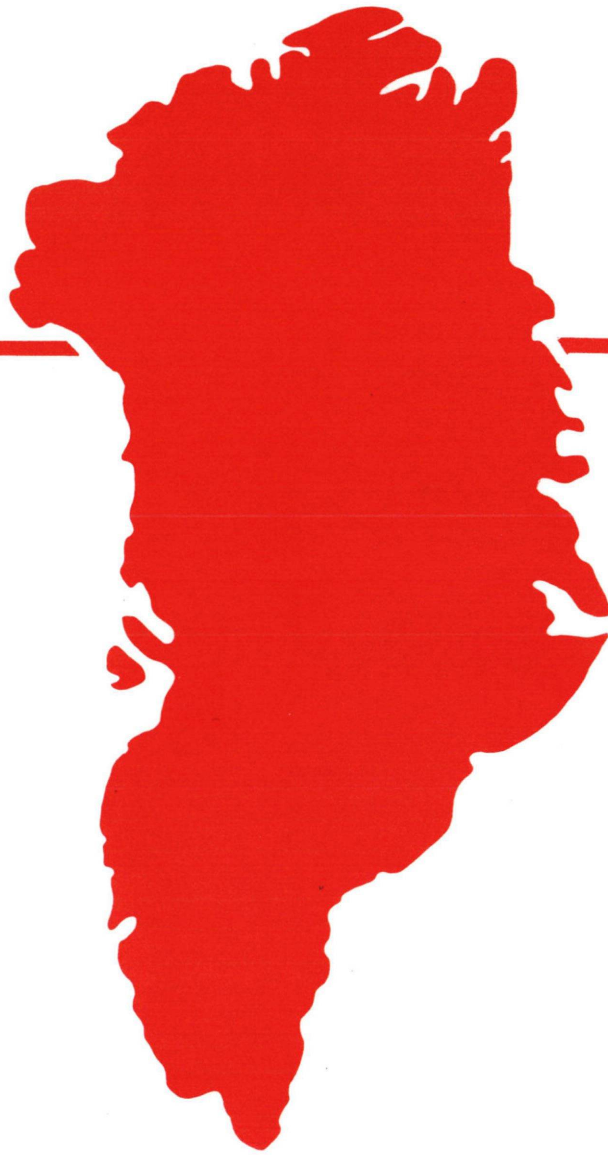
# Industrial mineral occurrences in Greenland - a review

Per Kalvig



Open File Series 94/4

February 1994

GGU

GRØNLANDS GEOLOGISKE UNDERSØGELSE
Ujarassiortut Kalaallit Nunaanni Misissuisoqarfiat
GEOLOGICAL SURVEY OF GREENLAND

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ISSN 0903-7322

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# Industrial mineral occurrences in Greenland - a review

Per Kalvig
MDI A/S

February 1994

CONTENTS

# 1. INTRODUCTION

The industrial mineral potential of Greenland, in combination with improved infrastructural facilities and a fast growing international demand for high quality industrial minerals products, has brought Greenland within the sphere of interest of the minerals industry. The aim of this paper is to present a brief review of some of the known, industrial mineral occurrences in Greenland, of which several are unique on a world scale. However, exploration efforts up to now have mainly focused on "traditional" metal ore targets and have not paid much attention to the industrial minerals. Consequently, the data concerning industrial mineral targets in general are rather scarce and scattered.

In this paper an industrial mineral is defined in accordance with Bates (1983), as any rock, mineral, or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels, and gemstones. However, certain exceptions to the definition have been made; some of the rare earth elements and Nb-Ta occurrences are included, because in terms of technical and commercial aspects they are comparable to the more traditional industrial mineral ore types. Diamonds are excluded.

The selection of minerals to be dealt with in this review has not been based on size or quality of data, since the majority of the occurrences are only briefly assessed. Minerals have been included if sufficient information in terms of geological descriptions or samples are available.

Each occurrence described has been classified entirely on subjective criteria, indicating:

(a) the degree of knowledge/the amount of data: if the occurrence in question is (1) a mineral potential; (2) a mineral resource; or (3) a mineral reserve, the codes 1, 2, or 3 are applied respectively;

(b) the size of the occurrence in question is rated in terms of life time by comparing international production figures for the commodity in question with the potential tonnages of the resources; this gives the potential life time of the occurrence. Occurrences having resources for more than about 15 years of production are rated as being large, and those having resources for less than about 10 years of production are rated as being small. The respective codes used in Fig. 1 are, 1: unknown, 2: small, 3: medium, and 4: large;

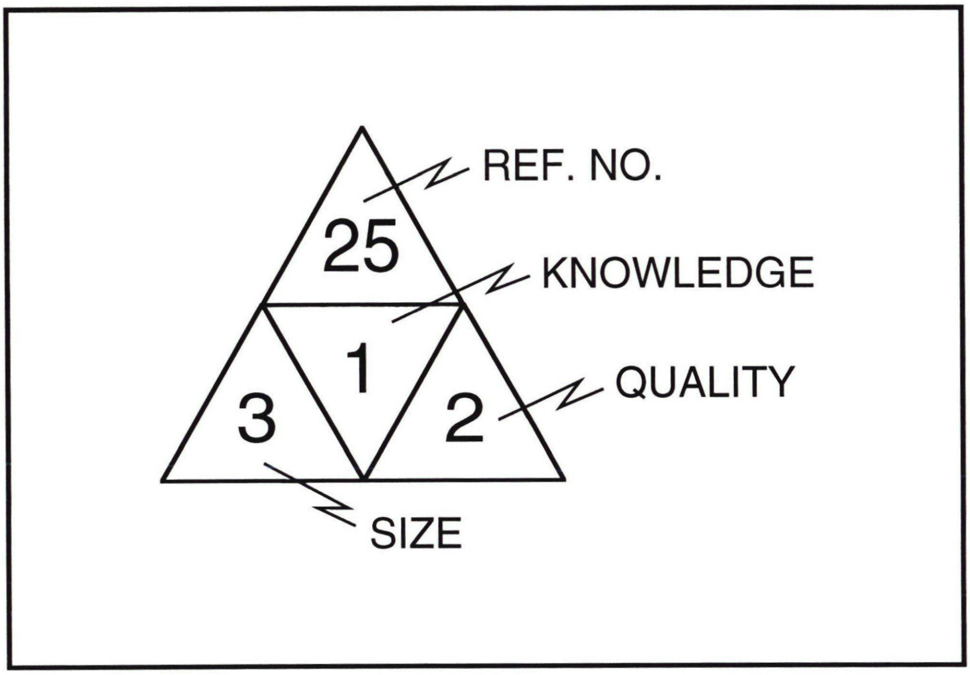


Fig. 1. Triangular symbol, applied for each of the occurrences described, showing the reference number and the symbols indicating the size, the quality and the degree of knowledge.

(c) the quality of the occurrence in question mainly refers to grade of the *in situ* material, and to a minor degree to the impurities present, since these are dependant on the requirements of the end-product. The respective codes given in Fig. 1 are, 1: unknown, 2: poor, 3: medium, and 4: high grade.

Each occurrence described has been given a unique reference number, which together with the codes described above, is placed within a triangular symbol in accordance with Fig. 1, and plotted on simplified maps of Greenland, attached to the individual chapters. The approximate coordinates of each occurrence and the name of the nearest settlement is given in the text.

Wherever possible reference is given to the latest comprehensive paper on the occurrence in question.

The paper distinguish between reserves, resources and mineral potentials in accordance with the definitions given by the IMM Council (1991): (1) A mineral reserve is that portion of a mineral resource on which technical and economic studies have been carried out to demonstrate that extraction can be justified; (2) A mineral resource is a tonnage or volume of rock or mineralisation or other material of intrinsic economic interest the grades, limits and other appropriate characteristics of which are known with a specified degree of knowledge; subdivisions are (a) measured and (b) indicated; (3) a mineral potential describes a body of rock or mineralisation or other material or an area for which evidence exists to suggest that it is worthy of investigation, but to which neither volume, tonnage nor grade shall be assigned.

A revised Greenlandic orthography was introduced in 1975, a change which implied a new spelling for many of the Greenland place names. The new spelling is used for all geographical names. However, where Greenlandic locality names have been incorporated into formal stratigraphic terminology the original spelling is retained.

The author owes special thanks to the Geological Survey of Greenland (GGU) and its staff and facilities, which provided the framework for this paper.

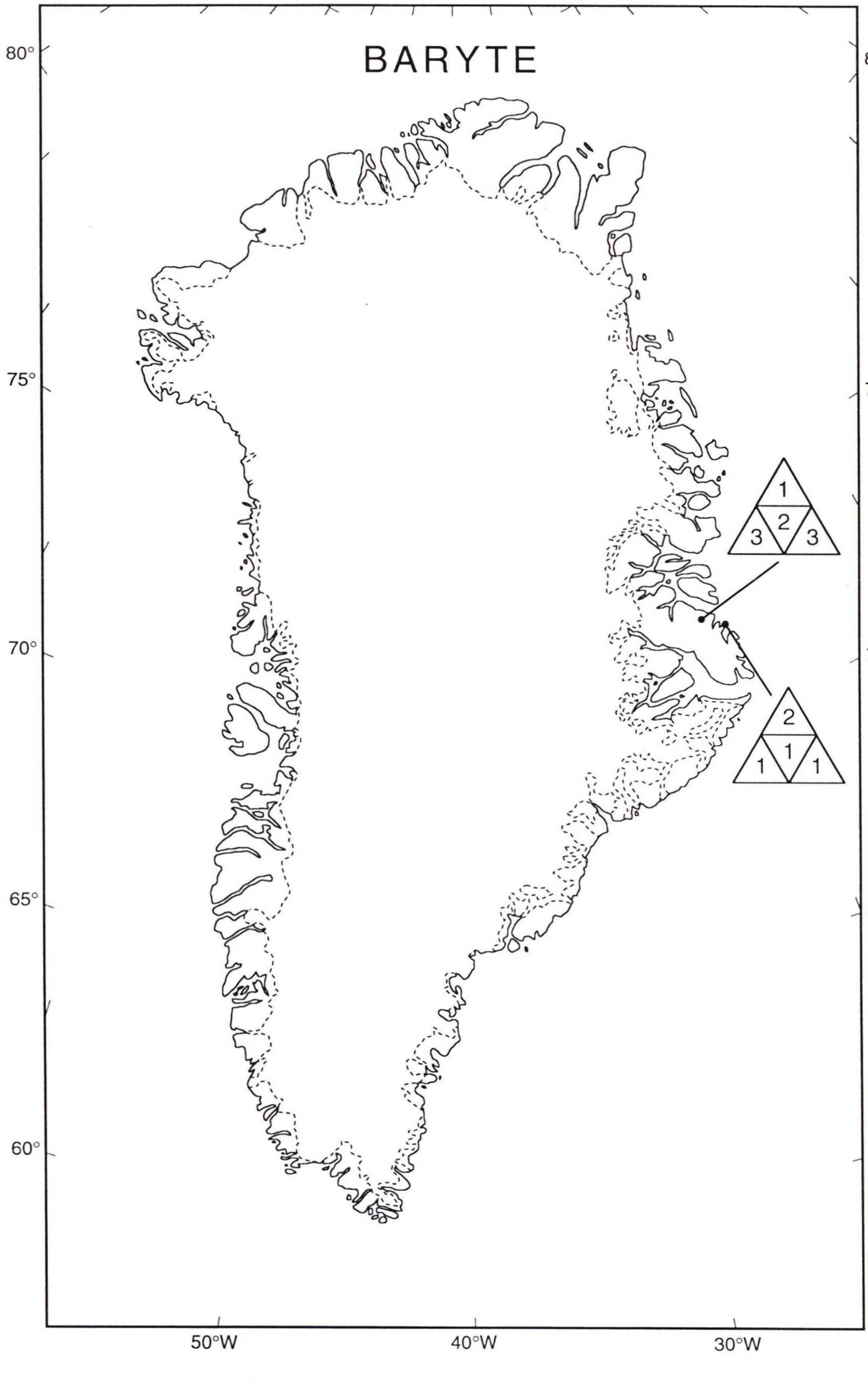


Fig. 2. Baryte occurrences: Bredehorn (1) and Wegener Halvø (2).

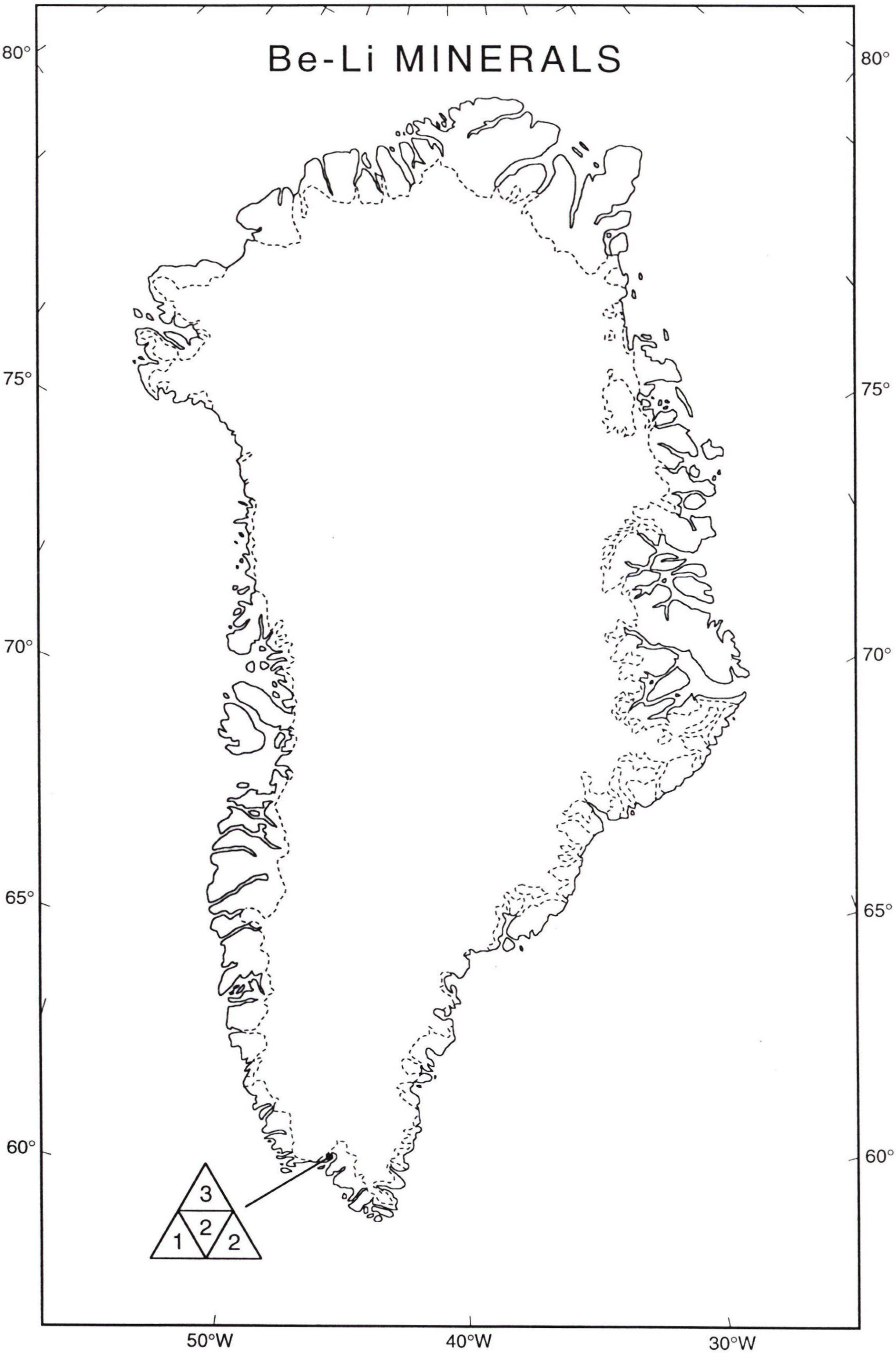


Fig. 3. Be-Li minerals: the Ilímaussaq intrusion.

# 2. INDUSTRIAL MINERAL OCCURRENCES, A BRIEF REVIEW

## 2.1 Baryte

### 2.1.1 **No: 1 Bredehorn** (71°45'N, 22°30'W), Scoresbysund, East Greenland (Fig. 2)

The conformable Bredehorn Ba-Pb-(Zn) occurrence is hosted in a Upper Permian carbonaceous rock (the Karstryggen Formation). The mineralisation forms a plateau 1000 to 1300 m a.s.l., 3 km south of Bredehorn, Scoresby Land, about 40 km south-east of the airstrip at Mesters Vig.

Regional mapping and sedimentological studies were carried out by GGU (1968-72 and 1982-83); exploration programmes were carried out by Nordisk Mineselskab A/S in the period 1972-83, including mapping, chip sampling, trenching, geophysics and shallow diamond drilling (10 holes; total 121 m).

The mineralisation occurs within a 1 km$^2$ fault-bounded area, appearing as conformable sheets and cross-cutting veins forming an up to 200 m wide belt along the faults. The main baryte horizon is exposed for 300 m; maximum thickness is *c.* 10 m. The mineral resource at "Zebra Klint" is estimated to contain approximately 300,000 tonnes of baryte, grading 72% $BaSO_4$; the overall resource is in the order of several million tonnes (Harpøth et al., 1986).

### 2.1.2 **No: 2 Wegener Halvø and Canning Land** (71°45'N, 22°40'W), (71°40'N, 22°25'W), Scoresbysund, East Greenland (Fig. 2)

Baryte occurrences are reported to be widespread along the post-Devonian Main Fault system, and on Wegener Halvø and Canning Land (Harpøth et al., 1986).

