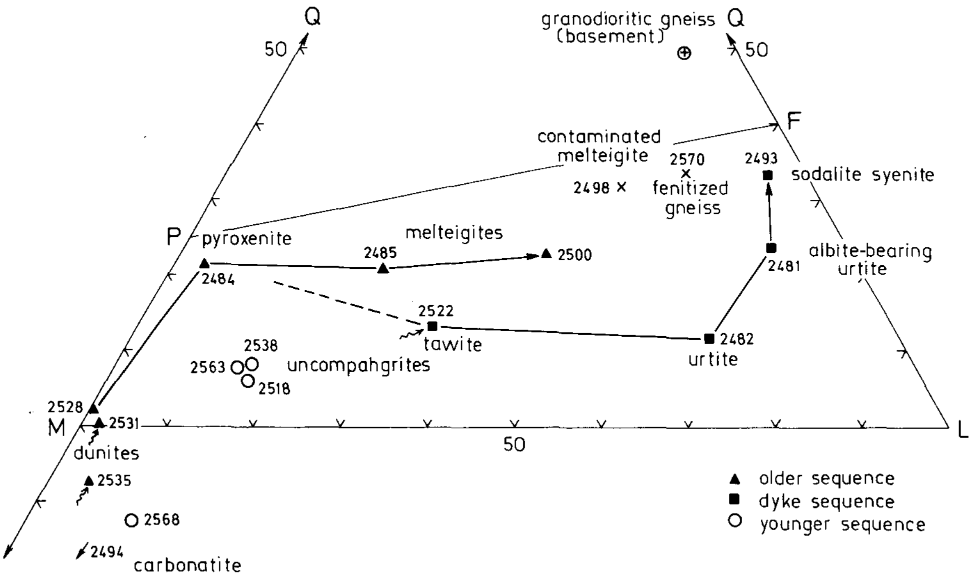

Fig. 28. QLM diagram after Niggli of the Gardiner rocks.

The variation in the geochemistry of the various rock types constituting the Gardiner intrusion is presented with the aid of figs 27–31.

The older sequence rocks and dyke rocks show generally similar trends and a common parentage is suggested.

From fig. 27 it can be seen that with fractionation *fm* values decrease, whereas *al* and *alk* values increase, particularly in the more differentiated material. In the rocks of the older sequence *c* tends to increase, reaches a peak, and then decreases.

Fig. 28 shows all rocks to lie beneath the line of saturation (P–F). With fractionation both dyke rocks and older sequence rocks become increasingly alkaline and undersaturated. Rocks taken from the contact zone with the gneissic country rocks and the latest dykes (sodalite syenite) fall off the observed trends suggesting contamination.

The amphibole pyroxenite (for which no analysis is available) comes to lie between the pyroxenite of the older sequence (sample 2484) and the tawite of the dyke sequence (sample 2522), suggesting a common parentage of the older and the dyke sequence rocks. On the other hand the stronger undersaturation and the distribution of the minor elements (see later) in the dyke sequence are evidence for contamination with the carbonatitic-uncompahgritic magma. This is also supported by the metasomatic alteration of dunites in the vicinity of late dykes of the dyke sequence. Strong metasomatism was found with the dunites around the uncompahgrites (see section on the dunites).

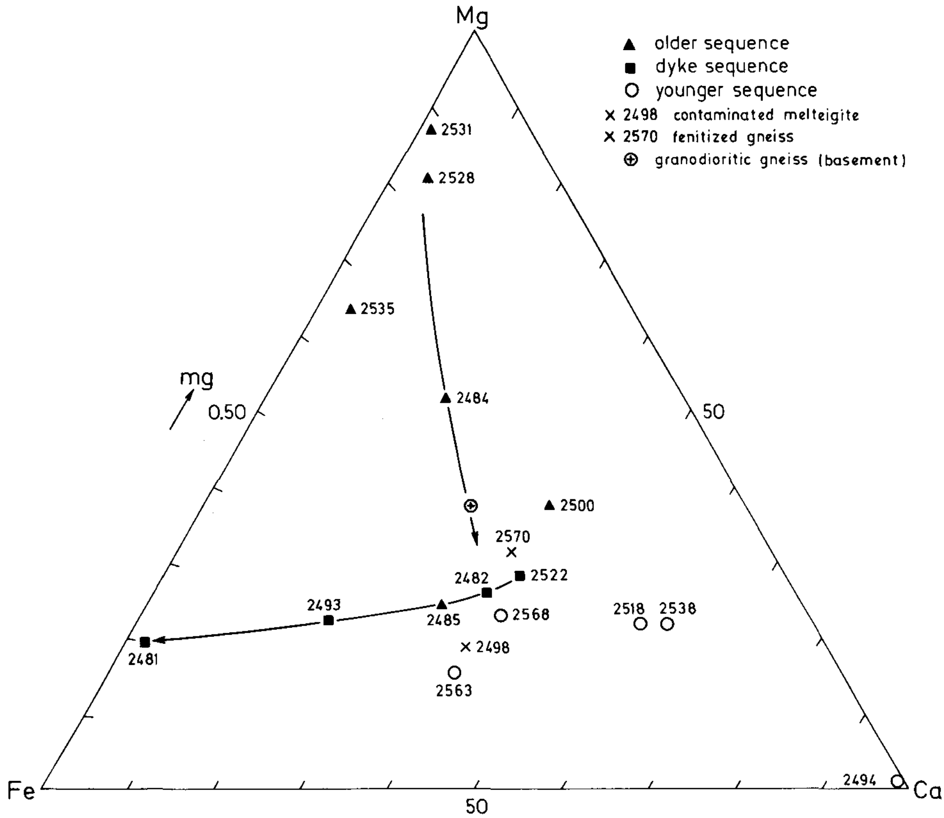

Fig. 29. Ca–Fe–Mg diagram of the Gardiner rocks.

Fig. 29 shows clearly that in both dyke rocks and older sequence rocks there is an increase in Fe and decrease in Mg during fractionation. There is an initial build up in Ca, followed by its depletion in the fractionated material due to the crystallization of abundant diopsidic pyroxene.

From fig. 30 it can be seen that the build up of alkalis during fractionation is principally due to Na enrichment, and from fig. 31 that the oxidation ratio increases. In both diagrams the sodalite syenite of the dyke sequence (sample 2493) falls out of the common trend by a higher k value and a lower oxidation degree respectively. This again suggests contamination with acid country rocks.

The metasomatically strongly affected dunite, sample 2535, falls out in all the diagrams (figs 27–31).

For rocks of the younger sequence, the variation diagrams show no clear trends because of the lack of material intermediate between the uncompahgrites and carbonatites. On certain of the plots a distinction can clearly be seen between the trends of carbonatite (sample 2494), and of the magnetite-perovskite-apatite concentrations (samples 2563, 2568).

