Further remarks on the post-embryonic *Hypophylloceras* shell

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Birkelund, T. & Hansen, H. J.: Further remarks on the post-embryonic *Hypophylloceras* shell. *Bull. geol. Soc. Denmark,* Vol. 24, pp. 87–92. Copenhagen, November 19th., 1975.
In the light of new studies on the ultrastructures of Dactylioceratidae by M. K. Howarth, a revised model of the post-embryonic shell layers of *Hypophylloceras* is suggested. The shell consists of an extremely thin outer prismatic layer, a very thin nacreous layer and a relatively thick inner prismatic layer. The outer prismatic layer and the nacreous layer are ribbed distal of third whorl, while the inner side of the inner prismatic layer is smooth. Between the dorsal part of the inner prismatic layer and the preceding whorl cavities occur in the rib intervals. The thickness of the *Hypophylloceras* shell is about two thirds that of a lytoceratid shell (*Saghalinites*).

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Inspired by M. K. Howarth's work on the shell structures of the Liassic Dactylioceratidae (1975), we have re-studied the shell of *Hypophylloceras (Neophylloceras) groenlandicum* described in Birkelund & Hansen (1974).

It appears in Howarth (1973, fig. 4) that the shell of *Dactylioceras* is very peculiar in that it consists of a main shell and an inner shell, so far only found in Dactylioceratidae. According to Howarth (1975) the strongly ribbed main shell consists of a thick nacreous layer sandwiched between thin outer and inner prismatic layers. Dorsally the main shell is covered by a septal prismatic layer being in contact with the crests of the ribs and bridging across the rib interspaces, leaving cavities. The inner side of the inner shell is also covered by a septal layer, but here in close connection with the nacreous layer of the inner shell.

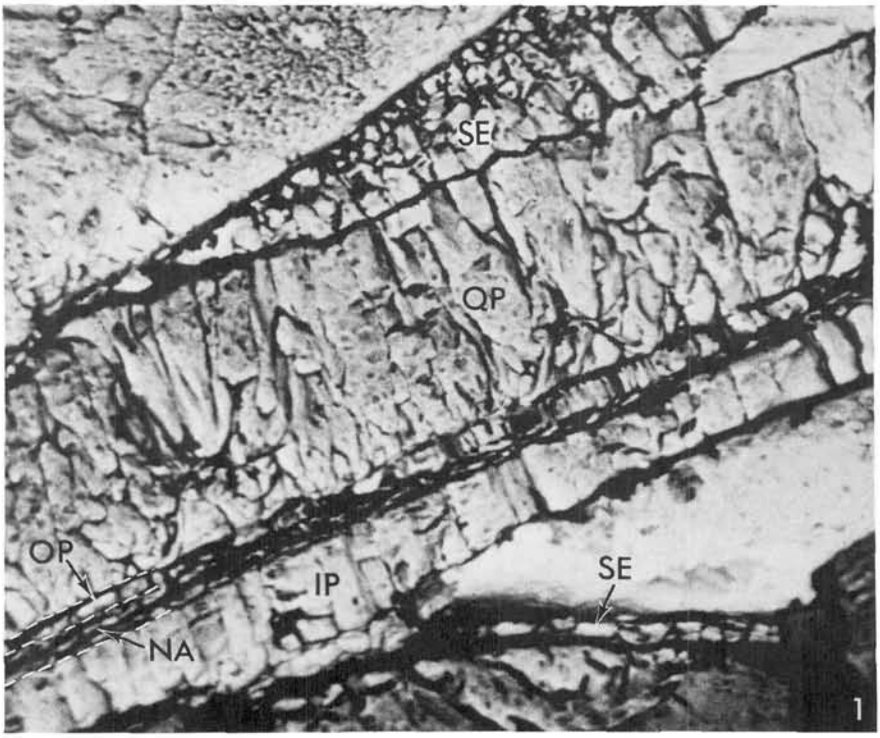
The outer septal layer of Dactylioceratidae is comparable in structure as well as in septal attachment to the so-called quasi-spherulitic outer prismatic layer of *Hypophylloceras* (see Birkelund & Hansen, 1974). Both layers have a quasi-spherulitic structure (Howarth, in press, text-fig. 1; pl. 3, figs. 5–6; Birkelund & Hansen, 1974, pl. 8, figs. 2–8; pl. 9, fig. 3; this paper, figs. 1–2), and in both the growth of the layer is partly continuous with the septa (Howarth, 1975, text-fig. 1; pl. 4, figs. 4–6; this paper, fig. 2).