## 2.2 Be-Li minerals

### 2.2.1 **No: 3 Narsaq** (60°57'N, 46°00'W), Narsaq, South Greenland (Fig. 3)

The Ilímaussaq intrusion holds minor quantities of beryllium minerals hosted in widespread hydrothermal veins. These veins are, however, abundant about 8 km north of the settlement Narsaq, on the Taseq slope about 500 m a.s.l., where they cut the country

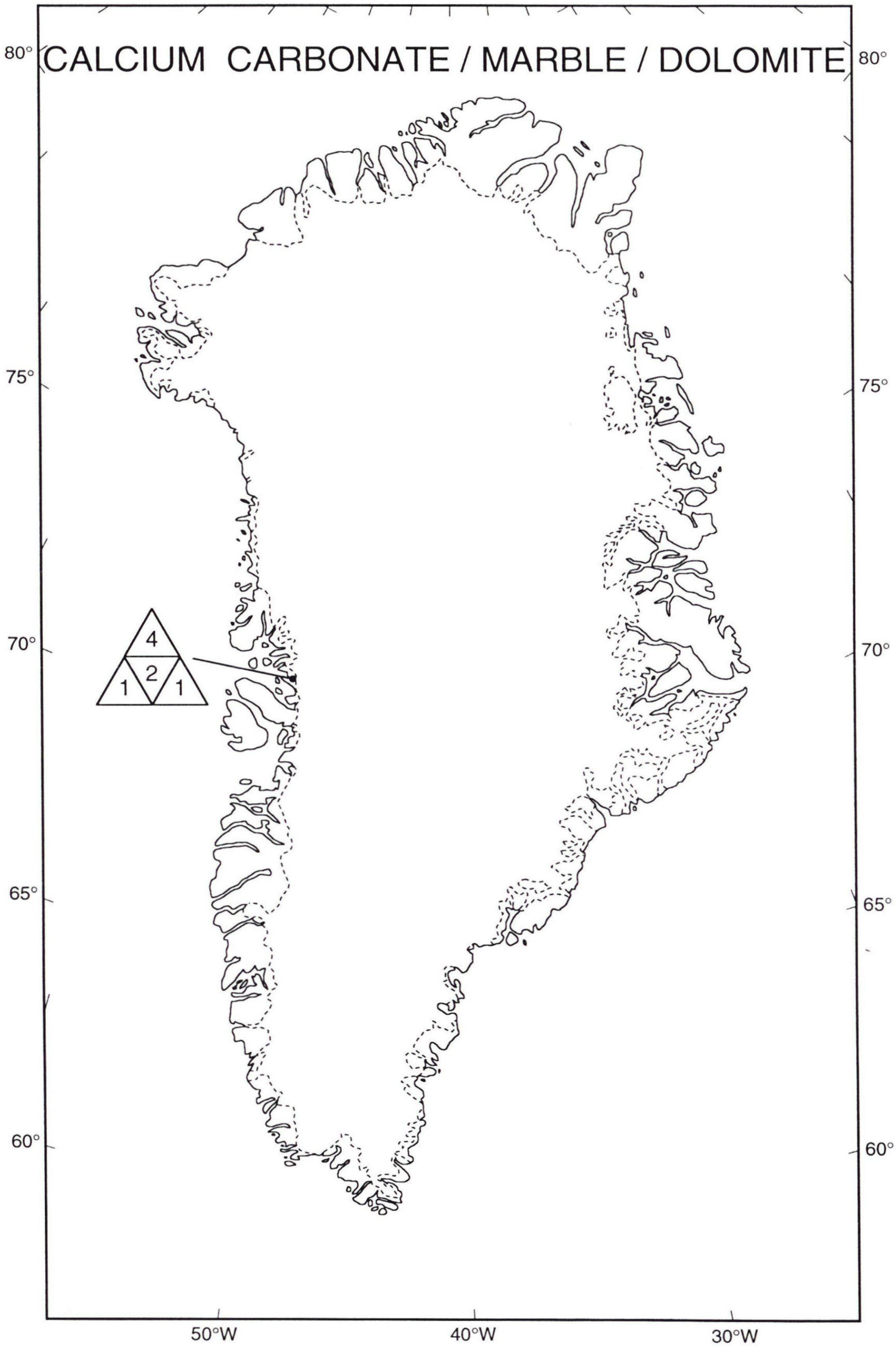


Fig. 4. Calcium carbonate, marble and dolomite occurrence at Maarmorilik.

rocks of naujaite and nepheline syenites. The major components of the veins are analcime, sodalite, ussingite, and natrolite. The most important Be-mineral is chkalovite ($Na_2(BeSi_2O_6)$, containing 11-13% BeO). The widths of the veins vary from few centimetres to 2 m and form a 500 m long and 200 m wide mineralized zone. The indicated mineral resource of the investigated area is 180,000 tonnes grading 0.1% BeO (Engell et al., 1971). The metallurgical consequenses of using chkalovite as a Be-resource are not known.

## 2.3 Calcium carbonate/marble

### 2.3.1 **No: 4 Maarmorilik** (71°10'N, 51°15'W), Ukkusissat, West Greenland (Fig. 4)

The Proterozoic Marmorilik Formation is dominated by marble sequences interbedded with layers of dolomite and occasionally baryte. In the Maarmorilik area the most prominent colours of the formation are greyish white. The composition of the rock varies, depending on the impurities present.

The Marmorilik Formation hosted the Black Angel lead-zinc ore that was exploited between 1973 and 1990. As a consequence detailed petrographical data on the marble is available, and some drill cores are stored at GGU.

Recently the marble has been tested for filler purposes, by a private company; results are not available. Between 1967 and 1972 about 4000 tonnes of marble were quarried. The quality is comparable to that of the Italian Carrara marble (Nielsen, 1976). The quantity of the mineral resource is unknown.

## 2.4 Carbonatites

Mineralisations related to carbonatites are dealt with in the sections on phosphates, niobium/tantalum and REE.

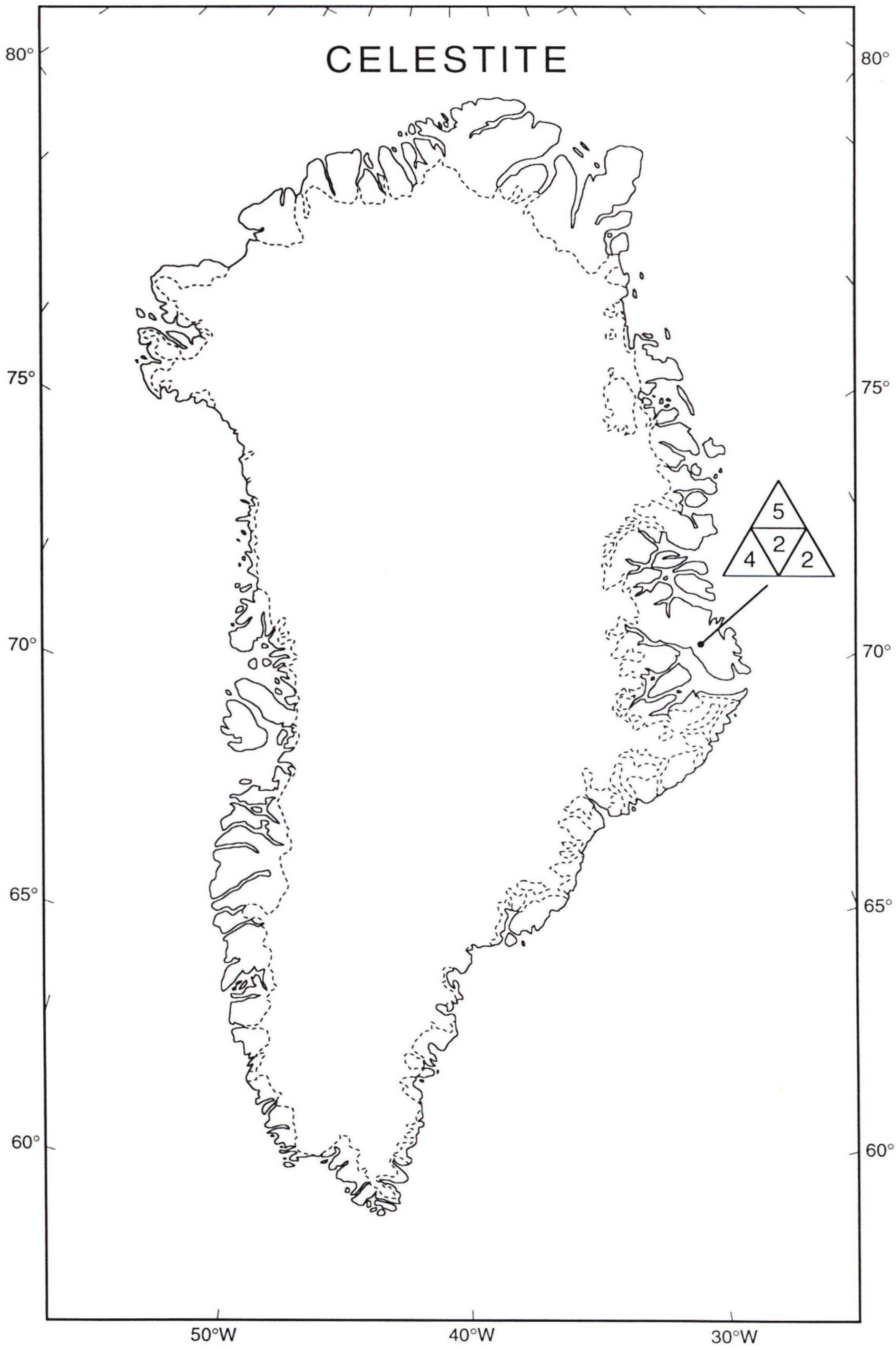


Fig. 5. Celestite occurrence at Karstryggen.

## 2.5 Celestite

### 2.5.1 **No: 5 Karstryggen** (71°30'N, 24°50'W), Scoresbysund, East Greenland (Fig. 5)

Upper Permian sediments at Karstryggen, part of the Jameson Land Basin, host a huge celestite occurrence associated with limestones and evaporites. Karstryggen is situated about 10 km north of Nordostbugt, north of the Scoresby Sund fjord complex.

The celestite occurrence was investigated towards the end of the 1970s, by GGU, university groups and Nordisk Mineselskab A/S.

The celestite mineralisation occurs in a 20 km long N-S trending belt about 8 km wide. Celestite is hosted both in a lower (3-10 m thick) algally laminated limestone unit and in a thick (>50 m) karstified conglomerate/breccia sequence. The meassured mineral resource in the Huledal area of Karstryggen is in the range of 25-50 million tonnes grading 50-60% $SrSO_4$. Thus the mineral resource forms a huge, low-grade celestite deposit. Higher grades are locally observed (Scholle et al., 1990; Harpøth, 1981; Harpøth et al., 1986).

Further details are given in section 3.1 below.

## 2.6 Chromite

### 2.6.1 **No: 6 Fiskenæsset** (63°07'N, 50°20'W), Qeqertarsuatsiaat, South-West Greenland (Fig. 6)

The Fiskenæsset layered anorthosite complex hosts a major low grade chromite deposit, occurring in an area about 100 km long by 50 km wide. The steeply dipping chromite ore zone is mainly hosted in the lower 100 m of the Anorthosite unit, and occurs as one or two stratigraphic chromitite horizons traceable throughout the unit. The fine-grained chromitites grade about 30-40% $Cr_2O_3$, and contain accessory amounts of rutile (about 0.35 wt%) and ilmenite as inclusions (Appel, 1992).

Exploration programmes were carried out in the period from 1969 to the mid 1980s, encompassing mapping, geochemistry, geophysics, and several ore beneficiation studies.

A rough estimate of the mineral potential of the complex indicates the presence of a resource in the order of 100 million tonnes of chrome ore (Ghisler, 1976). At the eastern part of Qeqertarssuatsiaq, the upper 50 m part of a subvertical 1400 m long and 1 to 7 m thick chromite horizon is claimed to have a mineral potential of about 2.5 million tonnes,

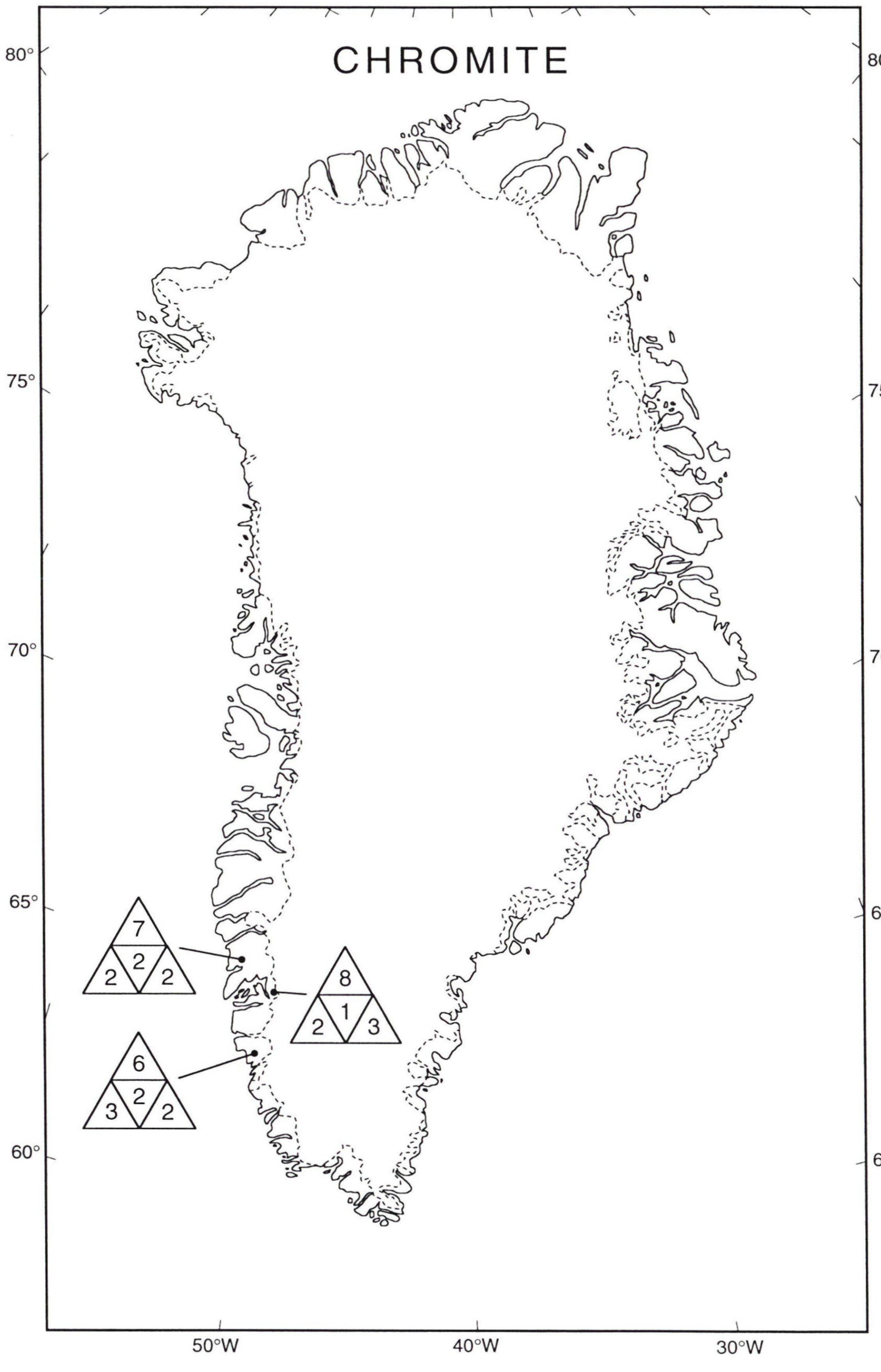


Fig. 6. Chromite occurrences: Fiskenæsset (6); Itipilua (7) and Godthåbsfjord (8).

corresponding to 350,000 tonnes of $Cr_2O_3$ and 3000 tonnes of $V_2O_5$ (Ghisler & Windley, 1967). It should, however, be emphasized that the chromite layers are strongly boudinaged, which renders mining difficult (P. Appel, personal communication, Oct. 1993).

Mining of the very complexly folded and thin chromite horizons could best be achieved by selective, open cut techniques.

Further data are given in section 3.2 below.

2.6.2 **No: 7 Itipilua** (65°00′N, 51°35′W), Atammik, West Greenland (Fig. 6)

A chromite bearing peridotite is hosted in the northern part of the Itipilua dunite occurrence (see section 3.5, Itipilua, olivine). The chromite rich bands vary in thickness from less than 1 cm to about 0.3 m, grading 28-38% $Cr_2O_3$ and 19-21% $Fe_2O_3$. The chromite zone is up to about 1000 m long and between 2.5 m and 6 m wide (Kalvig, 1990). The mean $Cr_2O_3$ content of the pure chromite is 44.3% and the Cr/Fe ratio is about 1.2 (Nielsen, 1973).

2.6.3 **No: 8 Godthåbsfjord** (64°40′N, 50°20′W), Nuuk, West Greenland (Fig. 6)

A dunite hosted chromitite occurs in the 3800 m.y. old Amitsoq gneiss of the Ivisârtoq region, in the inner Godthåbsfjord.

Chadwick & Crewe (1986) report the Ivisârtoq chromite as follows: Chromite in the north-east of the Ivisârtoq region is limited to a few large enclaves of dunitic rocks. It occurs in massive chromitite layers up to 2 m thick, in thin seams or as dispersed grains in the dunite host. The chromite grains contain relatively abundant $Fe^{3+}$ substituting for Cr. Chromite grains in the thicker chromitites have higher abundances of $Cr_2O_3$ and MgO, and lower $TiO_2$ and $V_2O_3$ compared with the thinner layers. Disseminated grains and those in the chromitites contain small amounts of Pt. No tonnage figures are reported.