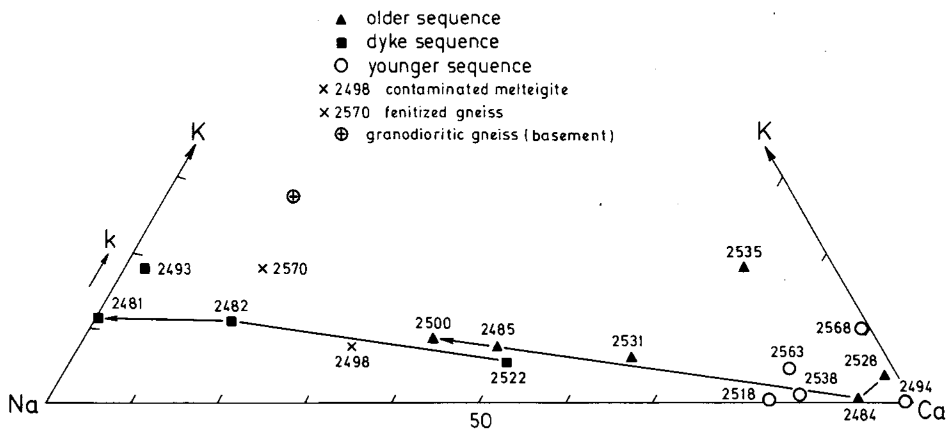

Fig. 30. Ca–Na–K diagram of the Gardiner rocks.

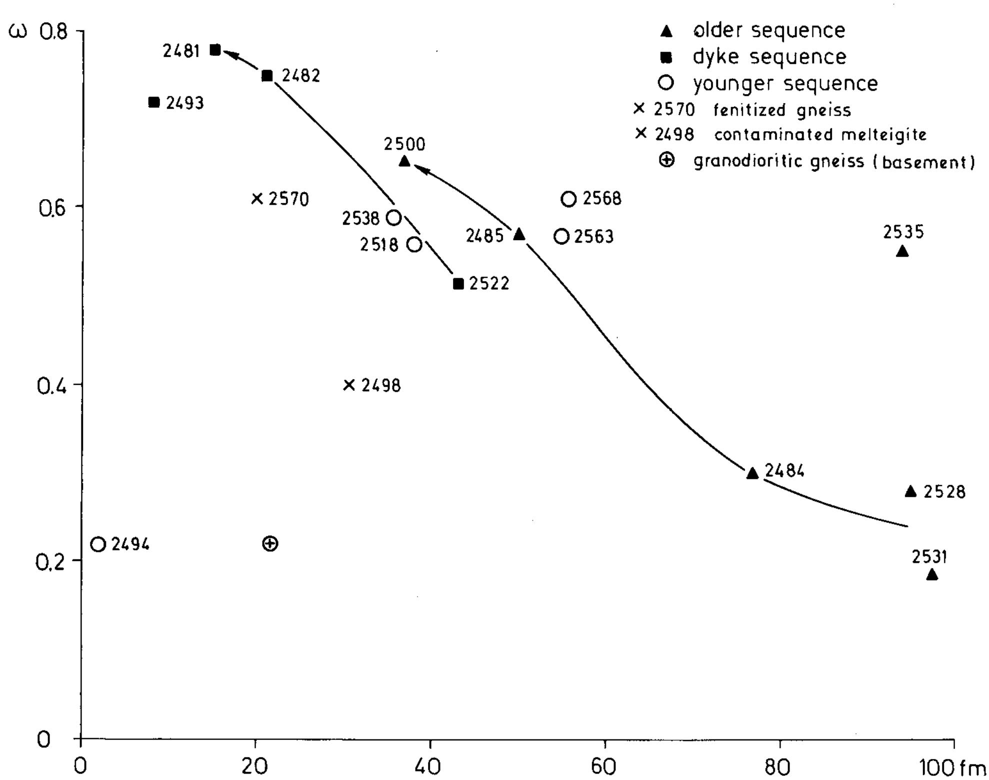

Fig. 31. *fm*–*ω* diagram after Niggli of the Gardiner rocks.

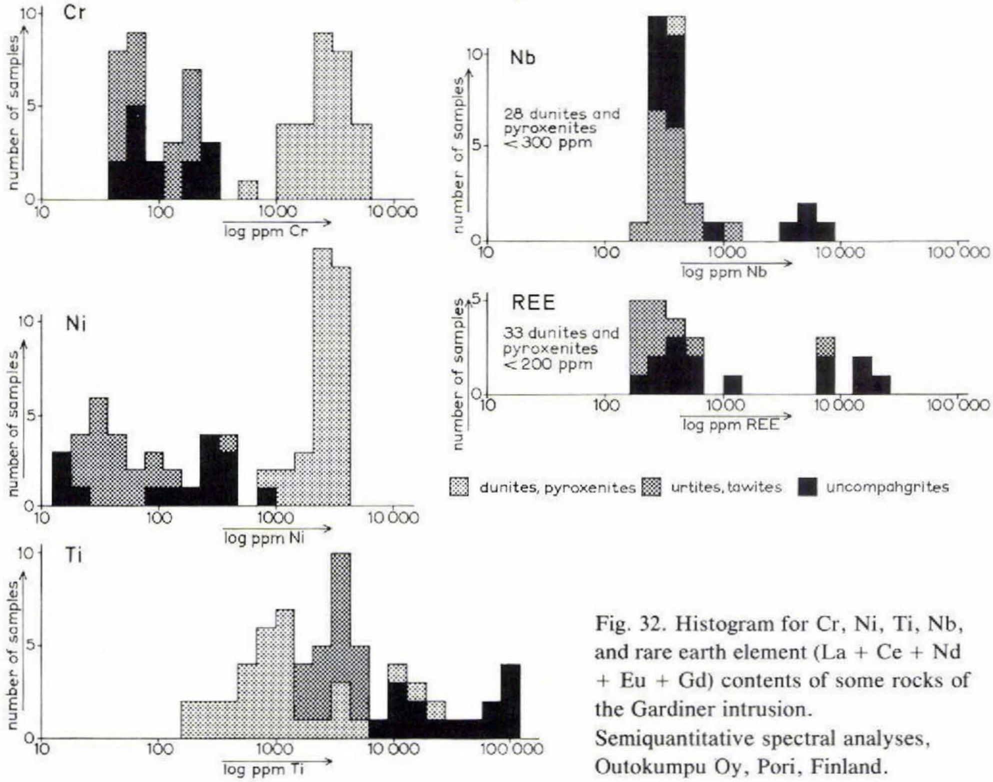

Fig. 32. Histogram for Cr, Ni, Ti, Nb, and rare earth element (La + Ce + Nd + Eu + Gd) contents of some rocks of the Gardiner intrusion. Semiquantitative spectral analyses, Outokumpu Oy, Pori, Finland.