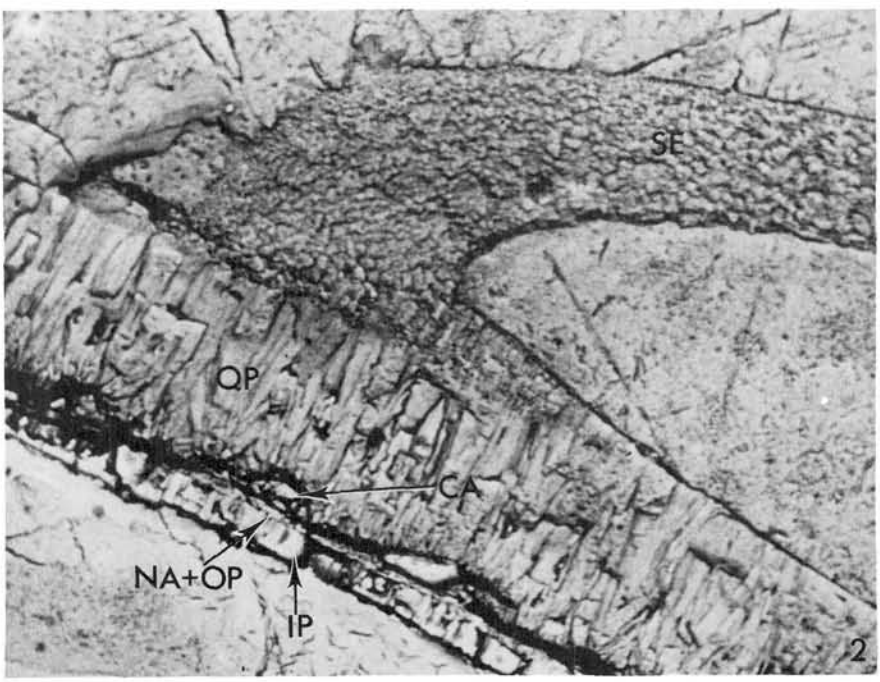
Post-embryonic growth of the *Hypophylloceras* shell

New sections of the shell of *Hypophylloceras* and the preparation of continuous SEM micrograph mosaics of specimens sectioned longitudinally (in the plane of coiling) and at right angles to the plane of coiling resulted in the discovery of a very thin outer prismatic layer between the nacreous layer and the quasi-spherulitic layer (fig. 1). On the basis of this find and comparison with Dactylioceratidae we suggest that the post-embryonic shell of *Hypophylloceras* developed as follows:

At the distal part of the second change in growth the shell consists of a relatively thick outer prismatic layer and a thin nacreous layer (Birkelund & Hansen, 1974, text-fig. 5c). Dorsally it is covered by the mural part of a septum of very irregular structure.

Already in the first whorl after the second change in growth the outer prismatic layer becomes very thin in relation to the nacreous layer, and about two whorls from the second change in growth its thickness is about $^1/_3$ that of the nacreous layer (fig. 1). In younger whorls it is so thin, however, that it is only occasionally distinguishable.





Figs 1 & 2. Hypophylloceras (Neophylloceras) groenlandicum Birkelund. Dorso-ventral longitudinal sections in the plane of coiling.
Fig. 1: 2 whorls distal of the second change in growth; × 960. Fig. 2: 2½ whorls distal of the second change in growth; note the continuity of the structures of the distal part of the septum and the "quasi-spherulitic layer"; × 290.
IP: Inner prismatic layer; NA: Nacreous layer; OP: Outer prismatic layer; QP: "Quasi-spherulitic layer" = inner prismatic layer of the succeeding whorl; SE: Septum; CA: Cavities. MMH 12998.