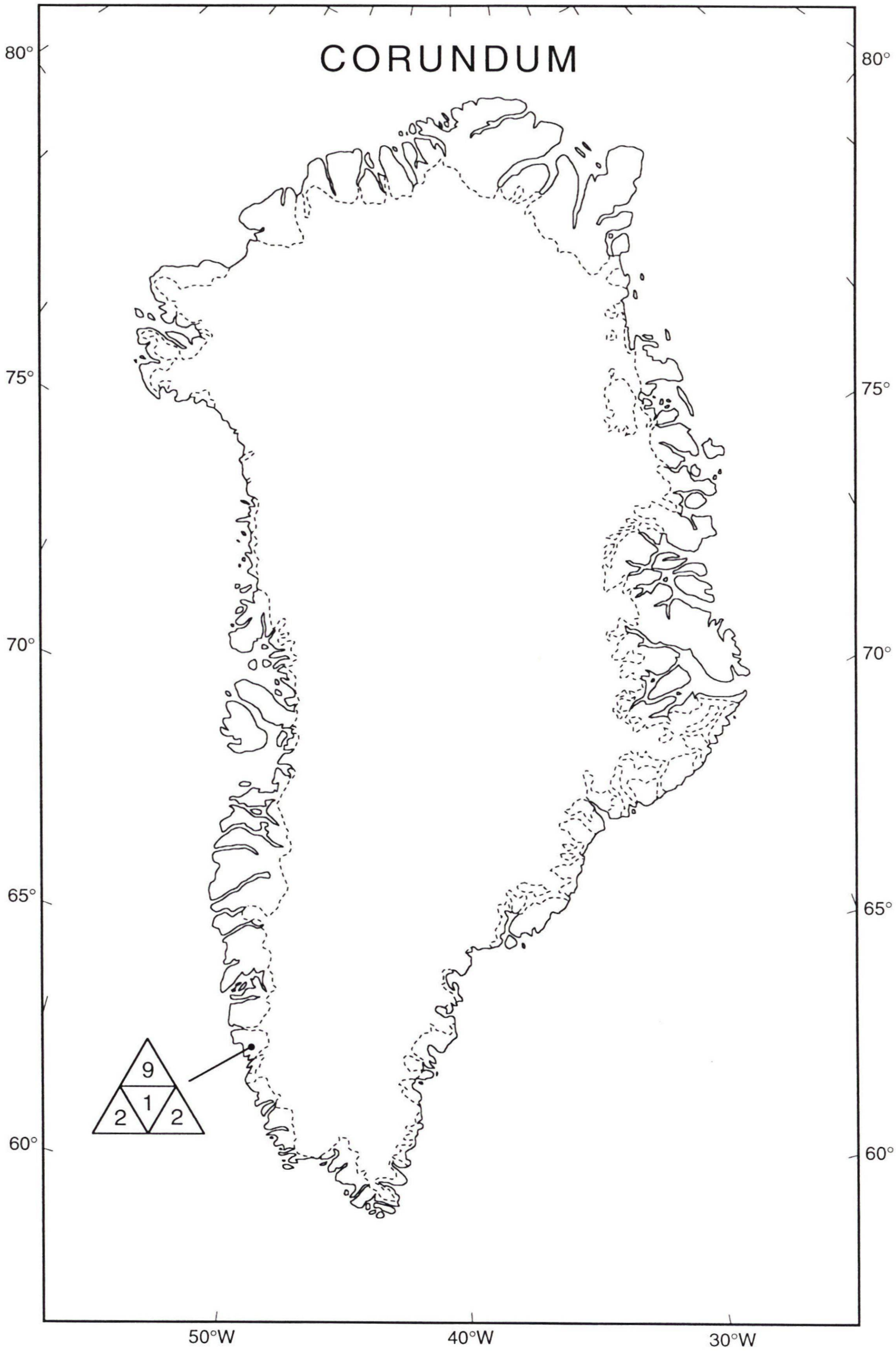


Fig. 7. Corundum occurrence at Siggartartulik.

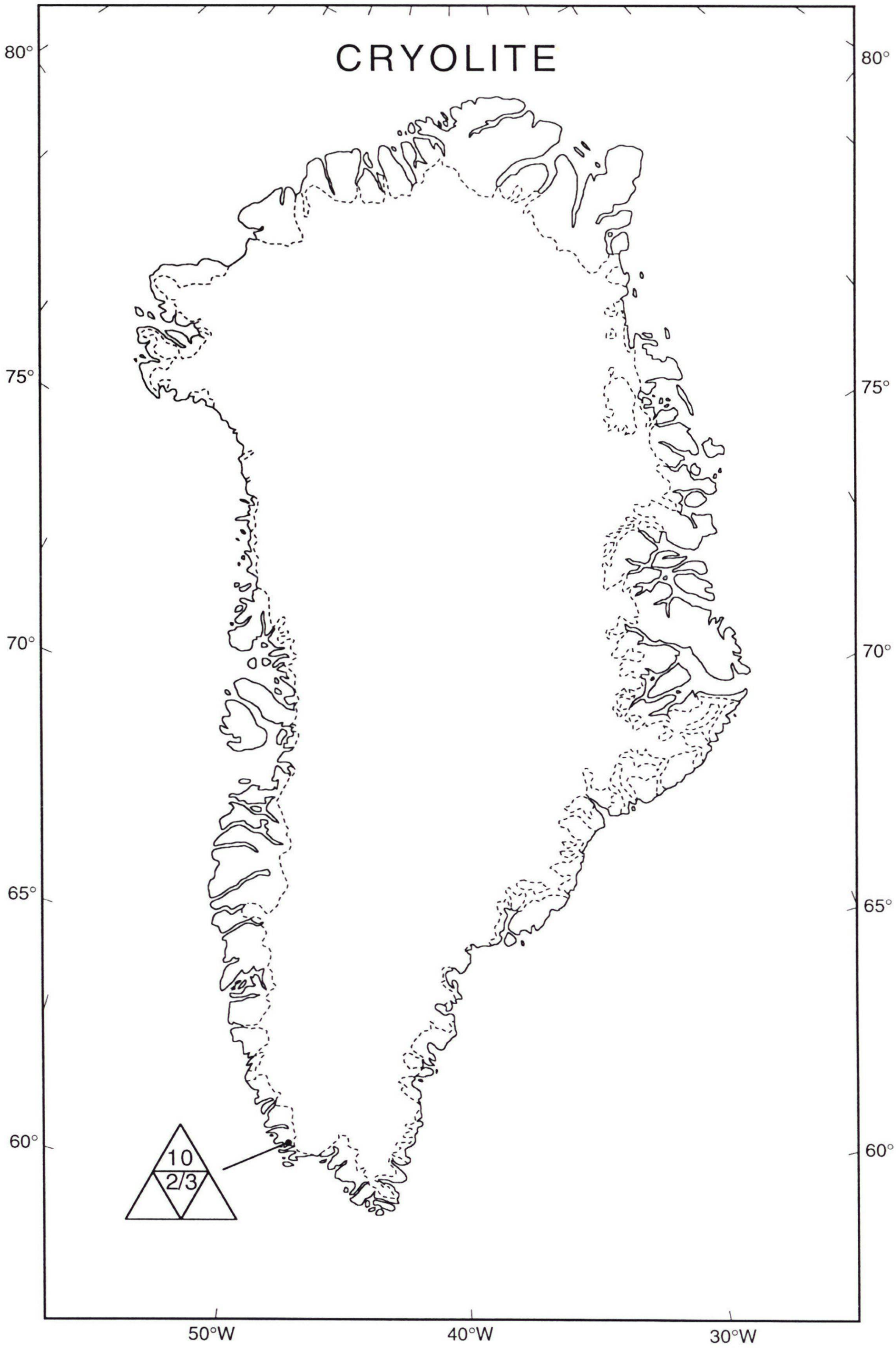


Fig. 8. Cryolite at Ivittuut.

Table 1. Selected chemical elements on the Ivisârtoq chromite (five samples) (based on Chadwick & Crewe, 1986)

| | $SiO_2$ % | $Al_2O_3$ % | $Fe_2O_3$ % | $Cr_2O_3$ % | NiO % | $V_2O_3$ % |
|---|---|---|---|---|---|---|
| Minimum | 0.00 | 14.9 | 8.9 | 45.1 | 0.07 | 0.07 |
| Maximum | 0.02 | 15.9 | 12.6 | 48.1 | 0.18 | 0.13 |

## 2.7 Corundum

### 2.7.1 No: 9 Siggartartulik (63°00′N, 50°30′W), Qeqertarsuatsiaat, West Greenland (Fig. 7)

The Precambrian Fiskenæsset anorthosite complex is a layered basic to ultrabasic intrusion. Corundum and sapphirine occur in the contact zone between anorthosite, and mafic and ultramafic rocks. The corundum is often of the ruby colour variety although gem quality specimens are rare (Nielsen, 1973; GGU/MDI, 1991).

Exploration for rubies was undertaken by Platinomino Aps during a 10 year period starting in the 1970s; geological mapping, grid-scale sampling and bulk sampling was undertaken. A reconnaissance programme focussed on ruby, sapphirine and phlogopite was carried out in 1991; on the basis of four localities visited it was concluded that the three-mineral assemblage was confined to small lenticular bodies not exceeding 1800 $m^3$, grading about 29 vol% phlogopite and 18 vol% sapphirine. Corundum was observed only occasionally and did not exceed 5 vol%; high-grade areas made up only some few cubic metres (MDI A/S, 1991b).

## 2.8 Cryolite

### 2.8.1 No: 10 Ivittuut (61°12′N, 48°12′W), Arsuk, South-West Greenland (Fig. 8)

The cryolite deposit at Ivittuut, is a zoned mineralised body in a leucogranite pipe of Proterozoic (Gardar) age, emplaced in a regional high-grade gneiss complex. The main

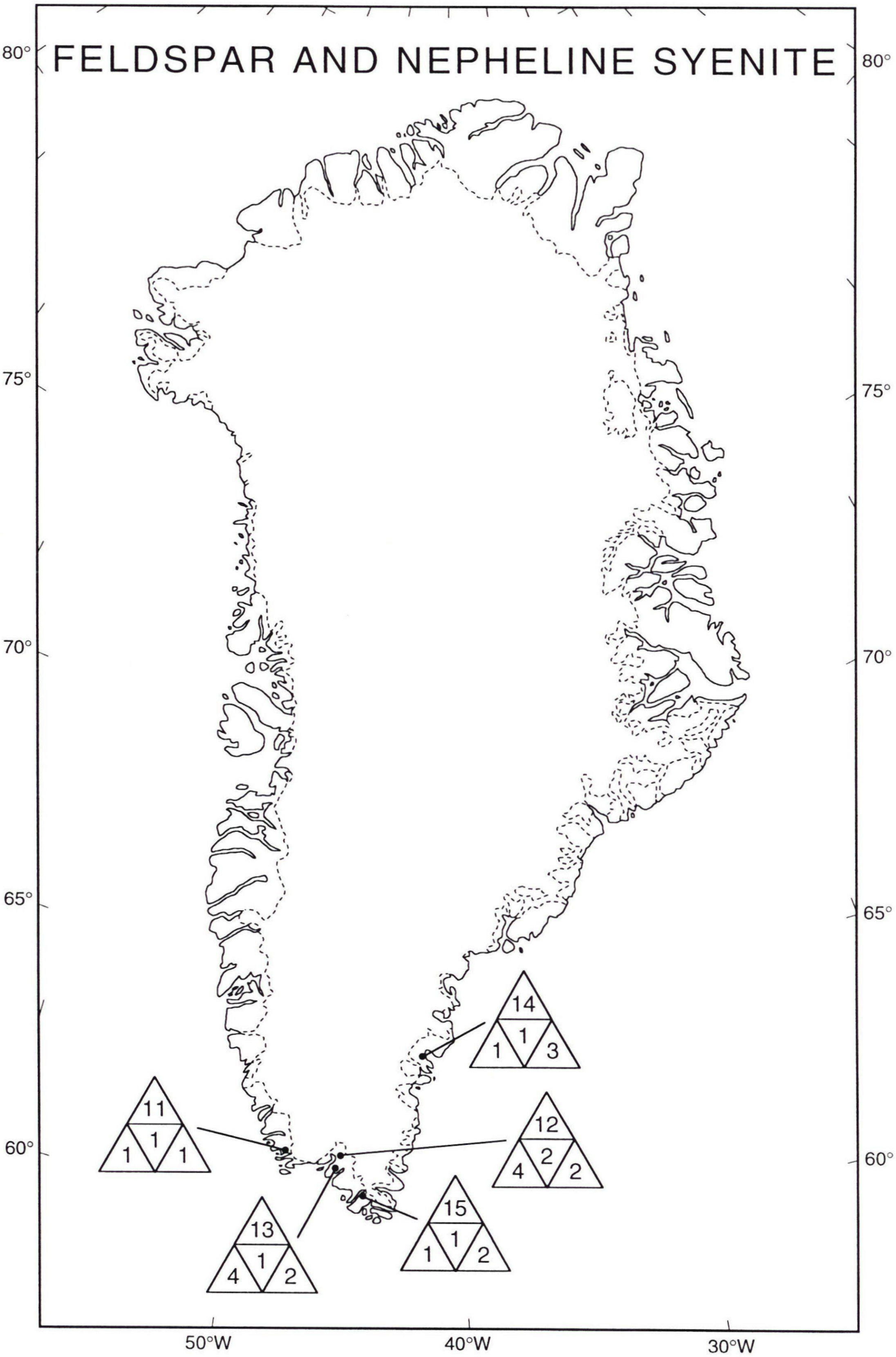


Fig. 9. Feldspar and nepheline syenite occurrences: Igaliku (12); Ilímaussaq (13); Singertât (14); Tasiusaq (15).

cryolite deposit was composed of: (a) an upper cryolite zone (from sea level to a deptharound 60 m) dominated by massive cryolite ($Na_3AlF_6$) containing siderite as main secondary mineral, together with fluorite and subordinate amounts of quartz, sulphides, and topaz; (b) an intermediate cryolite zone (from 60 m to 90 m depth) dominated by fluorite and siderite; and (c) the lower quartzite zone (from *c.* 90 m to *c.* 150 m). Calculated remaining *in situ* mineral resource is reported to amount to 1.8 million tonnes, grading 8% cryolite, 18% fluorite and 38% siderite. In addition, waste materials scattered around the pit amount to 0.9 million tonnes, ranging from 9% to 24% cryolite, in the -5 mm fraction, averaging 13% cryolite (Bondam, 1991).

Recent exploration programmes indicate the presence of a deep seated cryolite mineralisation adjacent to the mine (700-900 m b.s.l.), grading 3.6% cryolite (Bondam, 1991).

Further details of the mining of the deposit are given in section 3.3.

## 2.9 Feldspar and nepheline syenite

### 2.9.1 **No: 11 Grønnedal-Ika** (61°14′N, 48°03′W), Arsuk, South-West Greenland (Fig. 9)

A nepheline syenite body of Gardar age outcrops adjacent to Arsuk Fjord over an area of 3.5 by 9 km. The body consists predominantly of a foyaitic nepheline syenite comprising a two layer series, dominated by alkali feldspar, nepheline, aegerine-augite, and apatite (Bondam, 1992a). Willmers (1971) examined some aspects of the syenite as a potential source of raw material for the glass and ceramic industry, but concluded that due to the heterogenity of the rocks, along with low recovery and high iron values, extraction of the nepheline syenite would not be economic. Resource figures have not been reported.

### 2.9.2 **No: 12 Igaliku** (60°58′N, 45°25′W), Igaliku, South Greenland (Fig. 9)

A large body of raised beach sands, dominated by the constituents nepheline and feldspar, is located 6 km east of the settlement Igaliku. The area has been explored by GGU.

Recent metallurgical tests carried out by Mineral Development International A/S (MDI) yielded the following data: (a) the concentrate obtained by means of high-intensity magnetic separation assayed about 0.4%, 14% and 21% respectively for iron, potasium+sodium and aluminium; (b) mineral processing is expected to discard approximately 20 wt% iron-rich materiale (MDI, 1990; MDI, 1991). In terms of tonnage the mineral resource exceeds 5 million tonnes.

2.9.3 **No: 13 Ilímaussaq** (60°55'N, 45°45'W), Narsaq, South Greenland (Fig. 9)

The Proterozoic, alkaline Ilímaussaq intrusion is made up of a variety of nepheline syenites and syenites. Although exploration programmes in general have not been particularly directed towards evaluation of the nepheline, the existence of a large potential of these rocks is well established.

The nepheline syenites and syenites of the Ilímaussaq intrusion have been considered as potential sources of feldspar and nepheline. However, a significant proportion of iron (>1% $Fe_2O_3$) in the form of microlites has prevented their use within traditional market areas (Nielsen, 1973).

2.9.4 **No: 14 Singertât** (63°15'N, 42°00'W), Ammassalik, East Greenland (Fig. 9)

Pegmatites rich in nepheline are abundant within the alkaline Singertât Complex, at the head of the ice-blocked Kattertooq fjord. The complex is described by Nielsen & Rosing (1990). According to T. F. D. Nielsen (personal communication July 1993), the nepheline dominated pegmatites are found as veins up to 25 m wide outcropping at sea level. Average grain size is about 2 cm, while nepheline crystals up to 25 cm in length have been observed. The iron component appears solely as seperate iron oxides. A nepheline syenite concentrate produced on laboratory-scale magnet assayed (XRF): 50.7% $SiO_2$, 27.9% $Al_2O_3$, 0.08% $Fe_2O_3$ (AAS analysis), 0.3% MgO, 0.98% CaO, 12.7% $Na_2O$, 5.3% $K_2O$, 0.3% $P_2O_3$, and 0.7% LOI.