Minor elements

Table 17 shows the distribution of some minor elements for selected rocks of the Gardiner intrusion.

The most interesting minor elements, i.e. Cr, Ni, Ti, Nb, and the rare earth elements, are presented in fig. 32 for 66 rocks of the Gardiner intrusion. Ti, Nb, and the rare earth elements are enriched in the rocks of the dyke and the younger sequences, Cr and Ni are important minor elements in the ultramafic rocks of the older sequence.

The strong correlation of Ni versus Cr and Co on the one hand, and of Nb versus Ti and the rare earth elements on the other, is illustrated in figs 33 and 34 respectively.

As shown in table 18 and fig. 34, Nb and the rare earth elements occurring in the perovskite are enriched in the massive perovskite concentrations at the uncompahgrite contact.

Cu and As reach values of 0.15–0.25 wt. per cent and 0.2–0.3 wt. per cent respectively in the metasomatized rocks of the umcompahgrite contact zone.

4*

Table 17. Concentration (in ppm) of some minor elements in rocks of the Gardiner intrusion

Sample no.	Dunites 2531	Dunites 2535	Pyroxenite 2499	Contaminated melteigite 2498	Urtite 2481	Sodalite syenite 2493	Uncompahgrites 2518	Uncompahgrites 2538	Layered uncompahgrite 2563	Carbonatite 2494
V	20	20	70	200	30	100	300	70	100	100
Cr	2000	2500	3500	200	200	100	70	70	200	50
Co	300	400	200	50	<10	20	100	70	80	<10
Ni	3500	1000	2750	70	30	30	300	150	300	30
Cu	50	800	70	30	10	50	30	50	50	3
Zn	300	300	200	200	<100	100	300	200	200	<100
Nb	<300	300	<300	300	400	300	400	400	300	<300
Ba	<500	<500	<500	500	700	700	<500	<500	500	2500
La	<150	<150	<150	200	200	200	350	450	200	250
Ce	<800	<800	<800	<800	<800	<800	1000	1000	<800	<800

Semiquantitative spectral analyses, Outokumpu Oy, Pori, Finland

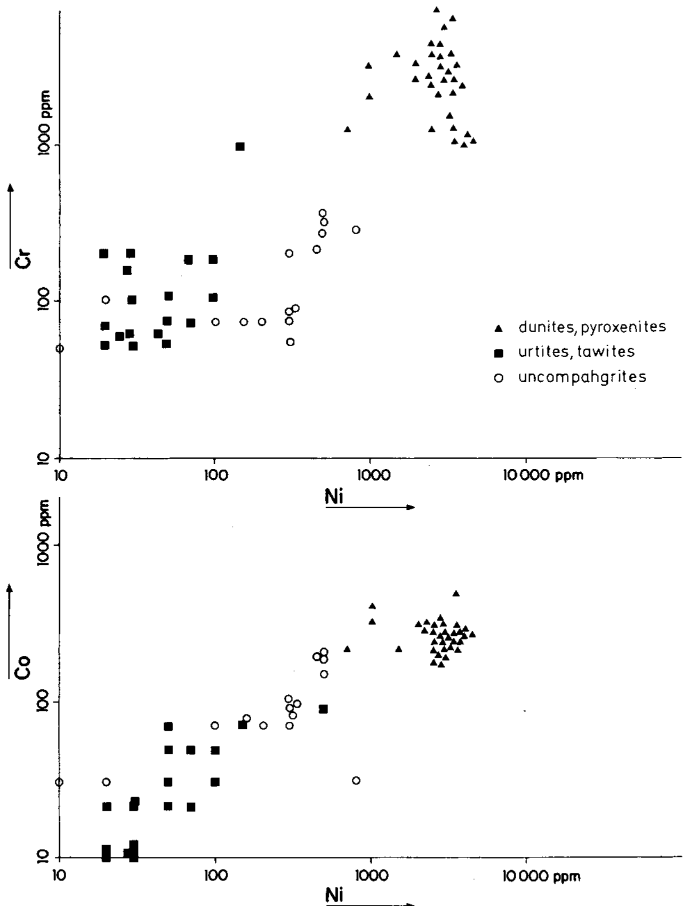

Fig. 33. Cr–Ni and Co–Ni ratios of some rocks of the Gardiner intrusion. Semiquantitative spectral analyses, Outokumpu Oy, Pori, Finland.

Table 18. Content of Nb and some rare earth elements in rocks of the massive perovskite concentrations in the uncompahgrite contact zone

Nb	0.1 –0.7 wt. %,	average 0.4 wt. %
Y	0.01–0.03	0.02
La	0.2 –0.6	0.3
Ce	0.3 –1.2	0.5
Nd	0.15–0.6	0.2
Eu	0.01–0.02	0.01
Gd		0.05