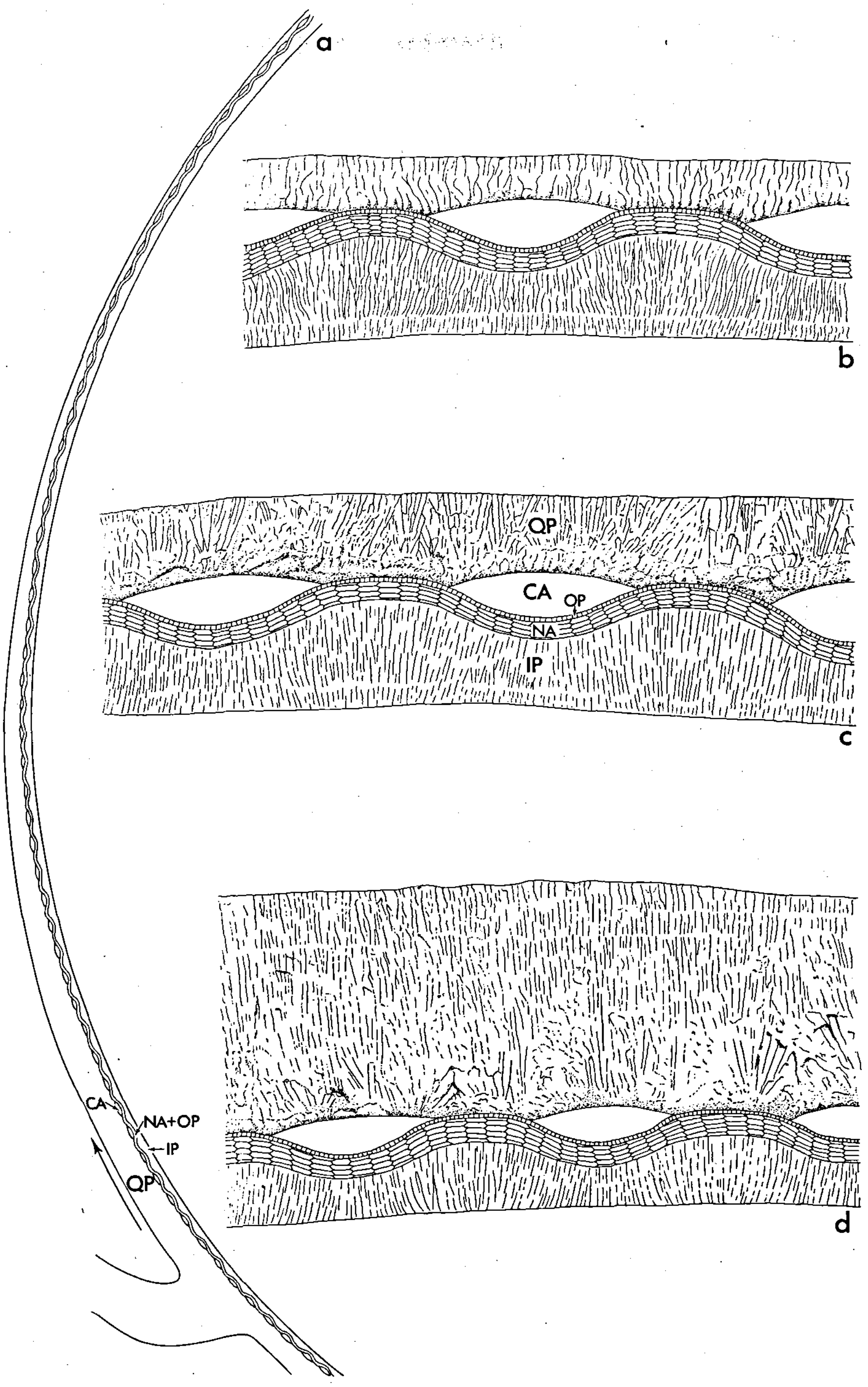


Fig. 3. a: Dorsal shell of proximal part of body chamber (QP) and ventral shell of preceding whorl (IP, NA and OP) of near-adult specimen; × 10. b, c, d: Schematic drawings of the shell structures. The outer prismatic shell layer is not preserved, but its presence is inferred; × 100. Abbreviations as in figs 1 & 2. MMH 12999.

The inner prismatic layer, on the other hand, becomes prominent already in the first whorl after the second change in growth, and two whorls from the second change in growth it makes up about ⅔ of the thickness of the shell (fig. 1). More distally it makes up an even greater part (Birkelund & Hansen, 1974, pl. 9, figs. 1–3). It is further remarkable by smoothing the inner side of the shell when it becomes ribbed about 2½ whorl distal of the second change in growth.

Dorsally the outer prismatic shell-layer and the nacreous layer wedge out, but the inner prismatic layer (= quasi-spherulitic outer prismatic layer of Birkelund & Hansen, 1974) is well developed. The structure of this layer is remarkable in forming several sublayers of intermingling quasi-spherulitically arranged prisms. The layer is only in contact with the ventral part of the preceding whorl on the crests of the ribs, leaving cavities where it bridges across the rib interspaces. Cavities are also developed where the dorsal inner prismatic layer covers the venter of a previous whorl that is at a stage before ribs develop and is therefore smooth. Perhaps these cavities reflect the ribs in the adjacent lateral and ventral parts of the whorl to which that dorsal shell belongs. Dark pigment in the cavities may represent remains of periostracum.

On the distal side of the septa a gradual transition from the nacreous or prismatic/nacreous structure of the septum to the prismatic structure of the inner prismatic shell layer may be seen at the confluence between septum and wall (fig. 2). On the distal side of the septum the inner prismatic shell layer may be thickened by about $^1/_4$ the thickness of the septum. A study of the dorsal side of the early part of the body-chamber of near-adult specimens shows further that the thickness of the inner prismatic layer decreases distally by $^3/_4$ in the proximal 90° of the body-chamber (fig. 3). It seems therefore that the mantle renews growth of the inner prismatic layer for the addition of new septa.

Although the structure of the inner prismatic layer of *Hypophylloceras* is somewhat different from other ammonites, but similar to the septal prismatic layer of Dactylioceratidae, the name 'inner prismatic layer' is retained, as the origin of that layer is very similar to the origin of the inner prismatic layer of other ammonites, being a product of the shell-forming epithelium of the mantle. Also in *Saghalinites* the inner prismatic layer decreases distally in thickness in the body-chamber, and in Dactylioceratidae Howarth (1975) has shown that it is formed $^1/_8$ whorl behind the mouth in adult specimens.

The re-interpretation of the shell layers of *Hypophylloceras* has an effect on measurements of shell thicknesses. In fig. 4 measurements on *Hypophylloceras* and *Saghalinites* excluding and including the dorsal part of the inner prismatic layer, are shown. The measurements show that the proper shell of *Hypophylloceras* is considerably thinner than the *Saghalinites* shell, especially in the early part of the shell. This may be evidence of the presence of the often postulated thin shell of phylloceratids (Arkell, 1957, p. L185). The shell of the body chamber is especially thin as the inner prismatic layer, which makes up the main part of the shell, wedges out distally. The inner prismatic layer is, however, believed to be deposited shortly after the formation of the outer prismatic layer and the nacreous layer; if this were not the case it would lead to a wall thickness of parts of the body chamber of about 40 μm at a shell diameter of about 20 mm. The thick shell of Phylloceratina described by Westermann (1971) may include the dorsal part of the inner prismatic layer, which is difficult to distinguish if the shell is recrystallised.

Acknowledgements. We are much indebted to Dr. M. K. Howarth for fruitful suggestions. Mrs. Erna Nordmann and H. Egelund prepared the drawings.