2.9.5 **No: 15 Tasiusaq** (60°12'N, 44°45'W) Tasiusaq, South Greenland (Fig. 9)

Adjacent to the settlement Tasiusaq widespread occurrences of feldspathic sediments occur along the shoreline and within the fjord. The major constituents of the sediments are microcline, albite and quartz, with some biotite, pyroxene, hornblende and accessories. Bulk samples have been collected for metallurgical beneficiation tests; applying spiral and high-intensity magnets concentrates containing about 16% $Al_2O_3$, 6% $Na_2O+K_2O$, and

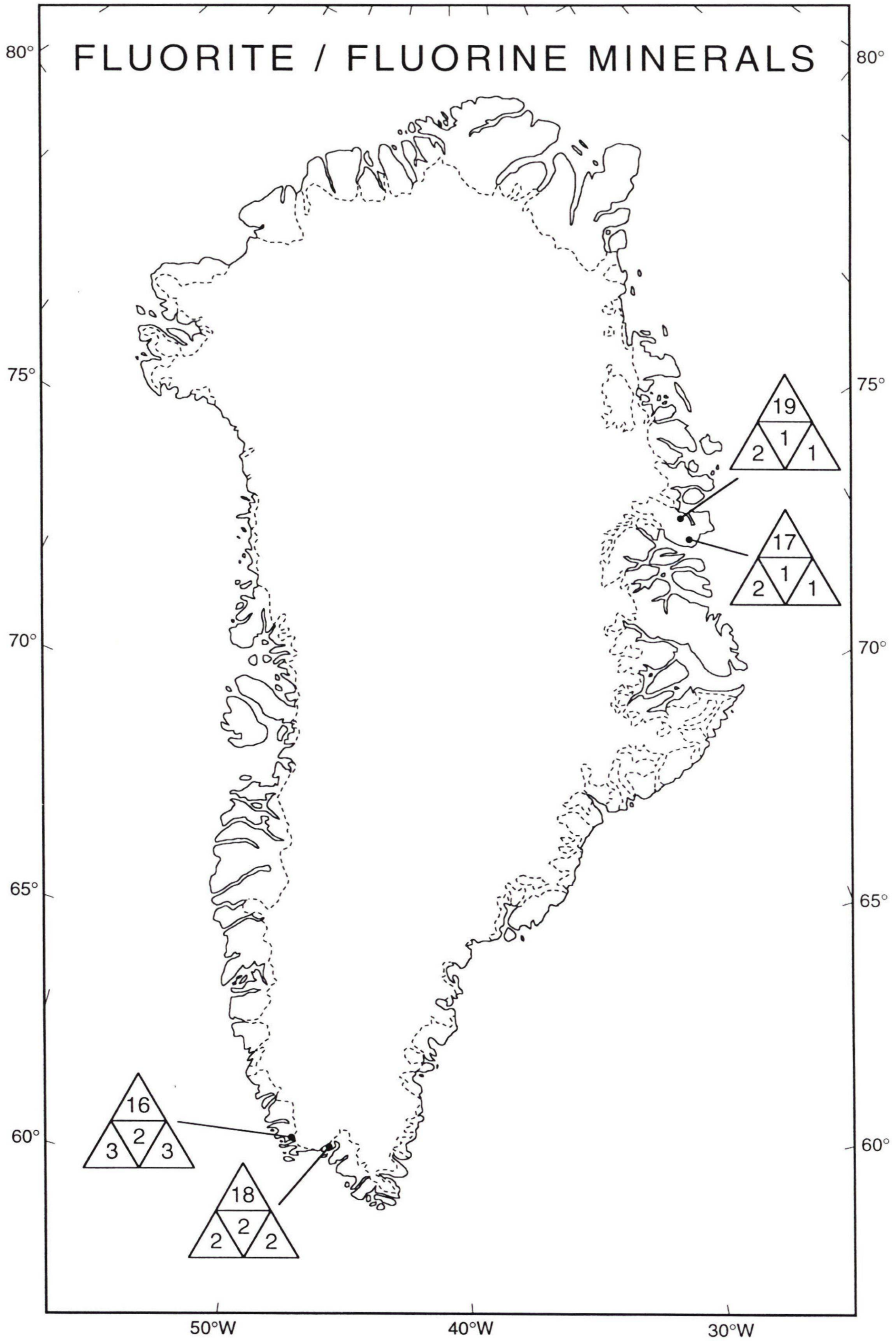


Fig. 10. Fluorite/fluorine mineral occurrences: Ivittuut (16); Kap Franklin (17); Kvanefjeld (18) and Moskusokselandet (19).

0.3% $Fe_2O_3$ were obtained (Carl Nielsen A/S, 1987). Figures on the mineral potential are not available.

## 2.10 <u>Fluorite/fluorine minerals</u>

### 2.10.1 **No: 16 Ivittuut** (61°12'N, 48°12'W), Ivittuut, South-West Greenland (Fig. 10)

Fluorite is widely distributed in parts of the cryolite deposit, and in the intermediate western part of the deposit (60-90 m below sea level) fluorite is a dominant mineral component (named the fluorite zone). According to one chemical anlysis (Bondam, 1991), the fluorite is composed of 47.7% Ca, 0.8% Al, 0.2% Mg, 1.4% Na, 47.8% F, and 1.5% $H_2O$. Recent resource estimates on the fluorite zone report *in situ* tonnage equal to approx. 500,000 tonnes grading 50% fluorite (Bondam, 1991).

### 2.10.2 **No: 17 Kap Franklin** (73°10'N, 22°20'N) Scoresbysund, East Greenland (Fig. 10)

Approximately 15 km west of Kap Franklin, on Gauss Halvø, several hydrothermal veins of fluorite appear as massive veins or fillings typically of decimetre thickness; the veins are of Middle Devonian age. Colours are purple, green, yellow, and black. The largest known lens is about 2 m wide and 25 m long (Harpøth et al., 1986).

### 2.10.3 **No: 18 Kvanefjeld** (60°58'N,46°00'W), Narsaq, South Greenland (Fig. 10)

Villiaumite (NaF; water soluble mineral) is widespread in the lujavrites and naujaite rocks belonging to the Ilímaussaq intrusion, although investigations are mainly confined to the Kvanefjeld area. The contents of NaF varies from accessory to *c.* 20 vol%.; due to the percolating groundwater villiaumite is dissolved in the rocks near the surface. Grain size varies from less than 1 mm to about 3 mm. The mineral potential of part of the Kvanefjeld area has been estimated, and is reported to encompass about 21,000 tonnes NaF based on a cut-off value equal to 0.5% villiaumite (Sørensen et al., 1974); however, the content of NaF in this part of the area varies between 0% and 4% (Kalvig, 1983). Ore beneficiation tests indicated that villiaumite flotates with use of oleic acid and anionic collectors.

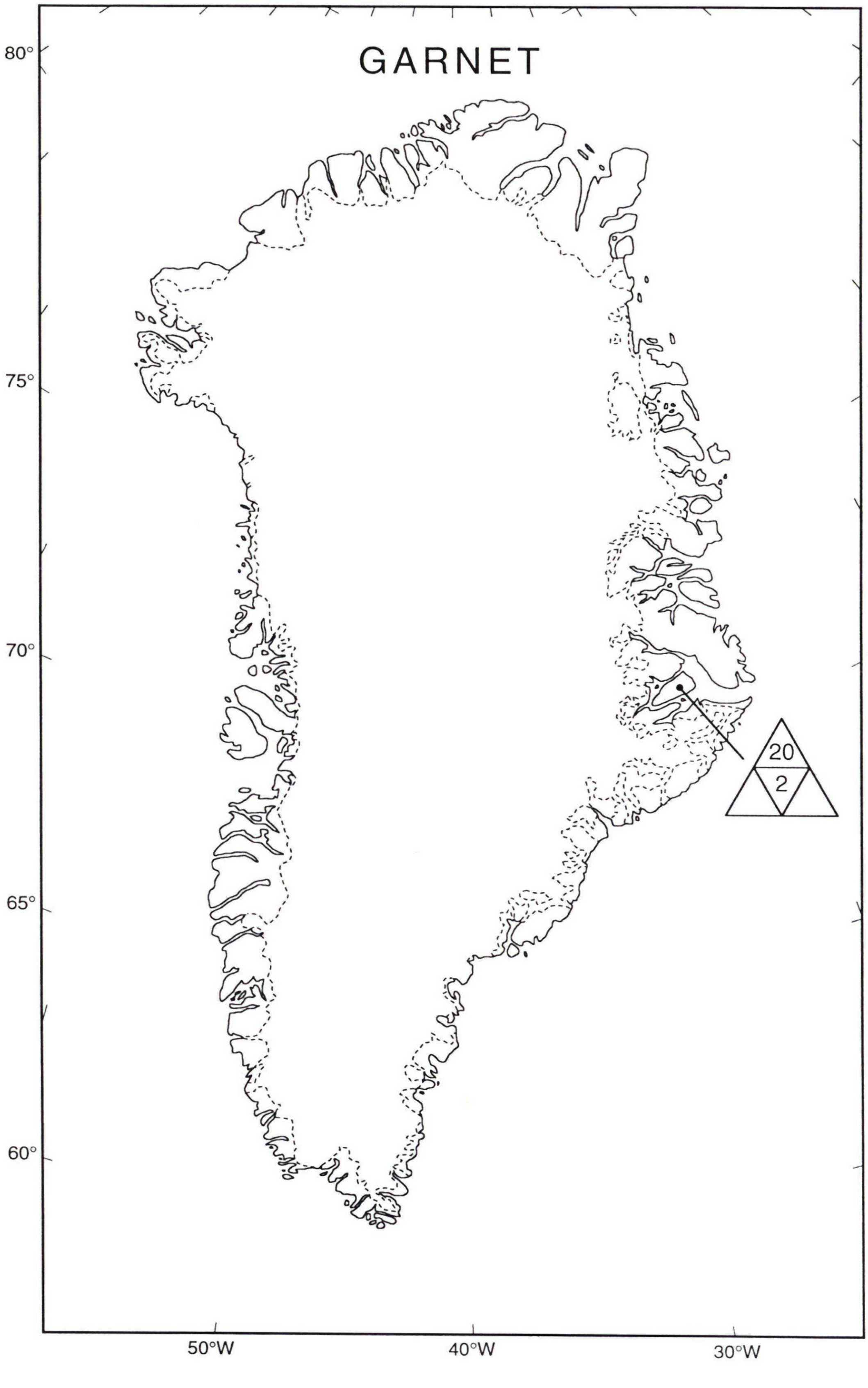


Fig. 11. Garnet occurrence at Milne Land.

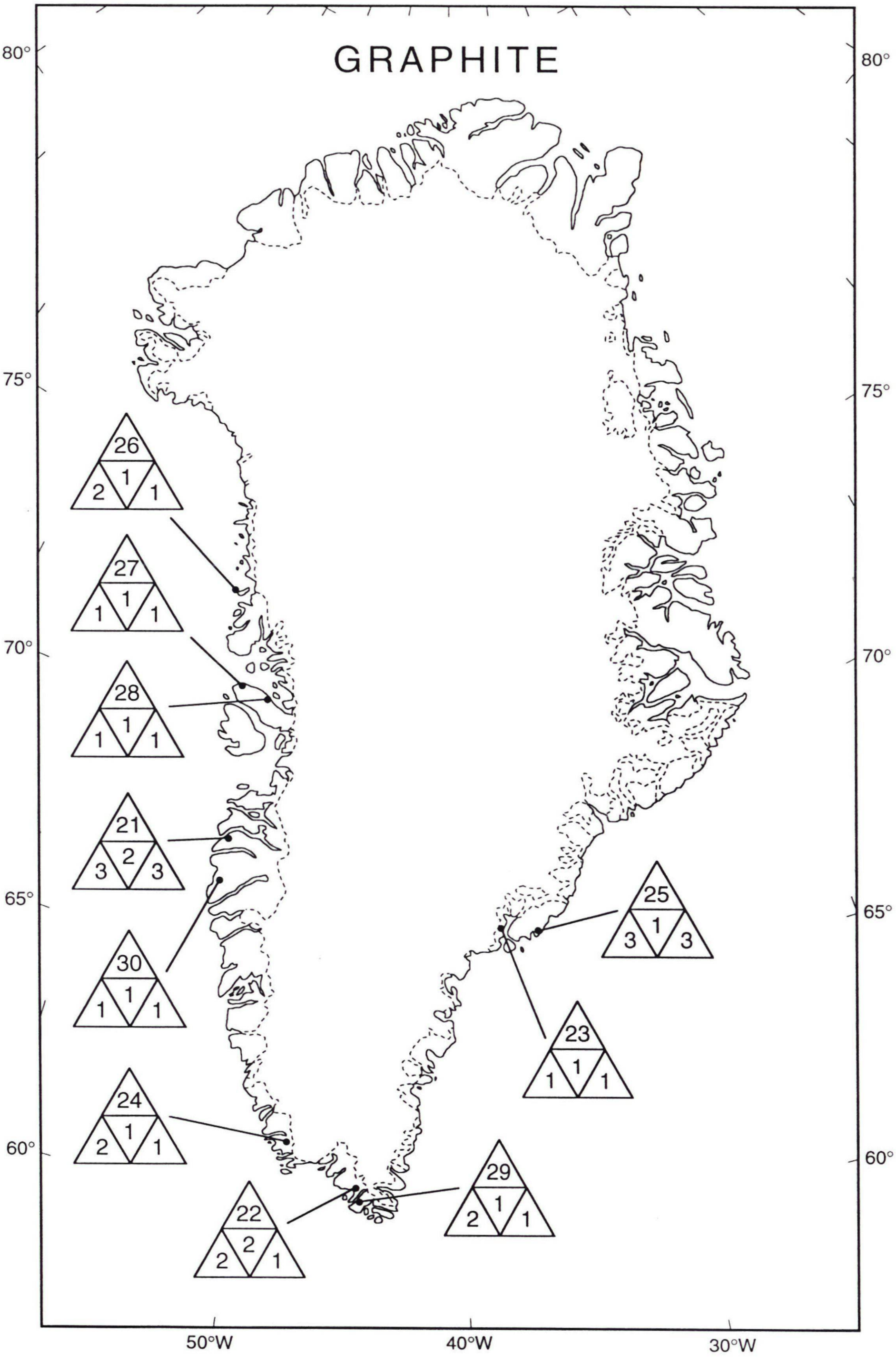


Fig. 12. Graphite occurrences: Akuliaruseq (21); Amitsoq (22); Aappaluttoq (23); Grænseland (24); Kangikajik (25); Langø/Qaneq (26); Niaqornat (27); Qaarsut (28); Sissarissoq (29) and Utoqqaat/Maligiaq (30).

2.10.4 **No: 19 Moskusokselandet** (73°40'N, 23°30'W), Scoresbysund, East Greenland (Fig. 10)

In the coastal parts of Moskusokselandet, north of Moskusoksefjord, fluorite occurs in association with Middle-Upper Devonian clastic sediments, rhyolites, and basalts. The dimensions of the largest zone observed, situated 6 km from the coast, is about 100 m long and 1-2 m wide, constituing a breccia zone in sandstone cemented with fluorite. Uranium mineralisation is associated with the Devonian acid volcanics (Harpøth et al., 1986).

2.11 **Garnet**

2.11.1 **No: 20 Milne Land** (70°40'N, 26°00'W), Scoresbysund, East Greenland (Fig. 11)

See sections 2.21 and 3.6., Zr, Y, and REE minerals.

2.12 **Graphite**

2.12.1 **No: 21 Akuliaruseq** (67°37'N, 51°45'W), Kangaatsiaq, West Greenland (Fig. 12)

The Akuliaruseq/Gamle Egedsminde graphite deposit is hosted in Proterozoic supracrustal rocks, which outcrop in a downfolded synform in hypersthene gneiss. Three parallel graphite bearing horizons, predominantly hosted in sillimanite schists, are exposed along strike for *c.* 7 km. Graphite mineralisation appears as: (a) graphite flakes, grading about 7% graphite carbon (Cg); and (b) massive graphite, grading about 22% Cg. The thicknesses of the graphite bearing rocks varies considerably.

Extensive exploration programmes were carried out by Kryolitselskabet Øresund A/S in the period from 1977 to 1986. The field programmes gave rise to mineral reserve estimations, ore beneficiation tests, and economic run-downs (Nunaoil, 1992). Some of the recent basic figures are given below:

- measured mineral resource contains 5.3 million tonnes grading 9.5% or 1.2 million tonnes grading 14.8% C;
- the concentrate contains graphite up to 20% >48 mesh, and 50% >100 mesh, grading approximately 91% Cg and 90% Cg respectively;

- the ore is of good quality, easy to refine, and is suitable for open-pit mining.

Further data given in section 3.4.

2.12.2 **No: 22 Amitsoq** (60°17'N, 45°08'W), Nanortalik, South Greenland (Fig. 12)

In the southern part of the island of Amitsoq in Nanortalik district, a graphitic schist occurs embedded in highly sheared gneiss. The ore consists of finely disseminated graphite flakes in a quartz matrix, accompanied by pyrite and biotite. The width of the graphite layer reaches a maximum of *c.* 13 m pinching over 400 m to 3.5 m (Bondam, 1992b). One grab sample from the mine site assayed 14.5% C; 0,9% S; LOI: 19,1%; the sample was dominated by graphite flakes (Carl Nielsen A/S, 1987).

Mineral resource figures measured at the beginning of the century, amounted to *c.* 250,000 tonnes as mineable resource (Bondam, 1992).

Quarrying activities were initiated in 1914 and continued on a very modest scale until 1922; in total about 4000 tonnes of ore were quarried.

2.12.3 **No: 23 Aappaluttoq** (66°06'N, 38°00'W), Ammassalik East Greenland (Fig. 12)

Graphite bearing metasedimentary rocks, ranging from biotite schists to quartzitic schists, outcrop along the west coast of Sermilik. At the sample locality, 3 km west of Sermilik, the metasedimentary sequence is between 50 m and 100 m thick, and may contain several graphite layers. The graphite schists observed vary in width from 5 m to 10 m, and extend for more than 200 m. One sample assayed *c.* 25% LOI and about 5% ash (Bondam, 1992b).

2.12.4 **No: 24 Grænseland** (61°25'N, 48°00'W), Arsuk, South-West Greenland (Fig. 12)

An anthracite-graphite deposit estimated to contain 10,000 tonnes of graphite occurs in sedimentary units of the Ketilidian Foselv Formation in Grænseland, north-east of Ivittuut. The southern part of the deposit is developed as a graphite schist and the northern part as an anthracite coal layer. The occurrence does not appear to have any economic importance (Berthelsen & Henriksen, 1975).

2.12.5 **No: 25 Kangikajik** (66°05'N, 35°50'W), Ammassalik, East Greenland (Fig. 12)

On the peninsula Kagikajik about 100 km north of Ammasalik/Tasiilaq five graphite bearing supracrustal areas enclosed in Archaean gneisses are observed. The graphite appears mainly as flake graphite (0.2-2 mm) hosted in schists grading from amphibolite to biotite schist to quartzite. Typically the graphite mineralised zones extend for about 100 m and have a width of about 5 m. Sequences of zones make up graphite-rich areas, which have been observed to extend along strike for several kilometres (Kalvig, 1992).

Two reconnaissance prospecting programmes were carried out in late 1980s and 1991, covering about 50% of the western part of the peninsula.

From the technical reports (Kalvig, 1992) the following data have been extracted: (a) the mineral potential equals about 500,000 tonnes af graphite; (b) promising metallurgical tests for one of two investigated areas assay about 9% Cg in the crude ore; 74% of the flakes >100 mesh; the grade of concentrate was about 92% Cg, although some impurities were observed.