Semiquantitative spectral analyses, Outokumpu Oy, Pori, Finland

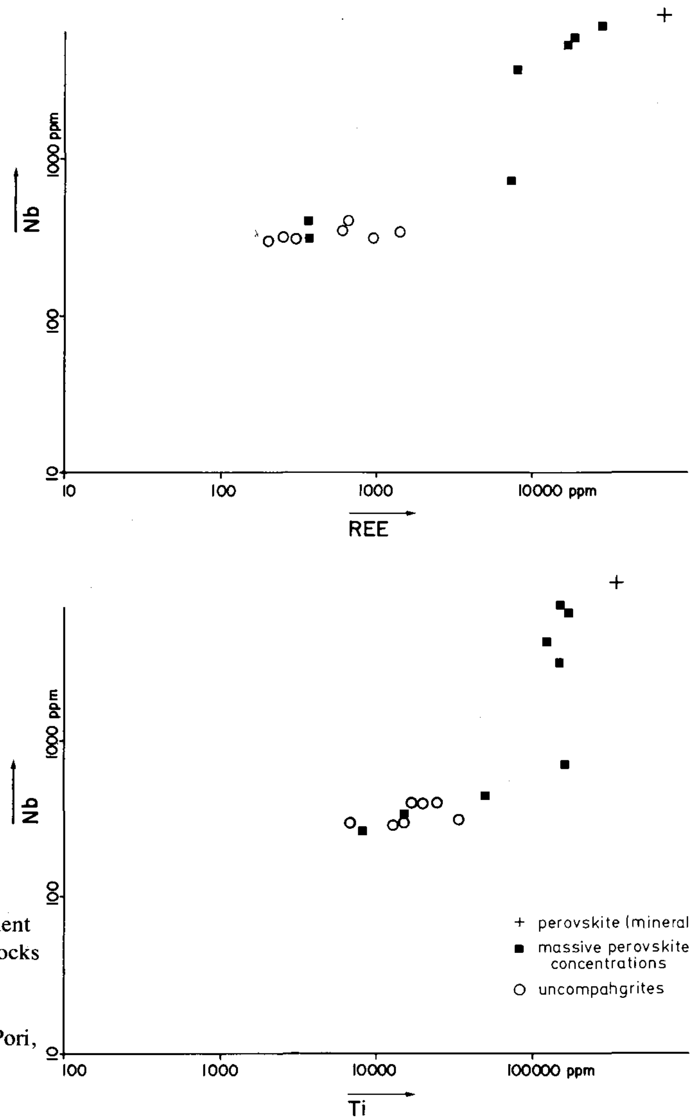

Fig. 34. Nb–rare earth element and Nb–Ti ratios of some rocks of the Gardiner intrusion. Semiquantitative spectral analyses, Outokumpu Oy, Pori, Finland.

Ti and P are enriched in the alkaline members of the older and the dyke sequences and strongly in the uncompahgrites and their contact rocks. Ti is present in sphene in the rocks of the older and the dyke sequences, and in perovskite in the uncompahgrites and associated metasomatized rocks.

The carbonatite (sample 2494) contains 0.60 wt. per cent Sr, 0.17 wt. per cent Ba, and no Rb which is in good agreement with the values of other carbonatites (e.g. the sövites of Kaiserstuhl, Germany).

Table 19. Results of wet chemical analyses of rocks from the Gardiner intrusion and some other rocks

Sample no.	2528[1]	2531[2]	2535[1]	2484[2]	2485[2]	2500[1]	2498[2]	2570[1]	gdg
SiO_2	39.90	40.00	29.10	49.00	46.80	49.80	54.80	61.20	68.17
TiO_2	0.58	0.23	3.10	2.00	4.40	0.75	2.20	0.51	0.63
Al_2O_3	0.38	0.80	1.90	1.52	7.16	12.95	16.00	16.55	16.13
Fe_2O_3	4.30	2.20	17.55	5.75	10.05	4.73	3.72	2.35	0.58
FeO	9.80	8.67	12.80	11.95	6.84	2.38	4.96	1.34	2.09
MnO	0.23	0.22	0.52	0.23	0.28	0.10	0.17	0.04	0.05
MgO	40.60	45.30	31.15	17.90	5.21	6.15	2.11	2.07	1.82
CaO	3.20	1.21	2.63	10.20	10.10	9.15	6.12	3.45	2.07
Na_2O	0.03	0.32	0.22	0.39	5.05	6.41	6.57	7.96	4.40
K_2O	0.11	0.09	0.56	0.03	1.32	1.64	1.25	3.30	3.22
P_2O_5	0.49	0.00	0.62	0.02	0.82	1.29	0.56	0.16	0.31
H_2O^+	0.50	0.65	0.31	0.56	1.45	3.11	1.13	0.70	0.40
CO_2	n.d.	tr.	n.d.	n.d.	n.d.	0.85	n.d.	0.75	n.d.
Cl^-	n.d.	n.d.	n.d.	n.d.	0.80	n.d.	n.d.	n.d.	n.d.
	100.12	99.69	100.46	99.75	100.28	99.31	99.59	100.38	99.87
Niggli numbers									
si	53	51	39	92	111	126	165	209	296
al	0.3	0.5	1.5	1.5	10	19.5	28.5	33.5	41.5
fm	95	97.5	94	77	50.5	37.5	30.5	20.5	21.5
c	4.5	1.5	3.75	20.5	26	25	19.5	12.5	9.5
alk	0.1	0.5	0.75	1	13.5	18	21.5	33.5	27.5
k	(0.67)	0.16	0.63	(0.05)	0.15	0.14	0.11	0.21	0.32
mg	0.84	0.88	0.66	0.65	0.36	0.62	0.31	0.51	0.54
ti	0.6	0.2	3.1	3.2	7.9	1.4	5.1	1.2	2.1
p	0.3	0	0.4	0	0.9	1.4	0.7	0.2	0.5
qz	−47.5	−51	−64	−12	−33	−46	−21	−25	+86
ω	0.28	0.19	0.55	0.30	0.57	0.65	0.40	0.61	0.22
Niggli numbers									
Cp	0.9	–	1.2	–	1.6	2.6	1.1	0.3	0.5
Ru	0.4	0.2	2.1	1.6	3.2	0.5	1.6	0.3	0.4
Kp	0.3	0.3	2.0	0.2	4.9	6.0	4.4	11.4	11.4
Ne	0.1	1.5	1.2	2.2	19.6	35.1	35.8	41.5	23.8
Ns	–	–	–	–	4.5	–	–	0.2	–
Cal	0.4	0.3	1.6	1.3	–	1.1	6.4	–	5.2
Cs	3.4	1.5	2.0	14.9	14.3	11.0	5.0	4.8	–
Sp	–	–	–	–	–	–	–	–	3.7
Fs	4.2	2.1	18.2	6.2	11.1	5.0	3.9	2.4	0.7
Fa	10.7	9.3	15.3	14.4	8.7	2.9	5.9	1.5	2.5
Fo	77.6	84.5	63.9	38.0	11.3	13.0	4.4	4.2	1.9
Q	2.0	0.3	−7.5	21.2	20.8	22.8	31.5	33.4	49.9
L	0.8	2.1	4.8	3.7	24.5	42.2	46.6	52.9	44.1
M	97.2	97.6	102.7	75.1	54.7	35.0	21.9	13.7	6.0

For sample localities, see fig. 35
Analysts: [1]W. Frisch, [2]H. R. Keusen

Older sequence
2528: dunite
2531: metasomatically influenced dunite
2535: metasomatically influenced dunite
(phlogopite-magnetite-dunite)
2484: pyroxenite
2485: melteigite (within pyroxenite)
2500: melteigite (marginal zone)
2498: contaminated marginal zone rock of dioritic composition

Country rocks
2570: fenitized granite gneiss (alkali syenite)
gdg : granodiorite gneiss, average material, Mellemø, 100 m west of contact of Skaergaard intrusion (Wager & Deer, 1939, p.10)