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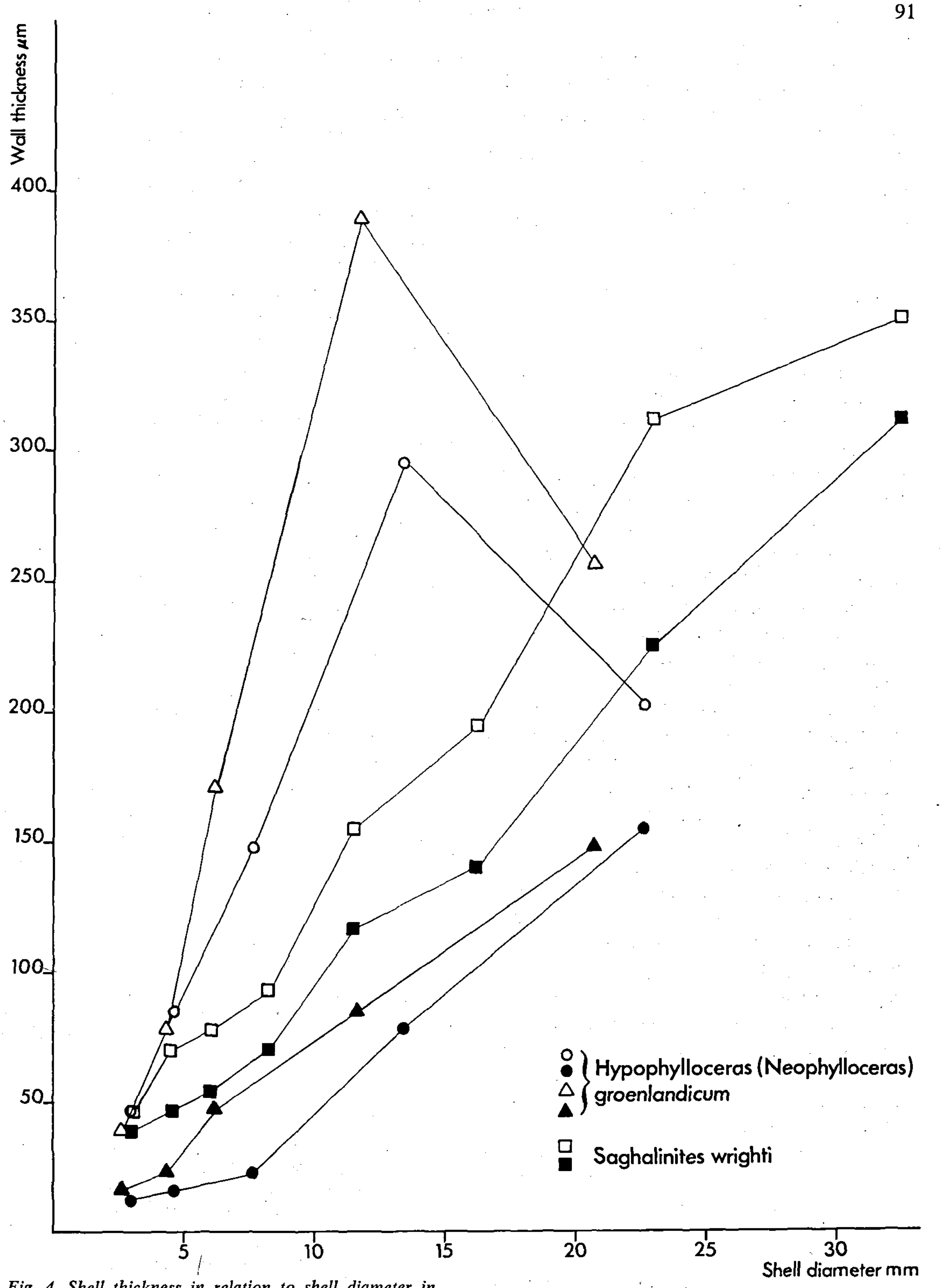

Fig. 4. Shell thickness in relation to shell diameter in Hypophylloceras (Neophylloceras) groenlandicum Birkelund and Saghalinites wrighti Birkelund. The black dots indicate the thickness of the ventral shell wall and the white dots the thickness of the ventral shell wall plus the dorsal shell of the succeeding whorl. The last measurement of the dorsal shell wall in all three specimens is situated in the body chamber. MMH 12989, 12998, 12999.

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Leucite from East Greenland: A new petrographic sub-province of the Tertiary North Atlantic province

C. K. BROOKS, J. G. RØNSBO and T. F. D. NIELSEN

Brooks, C. K., Rønsbo, J. G. and Nielsen, T. F. D.: Leucite from East Greenland: a new petrographic sub-province of the Tertiary North Atlantic province. *Bull. geol. Soc. Denmark*, vol. 24, pp. 93–98. Copenhagen, November, 19th., 1975.

A new occurrence of ultramafic alkaline rocks in the Kangerdlugssuaq district of East Greenland is briefly described and more detailed petrological and mineralogical data are presented for a leucite ankaratrite, which consists of diopside, leucite, nepheline, alkali feldspar, magnetite and phlogopite. The presence of potassic rocks in this area provides important additional evidence for the rifted origin of the area. This is the first well-substantiated report of leucite from Greenland.