2.12.6 **No: 26 Langø/Qaneq** (72°45'N, 56°08'W), Upernavik, West Greenland (Fig. 12)

Graphite occurs on the island Langø/Akia as irregular lenses and veins in garnet bearing schists. Further occurrences are found at Ikeq and Qaneq; the latter as a graphite mineralised pelitic gneiss traceable for about 900 m along strike (Bondam, 1992b).

Prospecting activities were carried out in the beginning of the century, including bulk-sampling and bench tests, although ore quality data are disputable, ranging from 81.3% to 90.4% C. The occurrence does not appear to have any economic importance (Bondam, 1992). Assays of the Ikeq and Qaneq graphite are not available.

2.12.7 **No: 27 Niaqornat** (70°45'N,53°40'W), Niaqornat, West Greenland (Fig. 12)

Graphite occurs in bituminous shales in Early Cretaceous to Danian clastic sediments, which were deposited in the Nuussuaq embayment. The occurrence is very similar to that occurring at Qaarsut (see below). Where cut by Tertiary dykes amorphous graphite prevails due to contact metamorphism.

Prospecting activities were carried out in the late 19th and the beginning of this century, and only scarce data are available. Bondam (1992b) reports massive graphite as being found beneath scree, and one occurrence is situated 35 m below a thick cover of basalts.

2.12.8 **No: 28 Qaarsut** (70°45′N, 52°45′W), Qaarsut, West Greenland (Fig. 12)

Graphite occurs in bituminous shales in Early Cretaceous to Danian clastic sediments, which were laid down in the Nuussuaq embayment. A similar occurrence at Niaqornat is described above (Bondam, 1992b).

Contact metamorphism due to intrusion of basic dykes has recrystallised thin coal seems to graphite. According to Bondam (1992) samples contained approximately 95% C and 3.6 to 4.9% ash (assayed in 1870).

Small scale mining was carried out occasionally between 1908 and 1924, utilising a 16 cm thick graphite layer occurring in a sandstone and shale sequence (Nielsen, 1973; Bondam, 1992b).

2.12.9 **No: 29 Sissarissoq** (60°08′N, 45°17′W), Nanortalik, South Greenland (Fig. 12)

About 2 km south of the settlement Nanortalik a graphite occurrence is hosted in a biotite-garnet-schist. The occurrence crops out as a small lens 30 m long and 1.5 m wide, and is dominated by amorphous graphite; accessory minerals are quartz, calcite, garnet, mica, and pyrite. Chemical analyses average 22-25% C and 7-12% S; the ratio of flake to amorpheus graphite is 3:7 (Carl Nielsen A/S, 1987; Bondam 1992b).

2.12.10 **No: 30 Utoqqaat/Maligiaq** (66°55′N,53°05′W), Sarfannguit, West Greenland (Fig. 12)

Graphite occurs in Archaean gneisses and amphibolites at Utoqqaat. On the northern shore of Amerloq seven graphite bearing schist units extending for 1.2 km have been reported; apparent width varies from 1-10 m. Sample material assayed 21% C and 5.5% S (Bondam, 1992b). In 1914 about 80 tonnes of material were excavated for test purposes.

The graphite bearing mica schists at Maligiaq further to the east, have been sampled over a distance of 800 m, and grade from 5% to 25% C (Olsen & Kalvig, 1988).

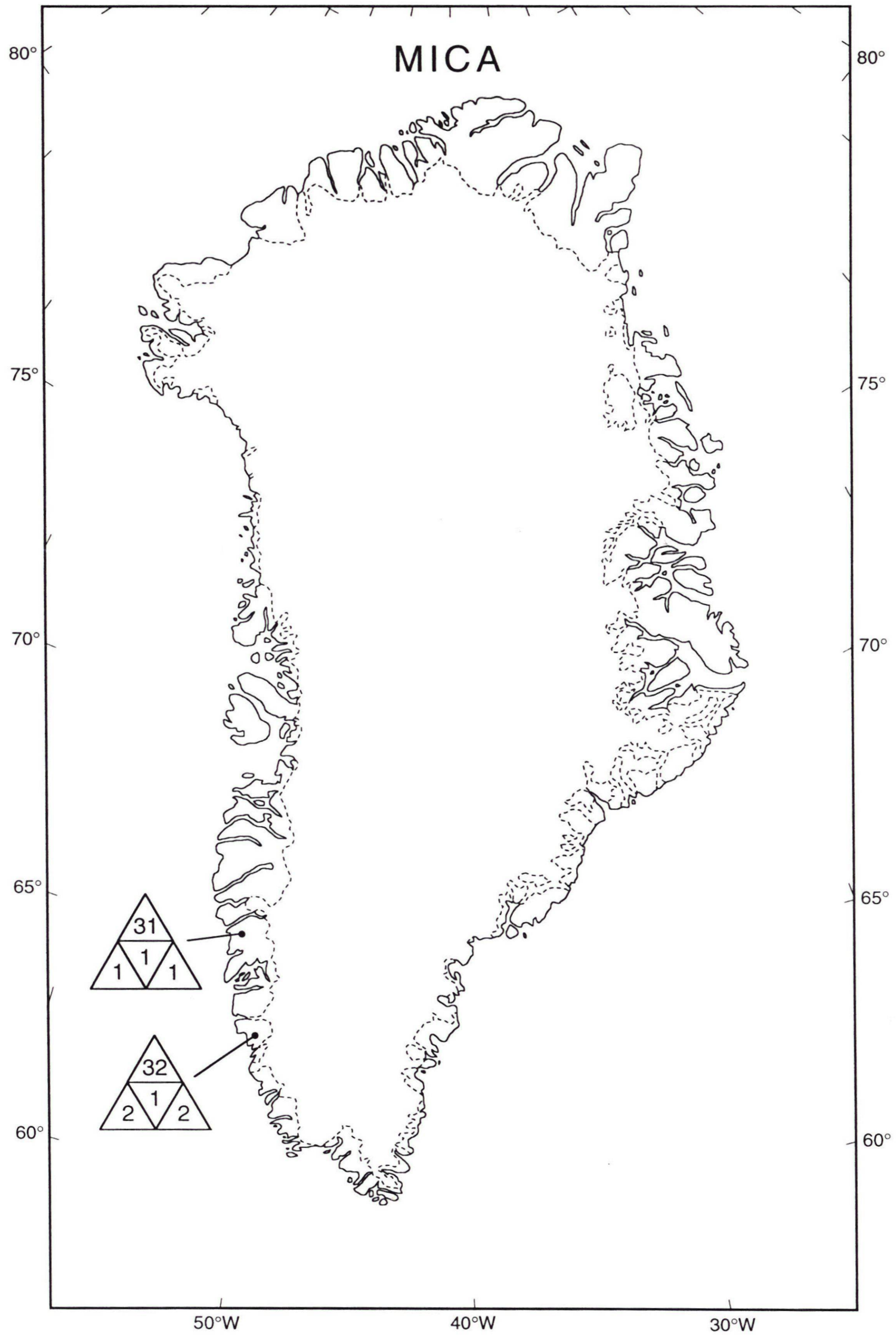


Fig. 13. Mica occurrences: Qaqarssuk complex (31) and Siggartartulik (32).

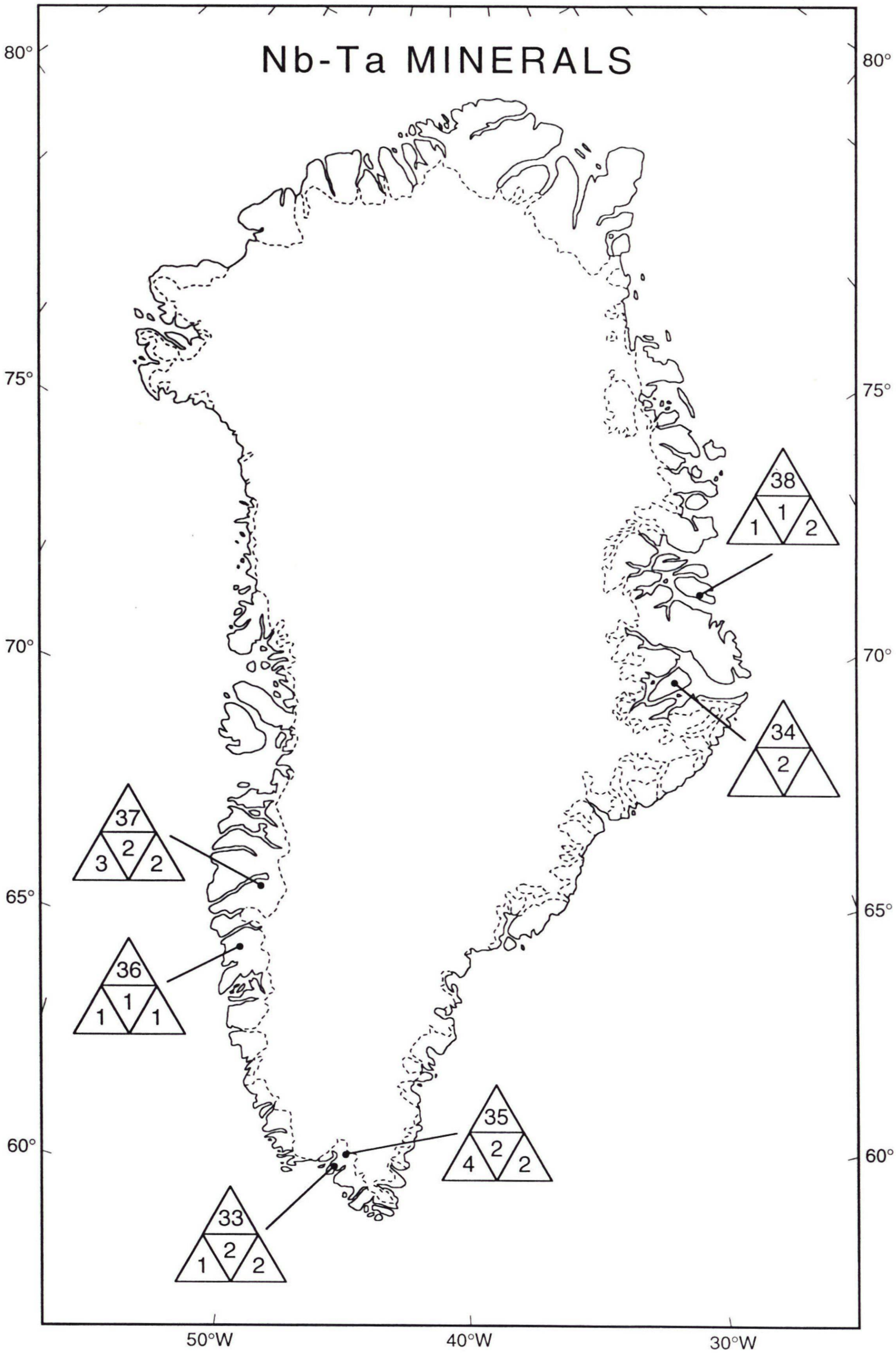


Fig. 14. Nb-Ta mineral occurrences: Ilímaussaq (33); Milne Land (34); Motzfeldt (35); Qaqarssuk (36); Sarfartoq (37) and Traill Ø (38).

## 2.13 Mica

### 2.13.1 No: 31 Qaqarssuk complex (65°30′N, 51°45′W), Maniitsoq, West Greenland (Fig. 13)

For a general description see section 2.16, Phospates.

Knudsen (1985) reported the occurrence of glimmerite at the Qaqarssuk complex, associated with the major carbonatite sheets. The rock is described as coarse-grained, brown to black in colour, consisting of phlogopite, amphibole, pyroxene, carbonate, apatite and magnetite. No quantitative data are reported. However, according to the maps (Knudsen, 1985) the glimmerite rock covers an area of approximately 4 $km^2$.

### 2.13.2 No: 32 Siggartartulik (63°00′N, 50°30′W), Qeqertarsuatsiaat, South-West Greenland (Fig. 13)

For a general description see section 2.7, Corundum.

"Phlogopitites" are rather common in the Siggartartulik area. However, the phlogopite typically constitutes stiff and kinked crystals; inclusions of feldspar and/or sappherine are common. No quantitative data are available (MDI A/S, 1991b).

## 2.14 Nb-Ta minerals

### 2.14.1 No: 33 Ilímaussaq intrusion (60°55′N, 45°45′W), Narsaq, South Greenland (Fig. 14)

In the Ilímaussaq alkaline intrusion, of the Gardar Province, Nb mineralisations are observed in numerous environments: (a) in the synenites (lujavrite) niobium is present as pyrochlore; (b) the metasomatised anorthosites and volcanics of the northern part of the intrusion host epistolite and murmanite; (c) in the layered kakortokites in the southern part of the intrusion Nb is associated with eudialyte according to Bohse et al., 1971, eudialyte grades about 0.4% $Nb_2O_5$). One of the units (unit +16) is reported to contain 5500 tonnes $Nb_2O_5$.

2.14.2 **No: 34 Milne Land** (70°40′N, 26°00′W), Scoresbysund, East Greenland (Fig. 14)

See section 2.21, Zirconium, Yttrium, and REE minerals, and section 3.6, Milne Land.

2.14.3 **No: 35 Motzfeldt** (61°15′N, 45°00′W), Narssarssuaq, South Greenland (Fig. 14)

The Motzfeldt Centre, part of the Gardar Province, constitutes a multiple syenite intrusion with a wide range of compositional characteristics. The centre is situated about 25 km to the east of Narssarssuaq, a high alpine area with summits reaching 1800 m. The centre was the subject of comprehensive geoscience research studies, organised by GGU, in the period between 1979 and 1986.

*In situ* differentiation in the outermost part of the intrusion gave rise to late peralkaline sheets of microsyenite, pegmatite, and alteration zones associated with Th-U-Nb-Ta-Zr-REE mineralisations; higher grades occur towards the margins and the roof (Tukiainen, 1986).

Pyrochlore is the predominant economic mineral, characterised by the enrichment of LREE, Ta, and U, and has marked compositional variations depending on the relative possition in the intrusion. The upper parts are enriched in Nb, U, and LREE, the lower parts enriched in Ta. The Nb resource within "minable rock volumes" of the microsyenite is estimated at 80 million tonnes grading 0.4-1.0% $Nb_2O_5$, and 0.01-0.03% $Ta_2O_5$, with an additonal 50 million tonnes from the alteration zones, grading 0.03-0.1% $Ta_2O_5$ (Tukiainen, 1986).

2.14.4 **No: 36 Qaqarssuk complex** (65°30′N, 51°45′W), Maniitsoq, West Greenland (Fig. 14)

For a general description see section 2.16, Phosphates.

The Qaqarssuk complex area was the subject of detailed exploration programmes by Kryolitselskabet Øresund A/S in the 1970s, and again became the focus of attention in the mid-1980s. According to Knudsen (1985) pyrochlore occurs in different rock types in the Qaqarssuk complex area. The bulk of the pyrochlore is associated with the magnetite-apatite-pyrochlore rock and with the glimmerite, and a minor part of the pyrochlore is hosted in the carbonatites and fenites. The pyrochlore is generally pure, although zoned crystals are common, and show compositional variations as a function of the enclosing rock type. No grade and tonnage figures are reported.

2.14.5 **No: 37 Sarfartôq** (66°30'N, 51°15'W), Kangerlussuaq, West Greenland (Fig. 14)

The Precambrian Sarfartôq carbonatite complex was emplaced, as a two stage intrusion in the boundery zone between the Archaean craton and the Nagssugtoqidian mobile belt. Hydrothermal activities gave rise to mineralisations in veins and shear zones (Secher, 1986); the pyrochlore mineralisation in the marginal zone of the intrusion is the most important economic zone. The complex is located 60 km SSW of Kangerlussuaq airport (formerly Søndre Strømfjord), and has outcrop area of 100 $km^2$.

The complex was discovered in 1975. Several programmes of investigation have been carried out headed by GGU in the late 1970s and by Hecla Mining Company in 1989; activities included detailed geological mapping, geophysics (airborne and ground), trenching and diamond drillings (13 core holes, 568 core metres).

The pyrochlore mineralisation occurs as massive replacement, thin veins and dissemination within the shear zones and gneisses. According to Druecker (1990) the diamond drilling programme on the Sarfartôq I Prospect proved a relatively wide and continuous low grade pyrochlore deposit (1-10% $Nb_2O_5$) enclosing lenses of high grade (>10% $Nb_2O_5$) material. The mineral resource of the drilled area (cut-off grade 10% $Nb_2O_5$) amounts to 25-30,000 tonnes $Nb_2O_5$.

2.14.6 **No: 38 Traill Ø** (72°20'N, 22°50'W), Scoresbysund, East Greenland (Fig. 14)

The Tertiary Kap Simpson complex, part of the Forchhammar syenite pluton, situated in eastern Traill Ø, was the subject of various exploration programmes carried out by Nordisk Mineselskab A/S and GGU in the early 1970s.