2522[2]	2482[1]	2481[2]	2493[2]	2518[2]	2538[1]	2563[2]	2568[1]	2494[2]	unc-1	unc-2
40.20	46.50	56.40	61.00	38.10	38.00	33.20	13.80	1.52	38.57	38.04
7.35	0.51	0.48	0.82	2.20	4.55	3.90	11.50	0.10	1.71	1.98
10.00	21.70	22.00	19.45	4.91	5.35	4.69	4.40	0.04	5.79	6.34
6.84	5.02	4.01	1.45	7.86	6.65	16.58	20.60	0.17	5.41	8.45
5.23	1.51	1.01	0.50	5.60	4.25	11.09	11.80	0.48	3.33	5.90
0.27	0.04	0.02	0.03	0.28	0.12	0.28	0.27	0.06	0.16	0.23
6.10	2.42	0.61	0.41	7.82	7.90	5.04	7.60	0.37	8.44	7.81
12.00	5.05	0.10	0.56	28.40	28.70	18.30	18.90	50.40	30.72	27.19
5.75	12.60	12.50	9.75	3.07	2.26	1.45	0.10	0.27	2.34	2.16
1.11	2.81	2.50	3.30	0.08	0.25	0.85	1.83	0.03	0.42	0.12
2.20	0.52	n.d.	n.d.	1.04	0.50	3.54	7.60	1.66	0.83	0.24
0.51	1.20	0.65	1.21	0.62	0.46	0.81	0.30	0.62	0.62	0.48
n.d.	0.14	n.d.	n.d.	n.d.	0.20	n.d.	0.55	43.80	1.28	0.30
2.80	n.d.	0.16	1.20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
100.36	100.02	100.44	99.68	99.98	99.04	99.73	99.25	99.52	99.62	99.24
92	114	178	237	65	67	62	23	3	66	65
13.5	31.5	41	44.5	5	5.5	5	4	0.05	6	6.5
43	21	15	8	38	36	55	60.5	2	33.5	39.5
29	13	0.5	2.5	52	54.5	36.5	33.5	97.5	56.5	50
14.5	34.5	43.5	45	5	4	3.5	2	0.45	4	4
0.11	0.13	0.12	0.18	0.02	0.08	0.39	0.90	(0.07)	0.10	0.03
0.48	0.42	0.20	0.28	0.52	0.57	0.25	0.31	0.47	0.64	0.50
12.6	0.9	1.1	2.3	2.9	6.0	5.5	14.2	0.1	2.2	2.6
2.1	0.5	–	–	0.7	0.4	2.8	5.3	1.3	0.6	0.2
−63	−115	−88	−42	−55	−49	−50	−85	−98	−50	−51
0.54	0.75	0.78	0.72	0.56	0.59	0.57	0.61	0.22	0.60	0.56
4.4	0.9	–	–	2.0	1.1	7.7	17.3	6.1	1.7	0.6
5.3	0.3	0.3	0.5	1.6	3.3	3.0	9.2	0.1	1.2	1.4
4.2	9.4	8.4	11.4	0.3	0.9	3.3	7.3	0.2	1.4	0.3
29.9	57.4	59.2	51.0	16.1	12.6	8.5	0.8	–	13.1	12.2
1.2	3.1	2.0	0.2	0.5	–	–	–	1.2	–	–
–	–	–	–	–	2.2	2.6	4.2	–	2.6	4.5
14.7	6.3	0.2	0.8	41.5	42.2	21.9	14.7	132.5	44.2	39.3
–	–	–	–	–	–	–	–	–	–	–
7.5	4.9	3.9	1.5	8.4	7.3	19.2	24.8	0.3	5.8	9.2
6.7	1.7	1.1	0.6	7.0	5.3	14.6	16.1	1.3	4.1	7.4
13.1	4.7	1.3	0.8	16.6	17.0	11.5	18.1	1.4	18.0	16.8
13.0	11.3	23.6	33.2	6.0	8.1	7.7	−12.5	−43.1	7.9	8.3
34.1	66.8	67.6	62.4	16.4	15.7	14.4	12.3	0.2	17.1	17.0
52.9	21.9	8.8	4.4	77.6	76.2	77.9	100.2	142.9	75.0	74.7

Dyke sequence
2522: tawite
2482: urtite
2481: albite-bearing urtite
2493: sodalite syenite

Younger sequence
2518: uncompahgrite (central body)
2538: uncompahgrite (outer body)
2563: layered uncompahgrite, rich in magnetite, perovskite and apatite
2568: layered magnetite-perovskite-apatite rock
2494: calcite carbonatite (sövite)

Uncompahgrites from type locality
unc-1 and unc-2: uncompahgrites from Iron Hill, Colorado; analyst G. Steiger (Larsen, 1942, p. 13)