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Leucite is a characteristic mineral of potassium-rich volcanic and sub-volcanic rocks and, although it is well known and abundant in certain areas, it is otherwise a rare mineral. In this note, we report an occurrence of leucite from East Greenland and this is the first reported occurrence not only from Greenland but from the entire Tertiary North Atlantic province. For this reason and also because its occurrence here lends weight to an earlier interpretation of the tectonics of the area (Brooks, 1973; Brooks & Rucklidge, 1974) we feel it is advisable to publish a preliminary note at this stage even though the available specimens are few and the field relations poorly known. Furthermore, the intrusion from which these samples originate is extremely inaccessible and it is doubtful when a new visit can be made to the locality.

Geological setting

The fjord of Kangerdlugssuaq is best known for the Skaergaard intrusion, which lies close to its mouth in an area of extensive Lower Tertiary tholeiitic plateau lavas which are regarded as being formed around the time of continental break-up in this part of the North Atlantic (Brooks, 1973). Rocks of alkaline affinities occur along the fjord (see fig. 1) and this led Brooks (1973) to postulate that the fjord is the non-spreading arm of a triple rift system.

Recent discoveries show that the rocks are considerably more undersaturated beyond the head of the fjord, where a completely different petrographic province of unknown extent crops out from under the inland ice. Thus, Brooks & Rucklidge (1974) have described undersaturated, alkaline rocks as erratic blocks which are believed to originate in this area and Frisch & Keusen (in press) report a circular intrusion, named Gardiner intrusion (see fig. 1), which consists of dunites, pyroxenites, uncompahgrites (melilite rocks) and possibly carbonatites.

The samples described here were taken from an intrusion, for which the name 'Batbjerg intrusion' is proposed, which is located on the innermost nunatak on the north-east side of the Kangerdlugssuaq Glacier (68°40'N, 28° 50'W, see fig. 1). It is probably also circular in plan, but a substantial part is hidden under glacier ice.

About twenty rock samples from the Batbjerg intrusion have been examined by us and although the number of samples is too small to give a reliable picture of the intrusion it would appear that it is made up predominantly of olivine and pyroxene rocks. The pyroxenites are medium-grained, vary from

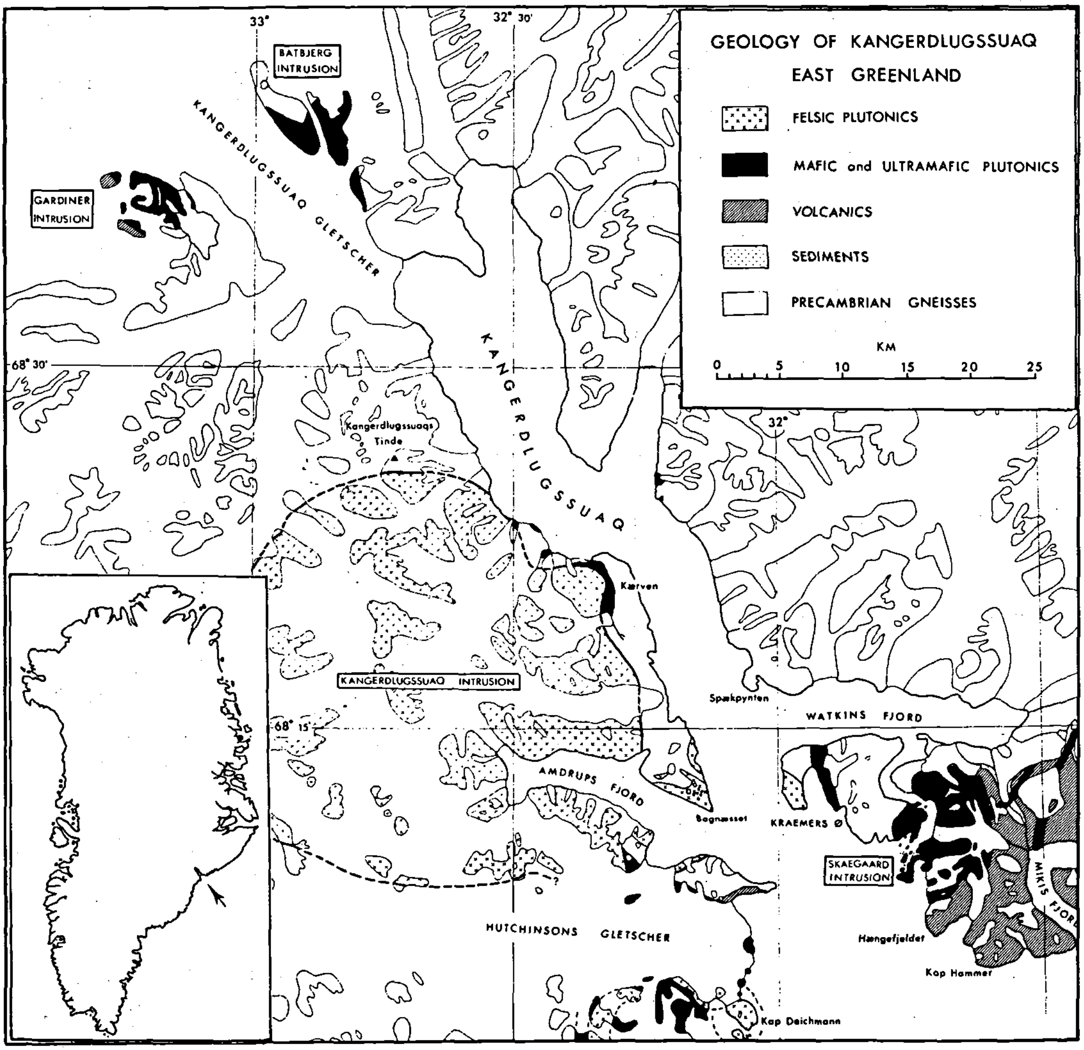

Fig. 1. Geological sketch map of the Kangerdlugssuaq district, East Greenland, showing the location of the Batbjerg, Gardiner and other intrusions.