Harpøth et al. (1986) report *in situ* Nb mineralisation south-east of Bjørnedal, appearing as mineralised quartz veins within a 400 m long zone, situated a few hundred metres from the intrusive alkali syenite. The veins are sub-vertical and dominated by quartz, with minor oligoclase, chlorite, biotite, carbonate, zircon, leucoxene and various Nb-bearing minerals (columbite, euxenite, samarskite, fergusonite, monazite and bastnaesite). The largest vein is about 30 m long and 15 cm wide. Selected samples

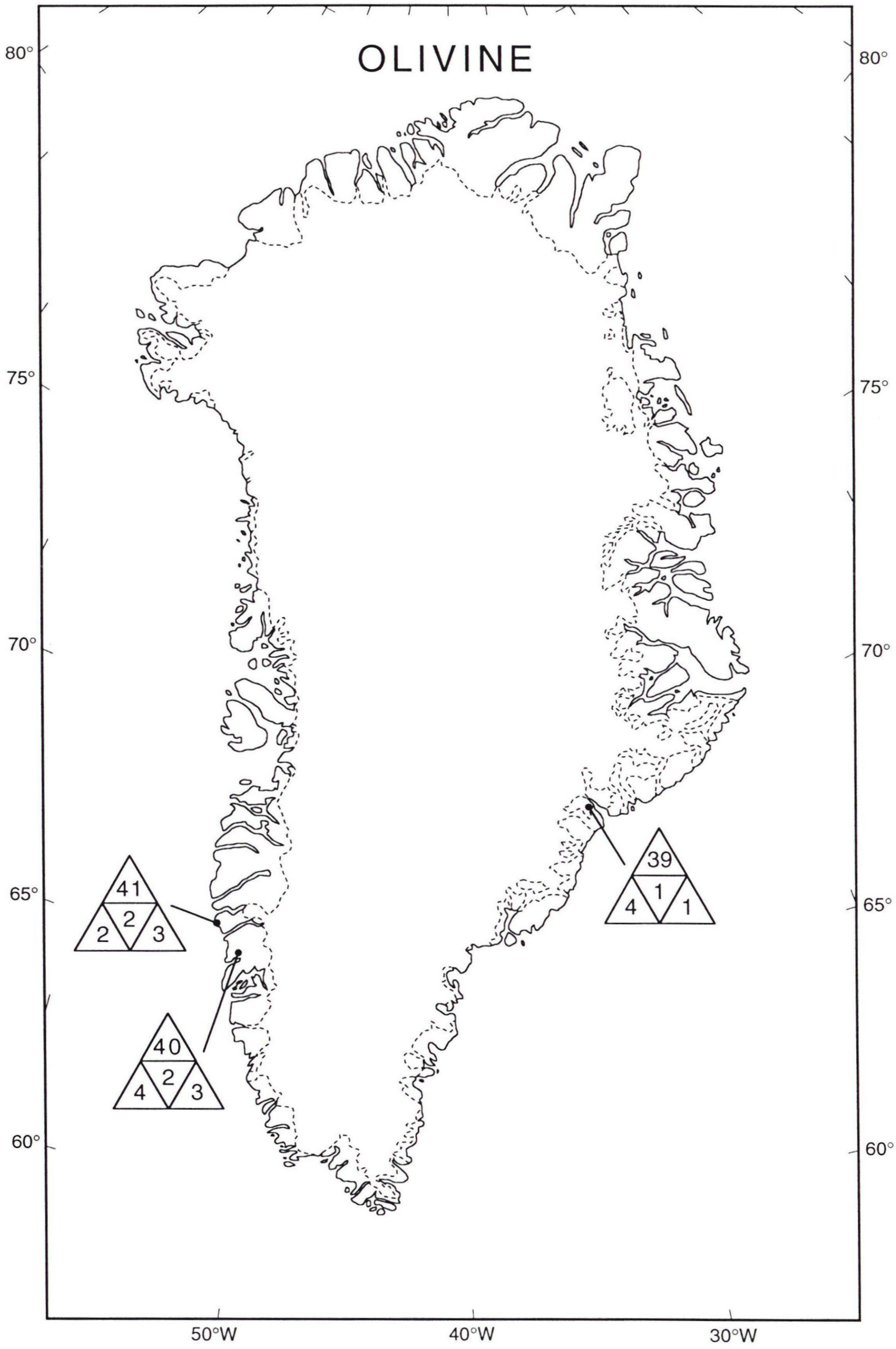


Fig. 15. Olivine occurrences: Gardiner complex (39); Itipilua (40) and Siorarsuit (41).

contain up to 3.2% Nb, 3% REE, 0.15% Be and 0.3% Y. The potential niobium content of the veins appears not to exceed 0.2% $Nb_2O_5$ (Harpøth et al., 1986).

## 2.15 <u>Olivine</u>

### 2.15.1 **No: 39 Gardiner complex** (68°35'N, 32°40'W), Ammassalik, central East Greenland (Fig. 15)

The Gardiner intrusion in the inner part of Kangerlussuaq, is part of the East Greenland Tertiary Province. This ultramafic intrusion consists of alternating rings of pyroxenite and dunite, and has an area of about 4 km$^2$, although about two thirds of the dunite are covered by ice. Frisch & Keusen (1977) report the central part of the dunites outcrops as being heavely altered due to metasomatism. The dunite consists of 70-97% olivine ($Fo_{90}$), 1-10% diopside, 0-8% phlogopite, 3-18% magnetite and 0-30% crysotile; accessory minerals include calcite, apatite and melilite. Serpentinisation has been weak. No qualitative or quantitative data are available.

### 2.15.2 **No: 40 Itipilua** (65°00'N, 51°35'W), Atammik, West Greenland (Fig. 15)

The Itipilua dunite is one of a series of Archaean ultrabasic intrusions outcropping in the Fiskefjord area. The body outcrops over an area of 1100 m by 450 m, situated between sea level and 140 m altitude. The intrusion is composed partly of dunite (s.s.), partly of peridotite rock, and contains rythmically layered chromite-rich horizons (see section 2.15 and 3.5), as well as some serpentinised zones. Erosion of the dunite has given rise to an accumulation of unconsolidated olivine rich sand adjacent to the intrusion.

Geological, geochemical, and geophysical exploration programmes were carried out in the 1970s, by Kryolitselskabet Øresund A/S. Five diamond drill holes were drilled to a maximum of 70 m.

The mineral assemblage constitutes: 75-85% olivine ($Fo_{92}$), 3-25% plagioclase, 1-5% diopside, 1-15% biotite/phlogopite, 0-10% serpentine and 1-3% opaque minerals; accessories include rutile, leucoxene, and apatite.

The measured mineral resource of dunite amounts to *c.* 52 million tonnes, and the additional mineral potential of the olivine sand is about 800,000 tonnes (Kalvig, 1992).

Further details are given in section 3.5.

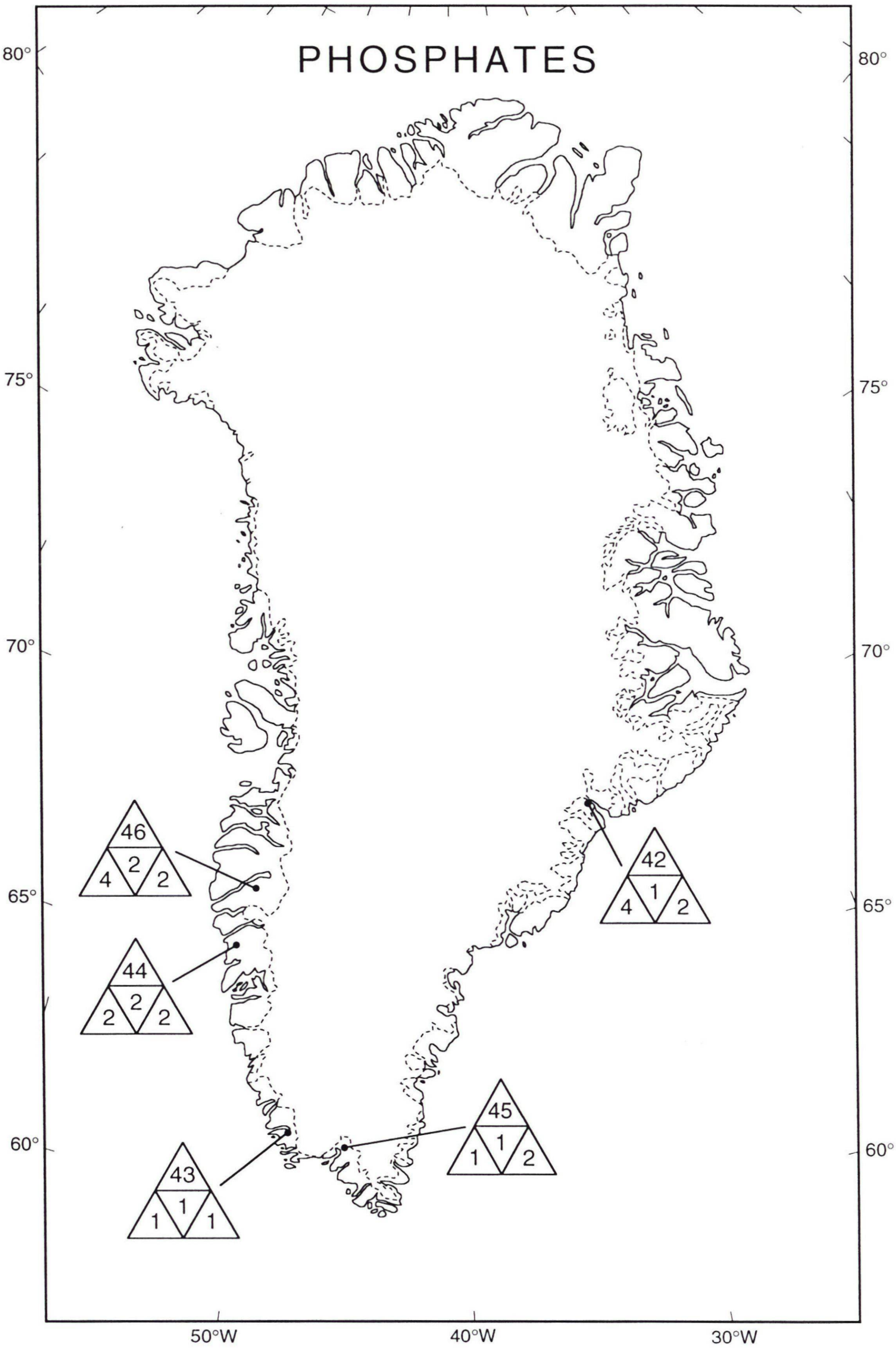


Fig. 16. Phosphate occurrences: Gardiner complex (42); Grønnedal-Ika (43); Qaqarssuk (44); Qassiarsuk (45) and Sarfartoq (46).

2.15.3 **No: 41 Siorarssuit** (65°15'N, 53°15'W), Kangaamiut, West Greenland (Fig. 15)

A small dunite intrusion occurs 10 km south of the settlement Kangaamiut, adjacent to the shoreline on the island Itilluip Qaqqaa. The composition of the dunite varies between dunite (s.s.) and peridotitic rocks. The coarse-grained dunite is composed of >80% olivine ($Fo_{92}$) with minor phlogopite, diopside, and hornblende; chromite is present as an accessory. Serpentinisation is observed locally (Kalvig, 1990).

The indicated mineral resource of dunite is 500,000 tonnes. Additionally, there is an estimated 30,000 tons of olivine sand (offshore and land-based) (Kalvig, 1990).

## 2.16 Phosphate

2.16.1 **No: 42 Gardiner complex** (68°35'N, 32°40'W), Ammassalik, East Greenland (Fig. 16)

The Tertiary Gardiner complex is characterised by ultramafic cumulates cut by concentric and radiating apatite bearing dykes.

Investigations of the complex have mainly been of a scientific nature. The mineral potential given in Table 2 is based on Knudsen (1985).

Table 2. Phosphate mineral potential within the Gardiner intrusion (after Knudsen, 1985)

| Rock type | Depth (m) | Length (m) | Widths (m) | $P_2O_5$ (Wt%) | Mineral potential (mio. tonnes) |
|---|---|---|---|---|---|
| Apatite-phlog. dyke | 300 | 2500 | 8 | 10 | 55 |
| Pyroxenite | 200 | 1200 | 200 | 5 | 144 |
| Metasom.zone | | | | 3 | 375 |
| Afrikandite | | | | 5 | 2,500 |

2.16.2 **No: 43 Grønnedal-Ika** (61°14′N, 48°03′W), Grønnedal, South-West Greenland (Fig. 16)

The Grønnedal-Ika syenite complex belongs to the Gardar Province. It covers an area of about 9 by 3.5 km, and comprises nepheline syenite penetrated by a central stock of carbonatite and breccia. Inside a marginal zone of brecciated and altered foyaite, sövite passed inwards to a siderite-rich core hosting sphalerite, apatite, Sr-baryte and REE (Emeleus & Upton, 1976); siderite is the main carbonate (Bondam, 1992a).

Exploration on the carbonatites was carried out in the late 1940s and again in the late 1980s, and included magnetic ground surveys and drilling (6 holes totalling 750 m). The drilling proved the presence of one carbonatite hosting magnetite and one hosting siderite only, intersected by younger dykes; apatite is unevenly distributed (Bondam, 1992a). According to Bondam the phosphorous content varies between 0.5 and 1.6% P; selected values for Sr, Ba, Y, and La are reported to assay 2.6%, 500 ppm, 0.06% and 0.2% respectively.

2.16.3 **No: 44 Qaqarssuk complex**, (65°30′N, 51°45′W), Maniitsoq, West Greenland (Fig. 16)

The Qaqarssuk carbonatite complex is situated about 55 km east of Maniitsoq, and 20 km from the coast. It forms a concentric, steep dipping ring dyke structure (3.5 km by 5 km) enclosed in Precambrian gneisses. Carbonatites appear as dykes and veinlets, ranging in width from centimetre scale to more than 10 m. Calcite and dolomite are the main constituents, with phlogopite, magnetite and apatite as accessories. The phosphate in the complex is almost entirely contained in fluor-apatite (Knudsen, 1985).

Exploration programmes were carried out between the early 1960s and late 1980s by Kryolitselskabet Øresund A/S, GGU, and universities (funded by EEC), and included mapping, diamond drilling (shallow and deep holes), geochemistry, and geophysics (magnetic, radiometric, seismic).

Table 3. Mineral resource figures on phosphate within the Qaqarssuk complex intrusion (based on Knudsen, 1985)

| Rock-type | Grade $\%P_2O_5$ | Resource mio. tonnes |
|---|---|---|
| Silico-søvite | 3.5 | 3.0 |
| Rauhaugite | 3.4 | 0.8 |
| Apatite-magnetite-pyrochlore | 8.6 | 0.8 |

Estimates on the mineral resources, down to 200 m below surface, are given in Table 3.

2.16.4 **No: 45 Qassiarsuk** (61°10'N, 45°32'W), Qassiarsuk, South Greenland (Fig. 16)

In the Qassiarsuk area a sequence of clastic sediments, lavas and pyroclastic rocks of the Eriksfjord Formation overlying the crystalline basement, is cut by numerous carbonatite and lamprophyre dykes and sills. The predominant phosphor bearing mineral of the area is a fluor-apatite characterised by fairly low lanthanide values. Average phosphate grades are about 4% $P_2O_5$, although peak values up to about 35% $P_2O_5$ are observed (Knudsen, 1985). No figures on the mineral potential are available.

2.16.5 **No: 46 Sarfartôq**, (66°30'N, 51°15'W), Kangerlussuaq, West Greenland (Fig. 16)

For general description see section 2.14, Nb-Ta Minerals.

The rauhaugite is the main source of phosphate, due to the content of fluor-apatite, averaging about 3.5 wt% $P_2O_5$. The grade seems to increase in the exterior parts of the core (Knudsen, 1979). The rauhaugites occur as sheets with thicknesses ranging from 2 to 30 m and traceable up to 500 m along strike. According to Knudsen (1985) the estimated mineral potential, when calculated to a depth of 100 m, yields about 500 million tonnes of rauhaugite, grading 3.5 wt% $P_2O_5$, and after deduction of non-mineable parts the estimate yields about 100 million tonnes of rock.

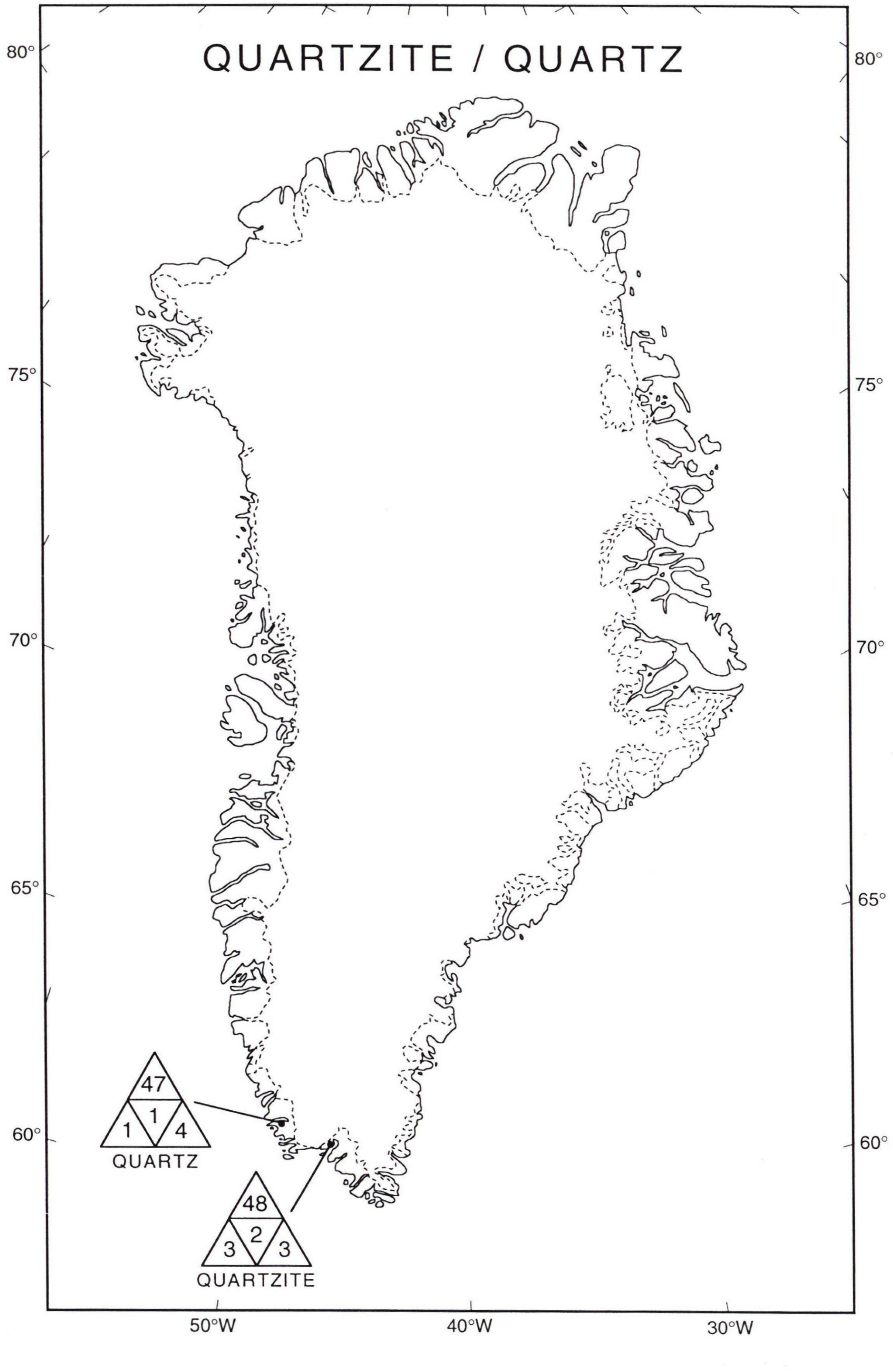


Fig. 17. Quartzite and quartz occurrences at Narsaq (48) and Ivittuut (47) respectively.