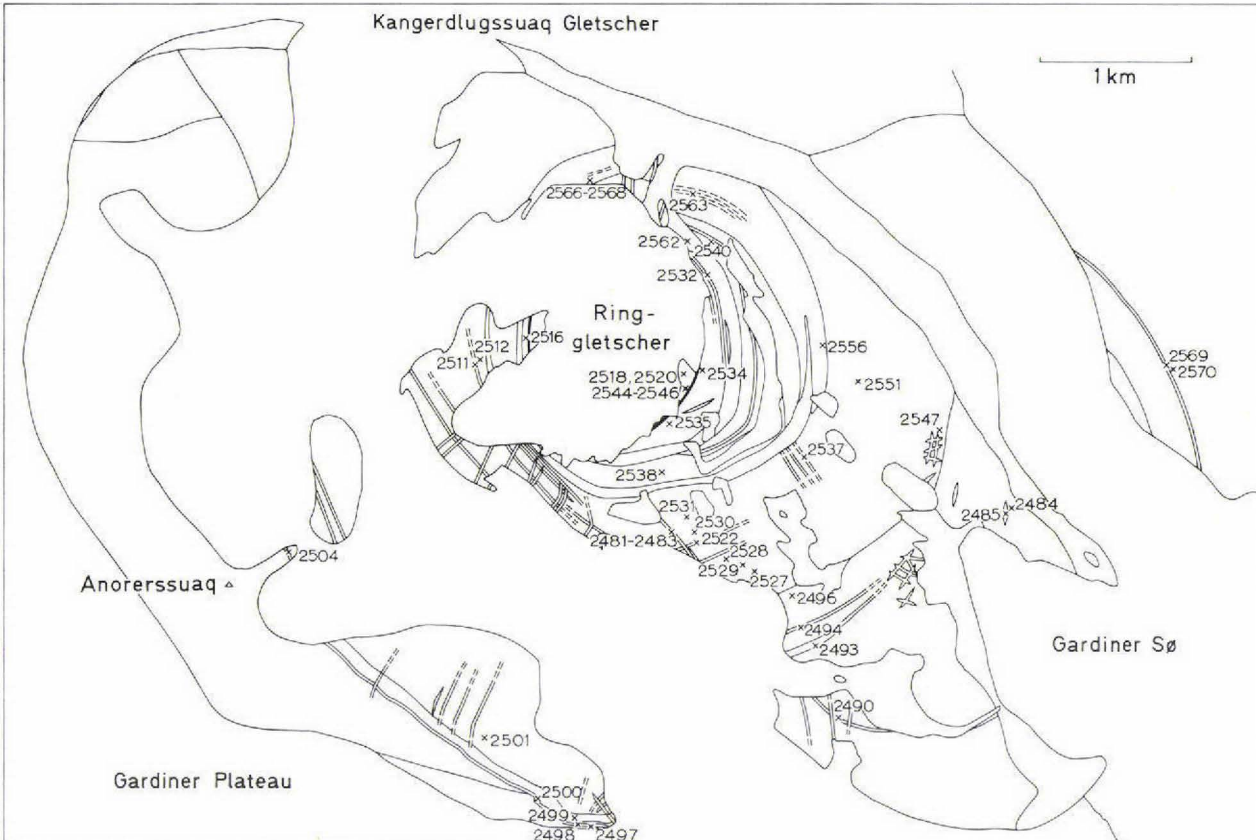

Fig. 35. Sample locality map of the Gardiner intrusion (samples mentioned in the text only). Sample numbers are those used in the field. A representative collection is held by the Geological Survey of Greenland.

CONCLUSIONS

The *older sequence* and the *dyke sequence* of the Gardiner intrusion appear to be closely related to each other. A peridotitic magma gave rise to the ultramafic representatives of the older sequence, and at a later stage in its fractionation to strongly alkaline undersaturated rocks.

Olivine was the first phase to crystallize and resulted in the formation of the dunites and the enrichment of Ca in the residual melt. Diopside then crystallized giving rise to the pyroxenites.

Alumina and alkalis could not enter the early formed phases, and accumulated in the melt. Rocks formed during later stages, i.e. the melteigites, tawites, urtites, and syenites are enriched in these elements.

It is probable that the alkaline rocks have split off from the pyroxenites. The melteigites with their transitional borders to the pyroxenite, and the character of the early dykes (i.e. the amphibole pyroxenites and tawites) make this presumption plausible. All these rocks have an early formed diopsidic pyroxene as a major constituent. The later formed minerals reflect the alkaline chemistry of these rocks: aegirine, sodic amphibole and feldspathoids. Aegirine and feldspathoids are extremely abundant in the latest uncontaminated differentiates, i.e. the urtites of the dyke sequence. The chemistry of the dyke rocks supports the suggestion of contamination with the magma of the younger sequence.

Assimilation of acid country rocks is responsible for the formation of the contaminated marginal zone rocks, and probably for certain of the late syenite dykes.

The *younger sequence* is characterized by its extreme undersaturation and a richness in volatiles. The high volatile content has resulted in the intense contact metasomatism.

From other localities uncompahgrites and other melilite rich intrusive rocks can be seen to be associated with carbonatites (e.g. Iron Hill and Oka). The genetic relationship between the strongly undersaturated melilite rocks rich in calcium and the carbonatite dykes of the Gardiner intrusion is extremely likely. For these reasons it is suggested that beneath the central part of the intrusion there may be a carbonatite body lying at a shallow depth (plate 2).

The intrusion best comparable with the Gardiner intrusion is Iron Hill, Colorado (Larsen, 1942). Although there are no dunites in Iron Hill, there is a large pyroxenite (diopside) body bordered by alkali syenites against the granitic and gneissic rocks of the basement. A younger carbonatite body sends dykes into the older rocks. Uncompahgrite occurs as smaller bodies within the pyroxenite.

In Oka, Quebec, central layered carbonatites are encircled by alternating ijolite, okaite (melilite with minor nepheline and haüyne) and carbonatite series (Gold, 1972). The age relationships are complex, but generally ijolite (older) – okaite – carbonatite (younger).

Another intrusion with melilite rocks is the Kovdor massif, the Kola peninsula (Borodin & Pavlenko, 1974). Nepheline-pyroxene rocks and melilite rocks (e.g. turjaites: melilite with minor nepheline) are grouped around a central body of dunite and altered dunite which is an older and partly replaced generation.

Concerning the genesis of the magma giving rise to the formation of the rocks of the Gardiner intrusion, the following suggestions are made:

(1) The uncompahgrites are genetically related to the dunites and pyroxenites. This is supported by the arrangement of the uncompahgrites within the intrusion and by the correspondence of the main rock types with those of other similar intrusions (especially Iron Hill).

(2) Some process of magma differentiation took place which is mainly independent of the country rocks; assimilation processes are not responsible for the generation of the uncompahgrites. This is supported by the entirely identical composition of the uncompahgrites from Iron Hill and the Gardiner intrusion. Limestone assimilation can be excluded as the Archaean basement of the Gardiner intrusion is bare of such rocks.

(3) The rocks of the dyke sequence split off from the residual magma of the older sequence. The strong undersaturation may be due to mixing with parts of the carbonatitic-uncompahgritic magma. This is supported by the distribution of the minor elements.

(4) As the intrusion is structurally related to a rift-like feature along the fjord of Kangerdlugssuaq (Brooks, 1973), it is likely that the common magma source is situated in the low-stress zone within the mantle beneath the rift structure. It is proposed that a peridotitic magma underwent fractionation whereby the role of volatiles, above all carbon dioxide and alkalis, is likely to be an important factor. As the dunite and pyroxenite producing magma was poor in volatiles, volatile supply is considered to have occurred after the generation of these rocks and may be responsible for the production of an uncompahgritic melt. The compositional layering of uncompahgrite observed in places is comparable with the layering in 'stratiform peridotites' (Thayer, 1960) which is evidence that there has been a melt of uncompahgritic composition.

SUMMARY

The Gardiner intrusion was discovered in the summer of 1971, and lies in the inner region of Kangerdlugssuaq fjord. It is composed dominantly of ultramafic rock types, and is one of a number of plutonic complexes occurring in the East Greenland Tertiary Igneous Province.

The intrusion occurs on the line of the north-north-west striking Kangerdlug-

ssuaq fault system. It is circular in shape with a diameter of 6 km, and cuts both Archaean gneisses, and Upper Cretaceous to Lower Tertiary plateau basalts.

Calculation has produced an estimate of 1–1.5 km for the cover thickness at the time of emplacement. The present exposure is at a high level with the contacts generally dipping away from the intrusion centre.

Rocks of the intrusion can be placed into three categories: (1) an older sequence composed of dunites, pyroxenites, and a narrow marginal zone of alkali rich rocks; (2) a strongly alkaline and undersaturated dyke sequence; and (3) a younger sequence of uncompahgrites (intrusive melilite rich rocks) and carbonatites.