olive green to almost black in hand specimen and tend to be fresh and rather friable. The dunitic rocks are dark-coloured and many specimens are sheared and serpentinized, probably due to faulting in a north-easterly direction, as reported by Polegeg & Köck (pers. comm., 1971). Phlogopite is abundant in many of these rocks and variants enriched in apatite and magnetite also occur. Felsic minerals are often completely absent, but in others nepheline is present and with increasing nepheline content the pyroxenites pass into melteigitic and ijolitic types. One dike rock in the collection is a porphyritic ultramafic type with phenocrysts of clinopyroxene (ca. 4 mm in size) in a fine-grained groundmass of clinopyroxene, phlogopite and ore with a total absence of light minerals. Also present are syenite dikes and a fenitized zone in the surrounding Precambrian gneisses.

These rocks from the Batbjerg intrusion are strongly reminiscent of those reported from the Gardiner intrusion (Frisch & Keusen, in press), in that they belong to an alkaline ultramafic association similar to that reviewed by Upton (1967) and, as such, are the only known representatives of this association in the Tertiary North Atlantic province. The main difference between the two intrusions appears to be the absence of melilite and perovskite at Batbjerg, both of which are important constituents of the Gardiner rocks. On the other hand, leucite, the subject of this note, does not appear to occur in the Gardiner intrusion. Whether the differences are real or apparent can only be determined when more work can be carried out, especially on the Batbjerg intrusion.

It is probable that these rocks are the intrusive equivalents of lavas similar to the nephelinite described by Brooks & Rucklidge (1974), just as the ijolitic and carbonatitic intrusive core of the Napak Volcano, Uganda (King, 1965) is regarded as the intrusive equivalent of the surrounding nephelinitic lavas and pyroclastics (Middlemost, 1974).

The field relationships of the Batbjerg intrusion does not allow a more precise dating than post-Precambrian, but the Gardiner intrusion cuts the plateau basalts which have been dated to the interval 55–60 m.y. by the K–Ar method (Beckinsale et al., 1970) and, in view of the petrographic similarity between the intrusions, a similar age is assumed for the Batbjerg intrusion.

Table 1. Leucite-bearing rock from the Batbjerg intrusion, Kangerdlugssuaq: chemistry and mineralogy.

		Trace elements	
SiO_2	45.75		
Al_2O_3	8.92		
Fe_2O_3	8.04	Rb	128
FeO	4.98	Ba	76
MgO	9.30	Sr	1970
CaO	13.45	Y	7
Na_2O	3.50	Zr	32
K_2O	3.25	Nb	0
MnO	0.19	Cu	122
TiO_2	1.01	Co	54
P_2O_5	0.97	Ni	73
H_2O^+	0.68	V	290
		Cr	194
sum	100.04		

C.I.P.W. weight norm (calculated) with analytical values and with Fe_2O_3/FeO adjusted to 0.44			*Mode (volume percent)*	
or	15.66	4.70	leucite	10
lc	2.78	11.37	nepheline	12
ne	15.05	15.05	feldspar	4
ac	1.61	1.61	clinopyroxene	52
di	47.37	48.95	phlogopite	3
ol	1.88	8.31	opaque ore	10
mt	10.85	4.77	apatite	1
il	1.92	1.92	alteration (nepheline + feldspar)	8
ap	2.25	2.25	no. of points:	ca. 4000

Major element analysis: Geological Survey of Greenland, Geochemical Laboratories.

Trace element analyses: Rb, Sr, Y, Zr & Nb by J. Bailey, Institute of Petrology, Copenhagen University (X-ray fluorescence). Ba, Cu, Co, Ni, V, Cr by Haldis Bollingberg, Institute of Petrology, Copenhagen University (optical spectrography).

The leucite-bearing sample

Leucite is confined to a single sample, but, in view of the rather dull appearance of this rock, there is no reason to believe it has been specially sampled. Unfortunately, the precise field relationships of this rock are not known. It is a dark green, melanocratic rock, in which white spots of leucite, up to 1 cm in size, may be seen on the weathered surface. In thin section, the leucite phenocrysts are seen to be accompanied by nepheline, up to 0.5 cm in size, set in a matrix of clinopyroxene prisms oriented to give a weak fluxion structure. Pools of clear, untwinned alkali feldspar and a turbid alteration product, the latter also occurring as rims on the leucite, are also present. Where nepheline is enclosed by the alkali feldspar it is perfectly euhedral. The alteration product was identified as a finely-divided mixture of alkali feldspar and nepheline. Also present are titaniferous magnetite, phlogopite and apatite as minor constituents. These phases have been investigated using the Hitachi XMA-5B microprobe at the Institute of Mineralogy, University of Copenhagen and the experimental techniques described by Pedersen et al. (in press). The approximate modal composition is shown in table 1.