## 2.17 **Quartzite/quartz**

### 2.17.1 **No: 47 Ivittuut** (61°12′N, 48°12′W), Arsuk, South-West Greenland (Fig. 17)

For general information, see sections 2.8 and 3.3, Cryolite.

The lowermost part of the now flooded cryolite pit, at depths between 80 m and 150 m consists of pegmatitic quartz layered occasionally with siderite-rich horizons. Chemical analysis of the crude quartz indicates a high grade quality; the lowerpart of the cryolite deposit is reported to contain about 6 million tonnes of quartz (Bondam, 1991). Beneficiation tests have not been performed.

### 2.17.2 **No: 48 Narsaq** (60°54′N, 46°04′W), Narsaq, South Greenland (Fig. 17)

A quartzite occurrence is situated adjacent to the shoreline *c.* 2 km SE of the settlement Narsaq, and is part of the Proterozoic Eriksfjord Formation. The dominant rock varies between meta-sandstone and quartzite, and is widely distributed in the Narsaq area.

Exploration was carried out at Narsaq in the period between 1984 and 1987 by A/S Carl Nielsen on behalf of the municipality, and encompassed geological mapping, chip-sampling, geochemistry, laboratory tests, and five shallow diamond drill holes (Frederiksen, 1986). A pit-design study, including the quartzitic and easy-mineable parts was performed, reporting estimated mineral resource figures amounting to 1.3 million tonnes (Kalvig & Schneider, 1988). Additional substantial mineral potentials are situated in the adjacent eastern area.

Laboratory tests on the quartzite proved quality suitable for use as a road metal and for use as high quality aggregate. About 5000 tonnes of quartzite aimed at full-scale tests were quarried in 1988; however, the tests were not carried out and hence quarried quartzite is still available at the site. The potential market areas for use as raw material for the non-coloured glass industry, and as fluxes for the ferrosilicon industry failed due to the content of iron and alkalies respectively.

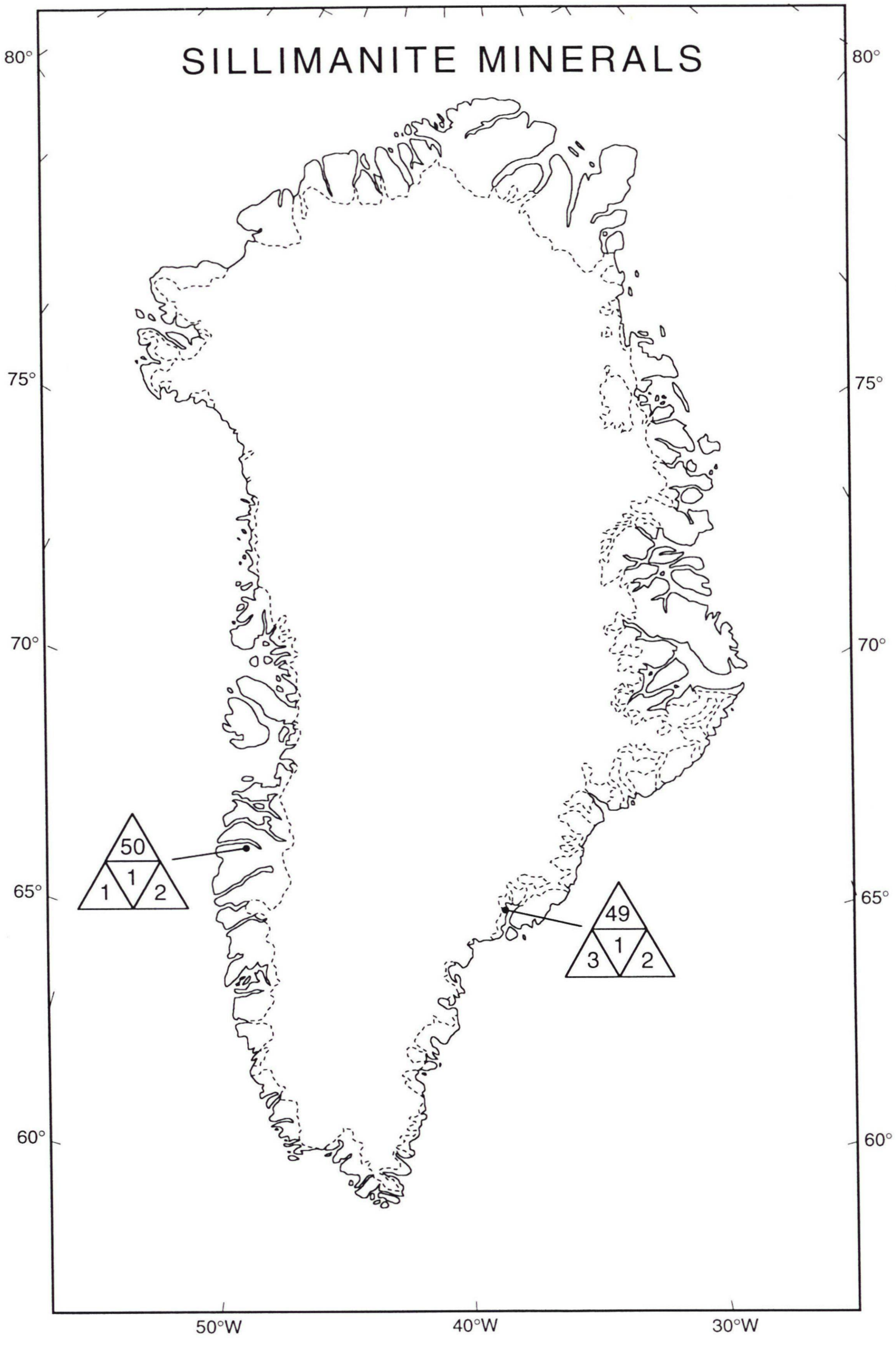


Fig. 18. Sillimanite mineral occurrences: Augpalugtoq (49) and Nordre Isortoq (50).

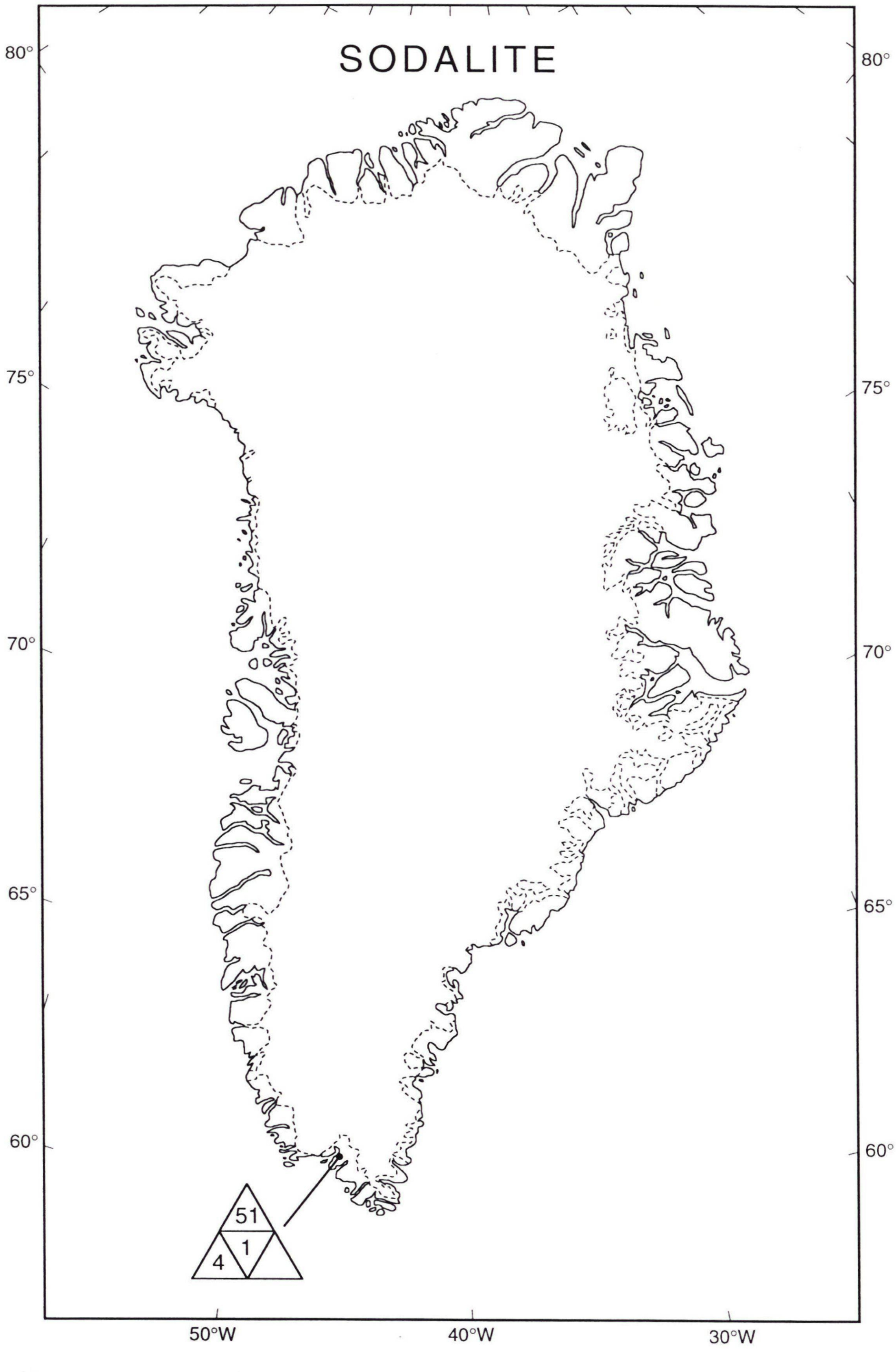


Fig. 19. Sodalite occurrence at Ilímaussaq, Narsaq.

## 2.18 <u>Sillimanite minerals</u>

### 2.18.1 **No: 49 Augpalugtoq** (66°06'N, 37°57'W, Tiniteqilaaq, East Greenland (Fig. 18)

Kyanite occurrences are reported from Augpalugtoq, Suportoq, and from the northern part of Ammassalik Fjord associated with biotite-garnet(-graphite) schists. The occurrence at Augpalugtog has been explored by GGU, and the the kyanite zone is described as being about 100 m wide and at least 4000 m long, hosted in a coarse grained garnet-kyanite-biotite schist (F. Kalsbeek & T. F. D. Nielsen, personel communication, 1989). Based on the test of a few samples the kyanite appears as 1 to 8 mm poikilitic grains, grading about 14-20 vol%, thus forming a low grade deposit.

### 2.18.2 **No: 50 Nordre Isortoq** (67°15'N, 53°00'W), Sisimiut, West Greenland (Fig. 18)

Pre-Nagssugtoqidian supracrustal units, dominated by garnet-biotite-sillimanite (-graphite-) gneisses and schists, are aboundant in the area bounded by Agto and Sisimiut. High grade sillimanite occurrences are mainly confined to hinge zones of folds. One major hinge zone at Nuanialaq at an altitude of 740 m, outcrops at a 250 by 100 m area and grades up to 30 vol% sillimanite. The sillimanite appears as individual prismatic grains (0.01-1.0 mm) and as millimetre-sized sillimanite aggregates, associated with garnet (pyrope/almandine), plagioclase, quartz, biotite and orthopyroxene with accessory graphite, sphene and opaque minerals. Although numerous sillimanite occurrences were observed during a reconnaissance programme, no commercial sized sillimanite potentials were localized (A/S Carl Nielsen, 1988).

## 2.19 <u>Sodalite</u>

### 2.19.1 **No: 51 Ilímaussaq** (60°55'N, 45°45'W), Narsaq, South Greenland (Fig. 19)

The Ilímaussaq intrusion, part of the Gardar Province, consists of various nepheline syenites, one of which is a naujaite hosting sodalite. Recent development work by Mineral Development International A/S has brought sodalite into focus for use as precursor for zeolites. The Ilímaussaq intrusion has been the subject of numerous research and exploration programmes since the 1960s, carried out by universities, GGU, and mining

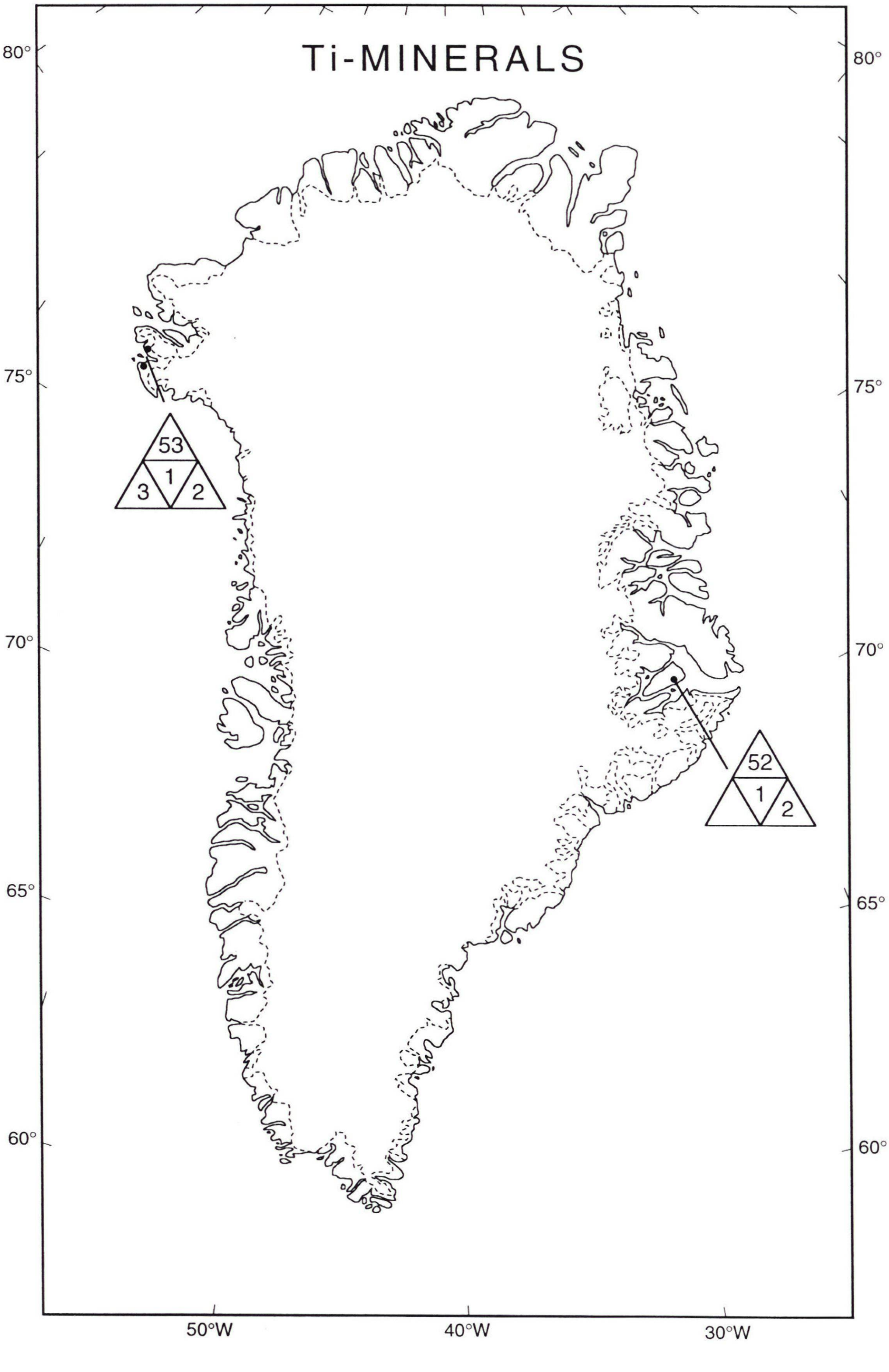


Fig. 20. Ti-mineral occurrences: Milne Land (52) and Thule Air Base (53).

companies. Studies have encompassed mapping, geochemistry, geophysics, and several drilling operations.

Sodalite is well known from a number of rock types represented within the intrusion, but compared to the naujaite many of these rocks have a considerably lower sodalite content and contain impurities in the form of felt-like needles of Na-pyroxene. The indicated mineral resource of the naujaite within a minor part of the southern part of the intrusion is in excess of 50 million tonnes grading about 50% sodalite. No data are available from the northern part of the intrusion.

## 2.20 Ti-minerals

### 2.20.1 **No: 52 Milne Land** (70°40′N, 26°00′W), Scoresbysund, East Greenland (Fig. 20)

See section 3.6, Zr, Y and REE minerals.

### 2.20.2 **No: 53 Thule Air Base** (77°35′N, 68°48′W) **and Moriusaq** (76°48′N, 70°00′W), Thule, North-West Greenland (Fig. 20)

The Thule black sand province extends along the coastline between Kap Alexander in the north and Kap Edward Holm in the south (Dawes, 1989). Several exploration programmes have been carried out in the region by private companies and GGU, focusing on the black sands.

The heavy mineral sands are observed on both active and raised beaches, the latter dominated by alluvial and littoral deposits forming the outer coast. The width of the raised beaches varies, but reaches 1 km at Moriusaq and about 3 km in the immidiate vicinity of Thule Air Base/North Star Bugt; at both sites the beaches stretch for tens of kilometres. The sands are concentrated in lenticular bodies up to 0.5 m thick, containing about 75 wt% ilmenite (Dawes, 1989). Sampling has been confined to the non-permafrost layer (< 1 m). The ilmenite resource at Thule Air base is deemed most promising (Dawes, 1989). However, around the settlement Moriusaq, the mineralised raised beaches carry a large tonnage potential grading about 12% $TiO_2$ (13 samples) (Greenex pers. commun. 1989). The active beaches in the region are up to 10 m wide and grade about 43% $TiO_2$ (Dawes, 1989). The potential byproducts rutile, monazite, zircon etc. are not present in economically interesting amounts in either the active or raised beaches. The ilmenite is considered to originate from the erosion of basaltic sills and dykes (Dawes, 1989).