The older sequence consists of a series of concentric zones of both dunite and pyroxenite, the zones being broader towards the outer parts of the intrusion and narrower towards the centre. In these rocks the olivines are highly forsteritic, and the pyroxenes diopside. The rocks of the marginal zone occur where the intrusion is in contact with country rock, and consist of melteigite where the country rock is plateau basalt, and of contaminated rocks where the country rock is the basement gneisses. The assimilation of granitic material by these marginal rocks has resulted in a marked increase in plagioclase (introduction of Al and Si). The bording gneisses themselves show a narrow zone of fenitization, characterized by the introduction of Na, Ca and Mg.

The dyke sequence consists of a wide variety of rock types which lie either radially or concentrically with respect to the centre of the intrusion. Amphibole pyroxenites, tawites, urtites, and sodalite, nepheline and alkali-feldspar syenites are all represented.

Geochemical evidence suggests a relationship between the older sequence and the dyke sequence rocks. Both sequences are undersaturated, and show continuous differentiation series on the variation diagrams, with a marked trend towards Na-enrichment. However, the distribution of the minor elements and the stronger undersaturation of the dyke rocks suggest contamination of the magma of the dyke sequence by the magma of the younger sequence. Thus it is suggested that the dyke sequence rocks have originated by differentiation of a peridotitic magma, and mixing with parts of the carbonatitic-uncompahgritic melt.

The younger sequence is represented by two circular bodies of uncompahgrite occurring near the centre of the intrusion. The uncompahgrite corresponds both in mode and chemical composition to that of the type locality.

Within the uncompahgrite are accumulations, consisting of magnetite, perovskite, apatite and phlogopite on the one hand, and melilite on the other. These layers dip at a moderate angle towards the centre of the intrusion, and are thought to have formed in the present inclined position. More massive aggregate concentrations of perovskite and magnetite occur, at most a few metres in thickness, particularly in a zone around the contact of the inner uncompahgrite body.

Wet chemical analyses of perovskite and melilite are given.

A small number of carbonatite dykes, genetically related to the uncompahgrite, occur within rocks of the older sequence. The carbonatite dykes indicate the possibility of the presence of a carbonatite centre of the intrusion.

The intrusion of uncompahgrite and carbonatite magma, rich in volatiles, has resulted in intense alkali metasomatism of the pyroxenites and particularly the dunites. Extensive replacement of pre-existing minerals has occurred, the major replacing minerals being phlogopite, together with calcite, pyroxene, amphibole, perovskite, and melanite-schorlomite.

It is likely that, finally, older and younger sequence rocks return to a common peridotitic magma source in the low-stress zone within the mantle beneath the Kangerdlugssuaq rift structure.

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APPENDIX

List of samples from the Gardiner intrusion, Kangerdlugssuaq, East Greenland

	GGU No.	
2481	47804	Albite-bearing urtite (dyke)
2482	47806	Urtite (dyke)
2483	47807	Altered urtite (dyke)
2484	47808	Pyroxenite
2485		Melteigite
2490	47812	Mela-diorite
2493	47813	Sodalite syenite
2494	47814	Calcite carbonatite (sövite) (dyke)
2496		Pyroxenite

2497		Nepheline syenite (dyke)
2498	47816	Diorite
2500		Melteigite
2501	47818	Dunite
2504		Melteigite
2511	47821	Tawite (dyke)
2512	47822	Dunite (partly serpentinized)
2516		Pyroxenite
2518	47823	Uncompahgrite
2520	47824	Alkali-feldspar syenite (dyke)
2522	47825	Tawite (dyke)
2527		Dunite
2528		Dunite
2529	47826	Dunite
2530	47827	Dunite
2531	47828	Dunite
2532		Urtite (dyke)
2534	47830	Dunite
2535		Dunite (phlogopite-bearing)
2537		Amphibole pyroxenite (dyke)
2538		Uncompahgrite
2540		Melanite-perovskite rock
2544		Melanite-perovskite rock
2545	47833	Melanite-perovskite rock
2546		Pyroxenite
2547		Dunite
2551		Dunite
2562		Alkali-feldspar syenite (dyke)
2563	47837	Layered uncompahgrite, 2 varieties
2566		Uncompahgrite
2567		Altered uncompahgrite
2568		Layered magnetite-perovskite-apatite rock
2569		Mela-diorite
2570	47840	Fenitized basement

Position of samples is indicated on fig. 35.

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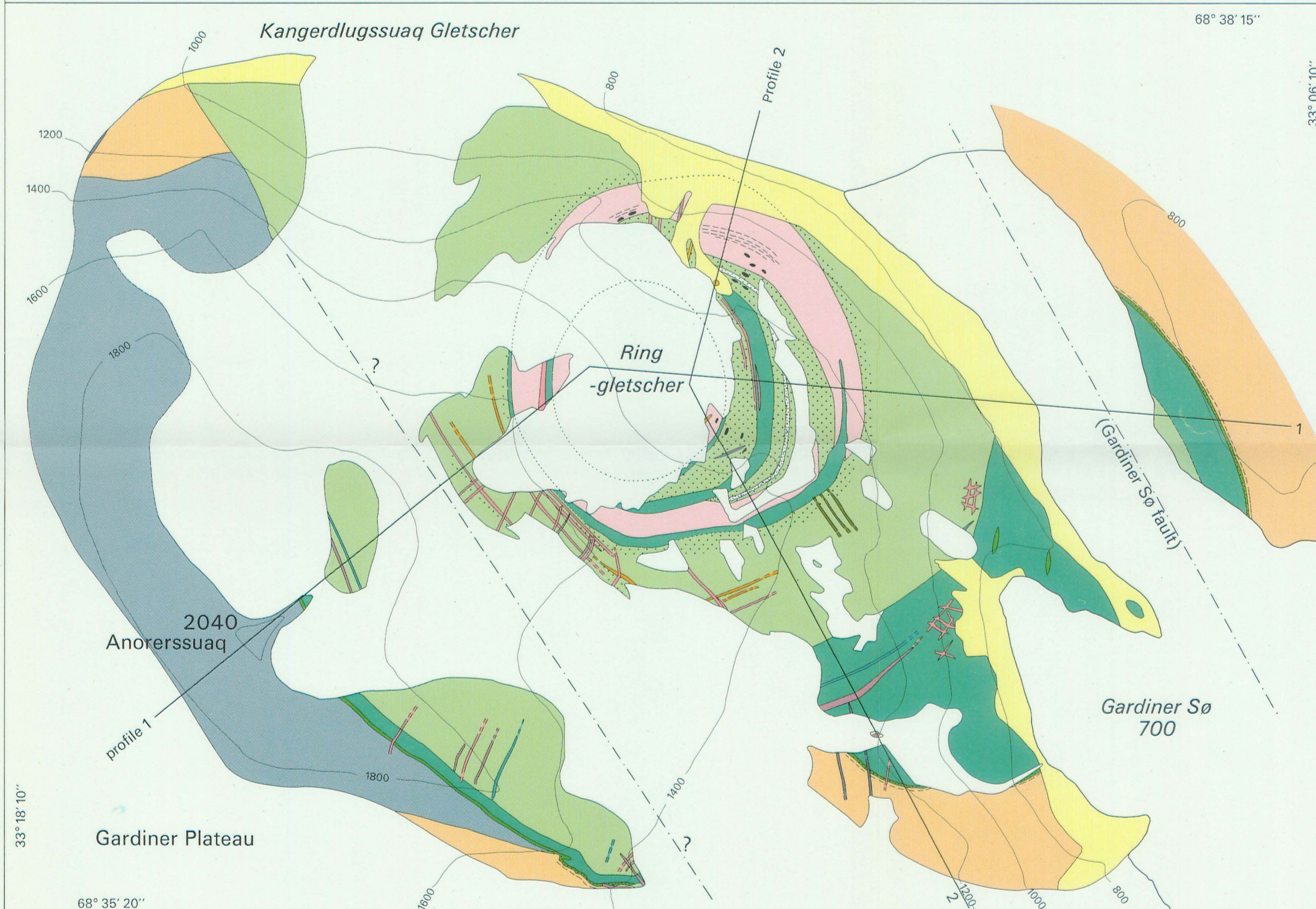
GARDINER INTRUSION: GEOLOGICAL MAP