Leucite, which shows the characteristic complex twinning, has a composition very close to the ideal leucite composition with only 1.1 mole percent of the soda-leucite ($NaAlSi_2O_6$) component. It is stoichiometric, unlike the leucites analysed by Carmichael (1967) from the Leucite Hills of Wyoming. The twinning, which was absent in Carmichael's samples, would seem to indicate fairly slow cooling from above the cubic-tetragonal inversion temperature of ca. 600°C (Faust, 1963).

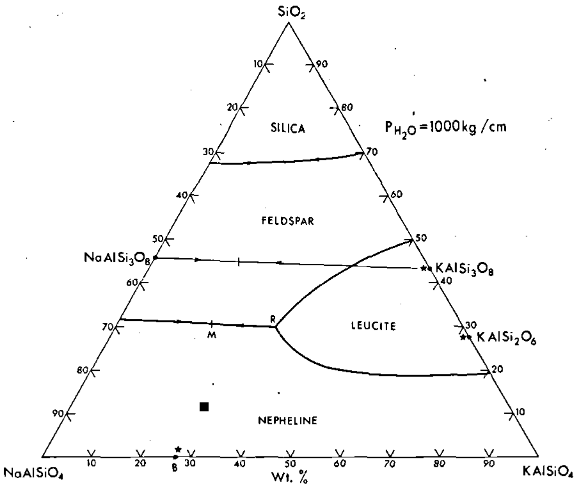

Fig. 2. Felsic mineral compositions in the leucite-bearing sample, indicated by stars, plotted in terms of SiO_2-$NaAlSiO_4$-$KAlSiO_4$. Field boundaries are after Hamilton & MacKenzie (1965) at the indicated water vapour pressure, while M is the phonolite minimum and B the Buerger nepheline composition (Tilley, 1954). The salic composition of the leucite-bearing sample is indicated by the filled square in the nepheline field.

Table 2. Composition of clinopyroxene in the leucite-bearing rock from the Batbjerg intrusion, Kangerdlugssuaq.

Average of 11 complete point analyses		Cations on basis of 4 cations and 6 oxygens		
SiO_2	52.6	Si	1.946	2.000
TiO_2	0.55	Al	0.039	
Al_2O_3	0.91	Fe^{3+}	0.015	
Fe_2O_3*	4.60			
FeO*	2.64	Fe^{3+}	0.113	1.998
MnO	0.14	Ti	0.015	
MgO	14.4	Fe^{2+}	0.082	
CaO	22.84	Mn	0.004	
Na_2O	1.24	Mg	0.789	
K_2O	0.03	Ca	0.905	
		Na	0.089	
sum	99.95	K.	0.001	

Atomic	
Mg	44.30
Fe^{2+} + Mn	4.86
Ca	50.85

End members (mol. %) after Kushiro, 1962	
$NaFe^{3+}Si_2O_6$	4.8
$CaTiAl_2O_6$	0.8
$CaFe^{3+}(Fe^{3+},Al)SiO_6$	1.3
CaAl $AlSiO_6$	0.0
$Ca_2Si_2O_6$	46.6
$Mg_2Si_2O_6$	42.2
$Fe_2Si_2O_6$	4.6

* Estimated from stoichiometry.
Maximum observed variation:

	41.73 Mg	7.43 Fe^{2+}	50.84 Ca
to	45.45 Mg	2.52 Fe^{2+}	52.03 Ca

Nepheline ($Ne_{72.5}Ks_{23.6}Qz_{3.9}$) approaches closely the Buerger ideal composition (Tilley, 1954) of $Ne_{73}Ks_{27}$ and falls below the 500° curve of Hamilton (1961). It is clearly of very low temperature origin, which is rather surprising, as the salic composition of the rock (see below) suggests that it should be the first felsic mineral to crystallize.

Alkali feldspar has a composition of $Or_{98.5}Ab_{1.3}An_{0.2}$ (mole percent). Lattice constants were refined from Guinier powder data and after Smith's (1974, figs 9–11) proposed nomenclature it is a potassian intermediate sanidine. We are not aware of occurrences of such a pure potash feldspar in rocks of this type, although some of the feldspars from ijolite-carbonatite complexes in Ontario analysed by Watkinson (1973) approach it, as do those from potassic lavas of Africa described by Sahama (1952).

The compositions of the light minerals are shown diagrammatically in fig. 2 along with the salic composition of the rock. It is clear that these minerals represent an equilibrium at very low temperatures. The leucite nepheline dolerite from Meiches, Hessen, described by Tilley (1958), which has a closely similar salic composition, shows a much greater degree of solid solution in the felsic phases.

Pale green *clinopyroxene* is subhedral and about 1.5 × 0.5 cm in size. Often the crystal centres and margins are clear, but an intermediate zone has a gridwork of exsolved iron ore lamellae. The average composition is shown in table 2, there being very little variation, although the cores and crystal margins tend to be slightly more magnesian than the intermediate zone.

In the allocation of cations to the tetrahedral sites, Fe^{3+} has been taken before Ti as suggested by Hartman (1969) and required to form the Ca ferri-Tchermak's component ($CaFe^{3+}SiO_6$). In this way an almost perfect distribution into the molecules suggested by Kushiro (1962) may be achieved. These are diopsides with small amounts of acmite, titan-pyroxene and Ca ferri-Tschermak's component as seems to be fairly typical of pyroxenes from alkaline, undersaturated and possibly oxidising environments (Sahama, 1952; Bell et al.; 1972; Upton & Thomas, 1973; Thompson, 1974), although the calculation of the Fe_2O_3/FeO ratio from stoichiometry is subject to considerable errors (Finger, 1972).