Mapped by W. Frisch and H. Keusen with collaboration of G. Malecki in August 1971



Quaternary

dolerite & ultramafic dykes (Lower Tertiary)

YOUNGER SEQUENCE OF INTRUSION

calcite carbonatite dykes

phlogopite zone

alkali-metasomatic alteration zones in dunite & pyroxenite

massive perovskite concentrations

layered uncompahgrite

uncompahgrite

DYKE SEQUENCE

alkali-feldspar syenite dykes

sodalite (nepheline) syenite dykes

urtite dykes

tawite dykes

amphibole pyroxenite dykes

OLDER SEQUENCE OF INTRUSION

fenite

contaminated rocks } 'marginal zone'

melteigite

pyroxenite

dunite

PRE-INTRUSIVE COUNTRY ROCKS

plateau basalts (Lower Tertiary)

granitic gneiss (Precambrian)

1 : 25 000

1 0 1 km

The topographic map has been drawn by the use of the provisional map 1:50 000 and of aerial photographs (central and south-eastern parts), as well as by observations and measurements with a Thommen altimeter. Gardiner Sø has been taken as a fixed point with 700 m above sea level

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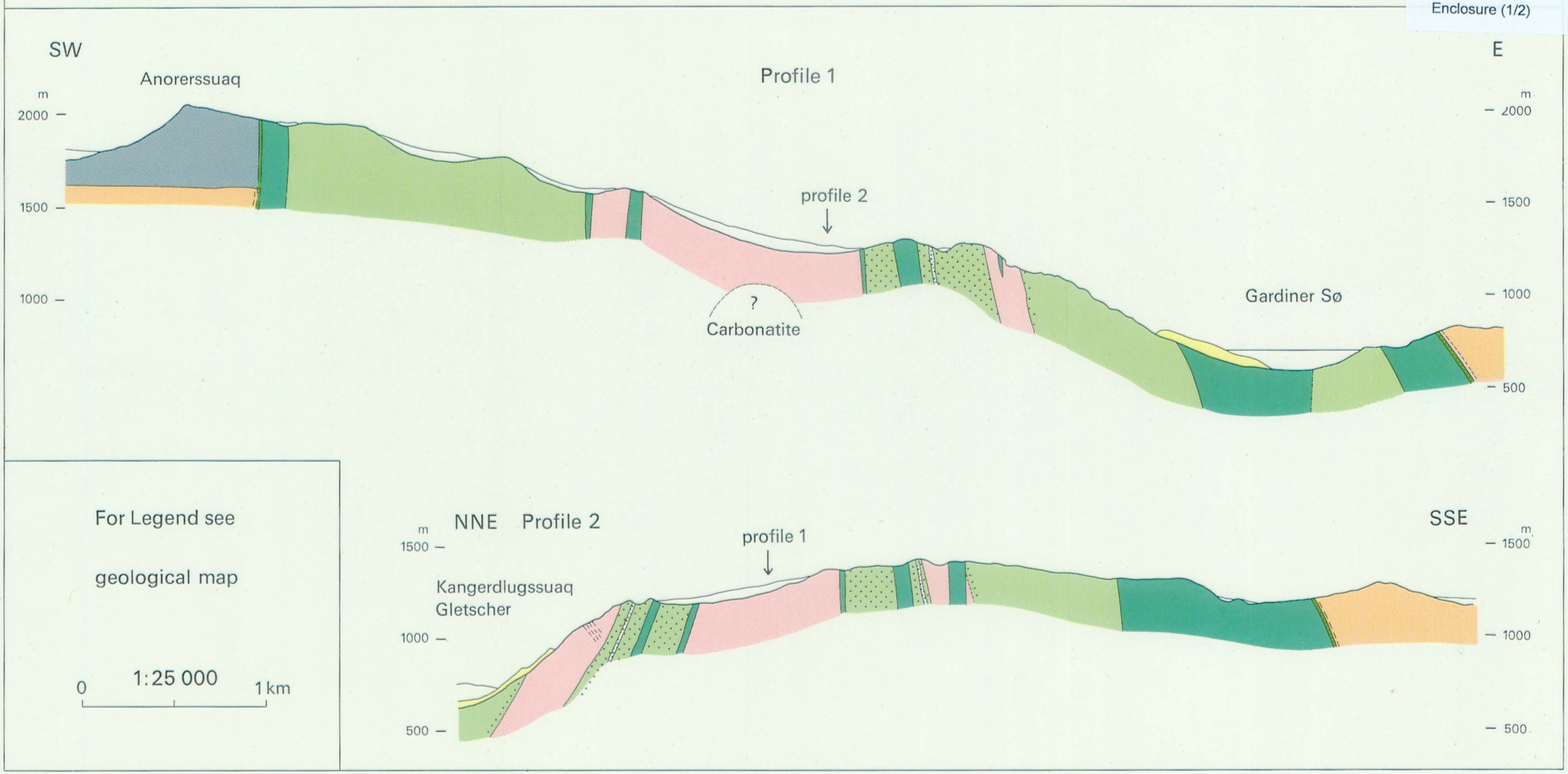
GARDINER INTRUSION: GEOLOGICAL PROFILES



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