Similar diopsides are reported from African potash ankaratrites (Sahama, 1952), the ijolites of Magnet Cove, Arkansas (Erickson & Blade, 1963) and the nearby Gardiner intrusion (Frisch & Keusen, in press), while similar, but more Fe-rich pyroxenes, occur in the nephelinite-ijolite suite of Uganda (Tyler & King, 1967). The diopsides described by Upton & Thomas (1973) from potassic ultramafic rocks in the Gardar province of South Greenland differ in that they have a much higher TiO_2 and Al_2O_3 content.

Titaniferous magnetite occurs in two generations: as small (ca. 0.04 mm) euhedral inclusions in the pyroxenes, and as larger grains, comparable in size with the pyroxenes, which they partially enclose. The second type have lamellae of exsolved ilmenite.

Phlogopite forms poikillitic plates enclosing other constituents. Partial analysis shows it to contain MgO: 16.3 %, FeO: 12.7 % and TiO_2: 10.6 %. This is an exceptionally TiO_2-rich phlogopite even for such rock-types. For example, Prider (1939) reported ca. 9 % TiO_2 in phlogopite from a leucite lamproite.

Apatite in euhedral prisms is the main accessory mineral, while a turbid *alteration product* occurs as rims on the leucite and as patches throughout the rock.

Chemistry. The composition of this sample is shown in table 1. It has an Na_2O/K_2O ratio close to unity, a rather unusual feature of basic rocks, which generally have more than twice as much Na_2O as K_2O (Wilkinson, 1974). The low Al_2O_3 and high CaO reflect the abundance of pyroxene and together with the high total FeO relative to MgO are characteristics of the kamafugitic association (Sahama, 1974).

Similarly, a high Fe_2O_3/FeO ratio appears, from the compilation of Upton (1967), to be a characteristic of alkali pyroxenites. However, in view of signs of subsolidus oxidation we have also calculated a norm with a lower degree of oxidation, using that observed in a fresh nephelinite from the area (Brooks & Rucklidge, 1974). The effect of this is to substantially increase the amount of normative leucite and olivine simultaneously reducing that of orthoclase and magnetite and bringing the norm into much better agreement with the mode (table 1).

This rock is similar petrographically to many described from the Toro-Ankole district of Uganda by Holmes & Harwood (1932) and is best matched chemically by the leucite ankaratrites of this area. Mineralogical and chemical data have recently been presented by Cundari (1973) for leucitites from Australia and although no samples are directly comparable there are clear similarities. Finally, as noted above, the salic composition ($Ne_{61.6}Ks_{26.8}Qz_{11.6}$) is very close to that of the leucite nepheline dolerite from Hessen described by Tilley (1958).

The *trace elements* are unusual in that there is no significant enrichment in either residual elements (Ba, Sr, Zr, etc.) or compatible elements such as Ni and Cr, as is usual in leucite-bearing rocks (Higazy, 1954; Erickson & Blade, 1963; Cundari, 1973).

Conclusions

Leucite is a mineral which is limited to potassium-rich rocks in two distinct tectonic settings. It occurs in rifted continental environments such as the Western Rift of Uganda (Holmes & Harwood, 1932) or above deep-lying parts of subduction zones as, for example, in Indonesia (De Roever, 1975). This report of its occurrence in Greenland, in which we have argued its similarity to the occurrences of rifted areas, is strong evidence for the rifted nature of Kangerdlugssuaq as suggested previously by Brooks (1973) and Brooks & Rucklidge (1974). Furthermore, its occurrence here reinforces the observations of Brooks & Rucklidge (1974) and Frisch & Keusen (in press) that there is in the interior parts of Kangerdlugssuaq a petrographic sub-province of highly undersaturated alkaline rocks which is unique in the entire Tertiary North Atlantic province.

This is the first well investigated occurrence of leucite in Greenland. Bøggild (1953) referred to an earlier report of leucite from South Greenland, but this now seems to be doubtful (Sørensen, pers. comm., 1974). Noe-

Nygaard (pers. comm., 1974) reports the possible presence of altered leucite (pseudoleucite?) in dikes from the Holsteinsborg district, but this is as yet unconfirmed.

Acknowledgements. The samples examined by us were collected by Siegfried Polegeg and Hermann Köck (Leoben, Austria) while prospecting for the Northern Mining Company (Nordisk Mineselskab A/S) of Copenhagen and we are extremely grateful both to them and to the company for kindly allowing us access to their samples and field descriptions.

We thank Ib Sørensen, Geological Survey of Greenland, for the major element analysis and Haldis Bollingberg and John Bailey, Institute of Petrology, University of Copenhagen, for trace element analyses.

Dansk sammendrag

En nyopdaget forekomst af ultramafiske alkaline bjergarter i Kangerdlugssuaq området (Østgrønland) beskrives kort og resultaterne af en mere detaljeret mineralogisk og petrologisk undersøgelse af en leucit ankaratrit præsenteres. Denne bjergart består af diopsid, leucit (den først veldokumenterede forekomst i Grønland), nephelin, alkali feldspat, magnetit og phlogopit. Forekomsten af disse K-rige bjergarter underbygger den pladetektoniske model for områdets udvikling i nedre tertiær.

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