Table 4. Chemical composition of ilmenite in black sand from Moriusaq. Main element analysis based on one sample (Dawes, 1989); trace elements analysis based on 16 samples (Greenex, pers. comm., 1989)

| Major elements | | Minor elements | | | |
|---|---|---|---|---|---|
| | % | | ppm | | ppb |
| $SiO_2$ | 1.0 | Ce | 39 | Au | <20 |
| $Al_2O_3$ | 0.4 | Cr | 543 | Pt | <20 |
| $TiO_2$ | 45.5 | Cu | 27 | Pl | <20 |
| $Fe_2O_3$ | 38.8 | V | 1905 | | |
| MgO | 0.9 | Zr | 835 | | |
| MnO | 0.6 | | | | |
| CaO | 0.1 | | | | |
| $Cr_2O_3$ | 0.1 | | | | |
| $V_2O_3$ | 0.4 | | | | |

The ilmenite and magnetite bearing black sands observed at Sonntag Bugt and Kap Edvard Holm are not thought to be extensive (Dawes, 1979).

## 2.21 <u>Zirconium, yttrium, and REE minerals</u>

### 2.21.1 **No: 54 Ilímaussaq** (60°55'N, 45°45'W), Narsaq, South Greenland (Fig. 21)

A repeated sequence of three kakortokite rock types constitute the southern part of the Ilímaussaq intrusion, which belongs to the Gardar Province; each unit can achieve thicknesses of up to 3 m. The kakortokite is a nepheline syenitic rock, consisting mainly of alkali feldspar, nepheline, alkali amphibole, and the Zr-Y-REE-Nb bearing mineral eudialyte $(Na,Ca,Fe)_6Zr[(OH,Cl)(Si_3O_9)_2]$ (Bohse et al., 1971). Ca is partly replaced by

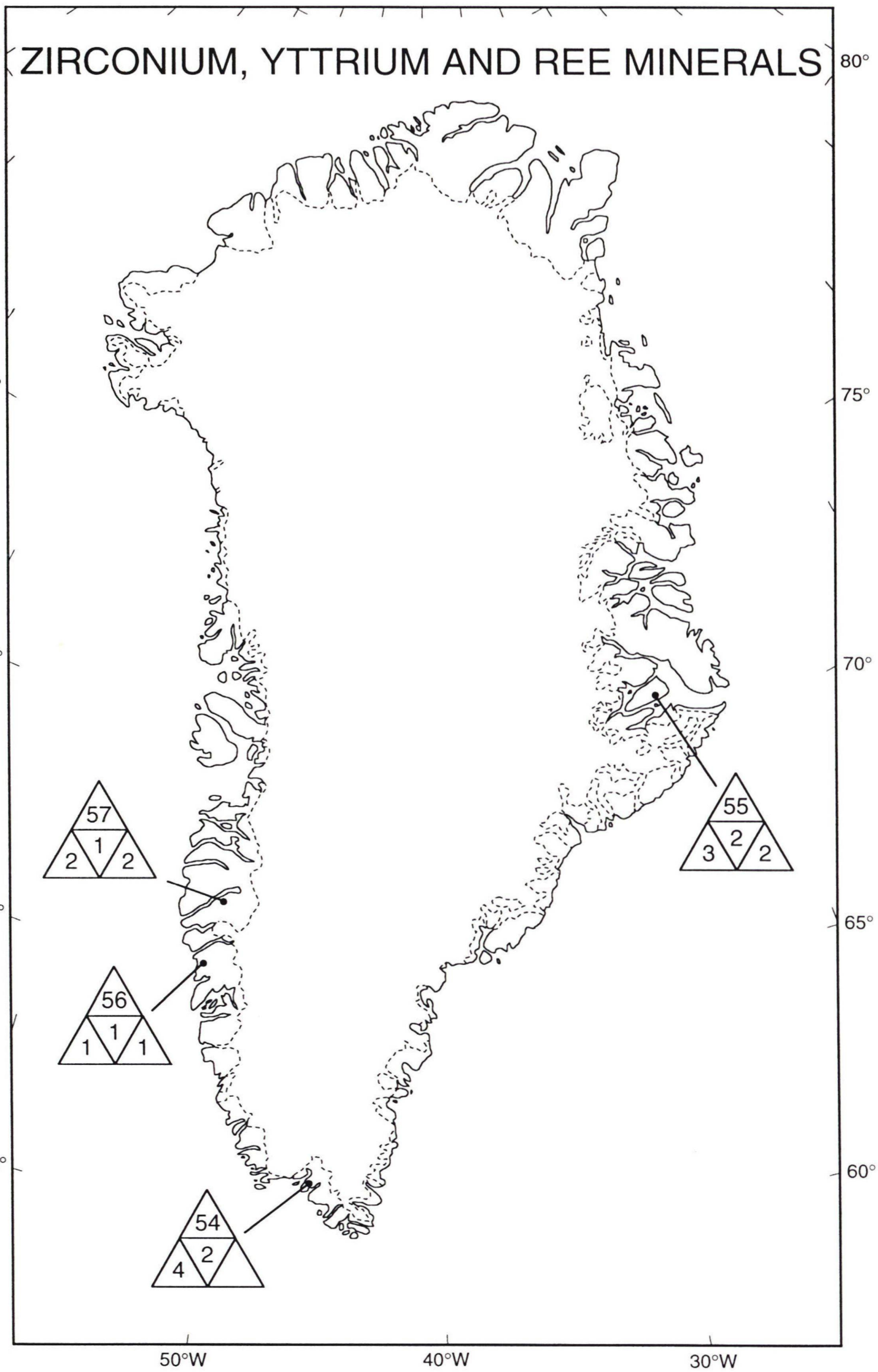


Fig. 21. Zirconium, yttrium and REE mineral occurrences: Ilímaussaq (54); Milne Land (55); Qaqarssuk (56) and Sarfartoq (57).

REE and Y, and Fe by Nb. The acid soluble eudialyte is a potential alternative source of Zr (13.3%), Y (0.4%), Nb (0.9%) and REE (2.2%).

Numereous exploration programmes have been carried out since the 1950s, by GGU, research institutions, universities, and mining companies (Kryolitselskabet Øresund A/S, Superfos A/S, A/S Carl Nielsen, Highwood Resources, Platinova and Mineral Development International A/S). The programmes encompassed geological mapping, chip-sampling, bulk-sampling, geochemistry, geophysics, diamond drilling, ore beneficiation studies and ceramic powders studies; references are given by Kalvig (1983).

Recently four potential mining areas have been outlined, situated between sea level and 600 m a.s.l. The measured mineral resources from Area 1 is 30,000 tonnes $ZrO_2$, grading 3.6% $ZrO_2$. The mineral potential of Area 2 and Area 4 amount to respectively 11,000 tonnes $ZrO_2$ grading 2% $ZrO_2$, and 16,000 tons $ZrO_2$ grading 2% $ZrO_2$ (Frederiksen, 1988). The sites are suited for open-pit mining techniques.

An additional mineral potential of REE is located in the Kvanefjeld area, constituing the northern part of the Ilímaussaq intrusion, and amounts to 1.1 million tonnes (Kalvig, 1983).

2.21.2 **No: 55 Milne Land** (70°40′N, 26°00′W), Scoresbysund, East Greenland (Fig. 21)

A palaeoplacer is situated in the basal part of the Jurassic Charcot Bugt Formation, representing a marine transgression over deeply eroded crystalline basement. The palaeoplacer is dominated by cross-bedded sandstones and sedimentary breccia, and hosts anatase, rutile, zircon, xenotime, monazite and garnet (Harpøth et al., 1985); it is a potential source of Ti, Nb, Ta, Zr, Y, La and Ce. The mineral occurrence is situated 15 km from the coast at about 800 m altitude.

Occasional exploration programmes were carried out between the early 1970s and mid 1980s, mainly by Nordisk Mineselskab A/S. Exploration activities in the early 1990s were carried out jointly by Nordisk Mineselskab, Nunaoil A/S and Coffs Harbour Rutile N.L. These encompassed mapping, surface grid sampling, geochemistry, geophysics, shallow diamond drilling (8 holes; total of 127 m), and metallurgical tests (Harpøth, 1988; Ross, 1992).

According to Harpøth (1988) the indicated mineral resource yields about 3.7 million tonnes grading 2.6% anatase, 1.1% zircon, 0.03% xenotime, 0.5% monazite and 3.1%

garnet. The heavy mineral fractions are rather fine-grained. One third of the mineral resource is regarded as open-pit minable.

Harpøth (1988) reported the presence of a potentially very large palaeoplacer in the near vicinity. At the present time, however, this occurrence is not been covered by any exploration programmes.

For further details, see section 3.6.

2.21.3 **No: 56 Qaqarssuk complex** (65°30′N, 51°45′W), Maniitsoq, West Greenland (Fig. 21)

For general description see section 2.16, Phospates.

According to Knudsen (1985) the lanthanide-rich carbonatites of the Qaqarssuk complex are localised as veins in the core of the complex; the veins extend for up to 100 m varying in thicknesses from a few millimeter to 4 metres. The rock is composed of calcite, dolomite, strontianite, quartz, and aggregates of intergrown alstonite (Sr-Ba carbonate) and ancylite (Sr-lanthanide carbonite); the ancylite is the main contributor of light lanthanides; additionally huanghoite (Ba-lanthanide carbonate) and burbankite (Na-,Ca-, lanthanide carbonate) have been observed as well as some sulphides. Enrichment of the light lanthanides are also present in ultramafics and fenitic rocks. Some chemical assays on the La-rich carbonatites (four samples) are given by Knudsen (1985) (all values in ppm): 0.1-15.4 $La_2O_3$; 0.3-26.6 $Ce_2O_3$; 0.5-0.8 $Pr_2O_3$; 0.3-5.0 $Nd_2O_3$; 0.1-0.4 $Sm_2O_3$ and 0.03 $Y_2O_3$.

2.21.4 **No: 57 Sarfartôq** (66°30′N, 51°15′W), Kangerlussuaq, West Greenland (Fig. 21)

For general description see section 2.14, Nb-Ta Minerals.

Secher (1986) observed increased values of REE at several localities within the Sarfartoq complex. Radioactive shear zones in the marginal part of the complex show concentrations of up to 0.5% LREE, with outstanding high Eu values (up to 236 ppm). However, these types of mineralisations are not very common. Hydrothermal veins, scattered throughout the complex, consist of dolomite and REE-carbonate which carry up to 7% REE, mainly La and Ce; the veins do not appear to be of economic importance (Secher, 1986).

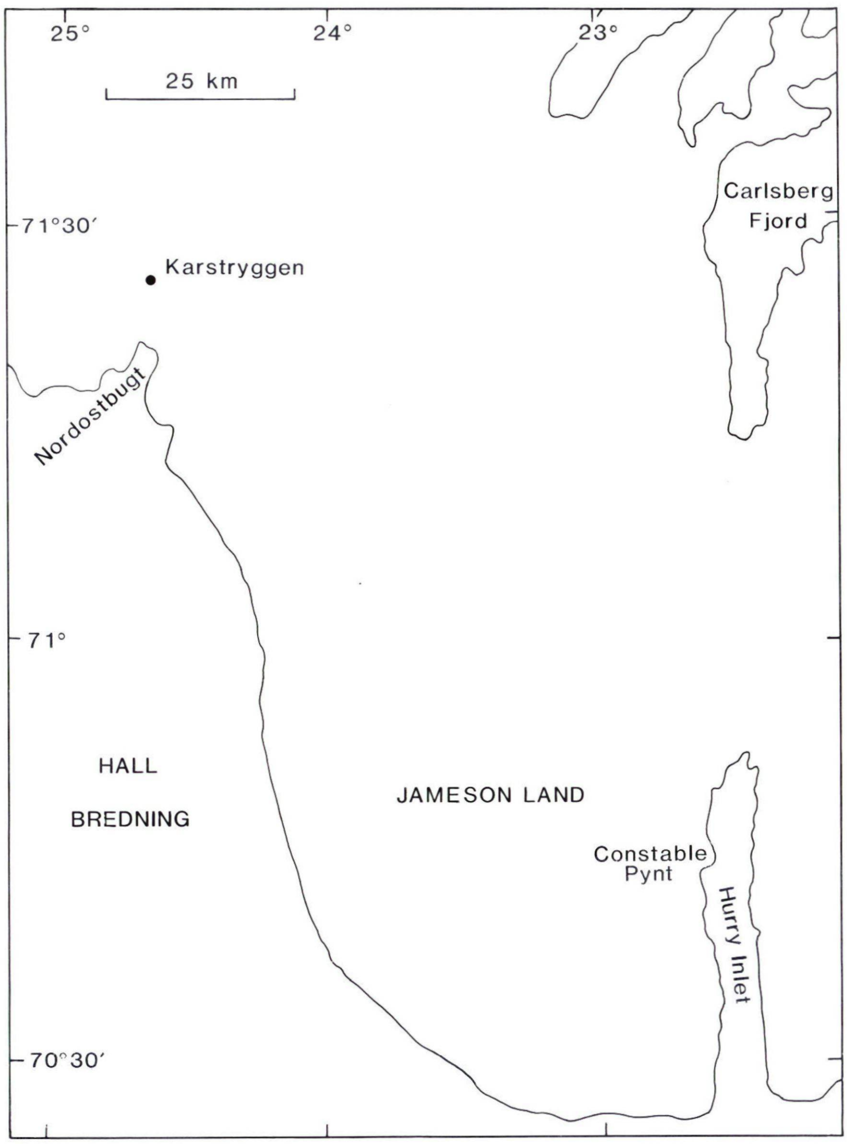


Fig. 22. Locality map showing the position of the Karstryggen celestite occurrence.

# 3. SELECTED OCCURRENCES

## 3.1 Celestite, Karstryggen, East Greenland

### 3.1.1 **Introduction**

The Karstryggen celestite occurrence is situated on the west side of the Jameson Land Basin about 10 km north of Nordostbugt (Fig. 5, 22). It has an area of about 80 km$^2$ with a N-S length of 20 km and an E-W with of 8 km from the head of Revdal to Muslingeelv. The occurrence is situated at altitudes of 850-1000 m. Access to the site is possible by chartered aircraft from Iceland to Constable Pynt, and from there by chartered helicopter. The flight distance between Constable Pynt and site is about 90 km. The fjord is navigable for ice-strengthened vessels during a two months period in the late summer. No infrastructural facilities are available.

The celestite occurrence was discovered by Nordisk Mineselskab A/S in 1980, and has been the subject of several seasons of geological exploration activities, encompassing geological mapping, sedimentological studies and chip-sampling. Studies have included participants from the University of Copenhagen.

### 3.1.2 **Geological description**

The most recent and comprehensive geological description of the celestite mineralisation is that given by Scholle et al. (1990), which forms the basis of the descriptions below.

The celestite is hosted by the Upper Permian Karstryggen and Wegener Halvø Formations, both overlying the Huledal Formation conglomerates and the Lower Permian basement, cf. Fig. 23 and Fig. 24.

The Karstryggen Formation consists of 20-150 m of complexly interbedded limestones, breccias and evaporites. Karstification and fluviatile channelling are intense. The main occurrences of celestite are confined to the limestones in the proximity of the evaporites, replacing calcite, dolomite and gypsum. Replacement celestite is widespread in the Revdal-Huledal areas, grading 15-30% $SrSO_4$ over several metres. In addition celestite occurs as cement in algally laminated limestones, and as local lenses and veinlets related to the karst structures.

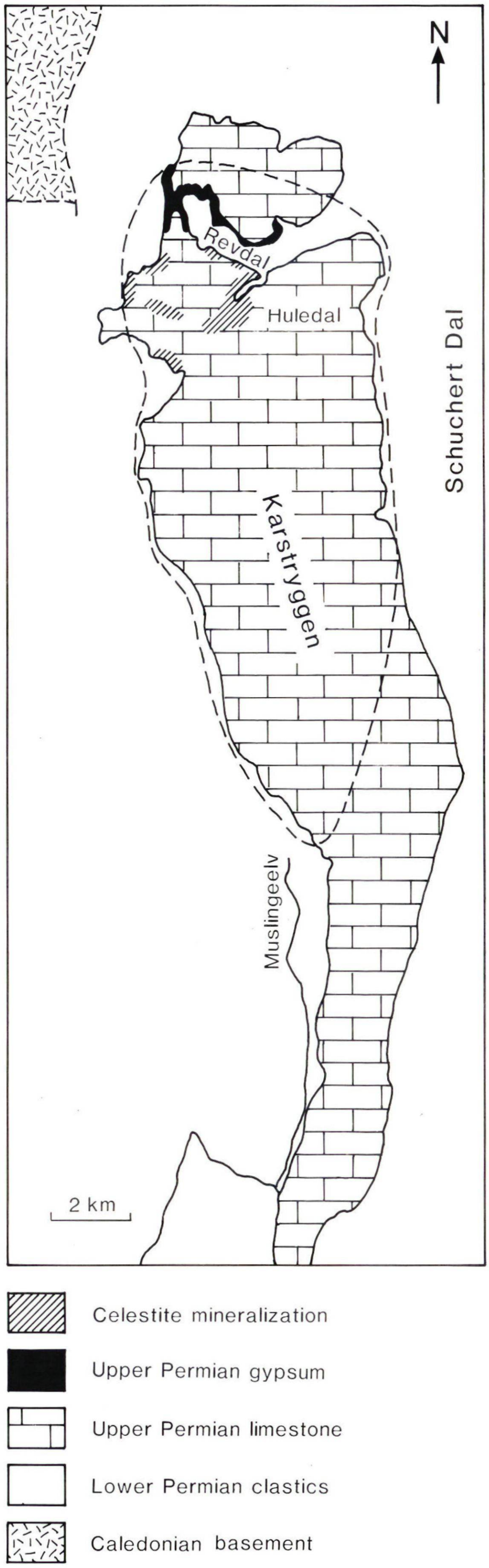


Fig. 23. Simplified geological map of the Karstryggen area (from Scholle *et al.*, 1990).

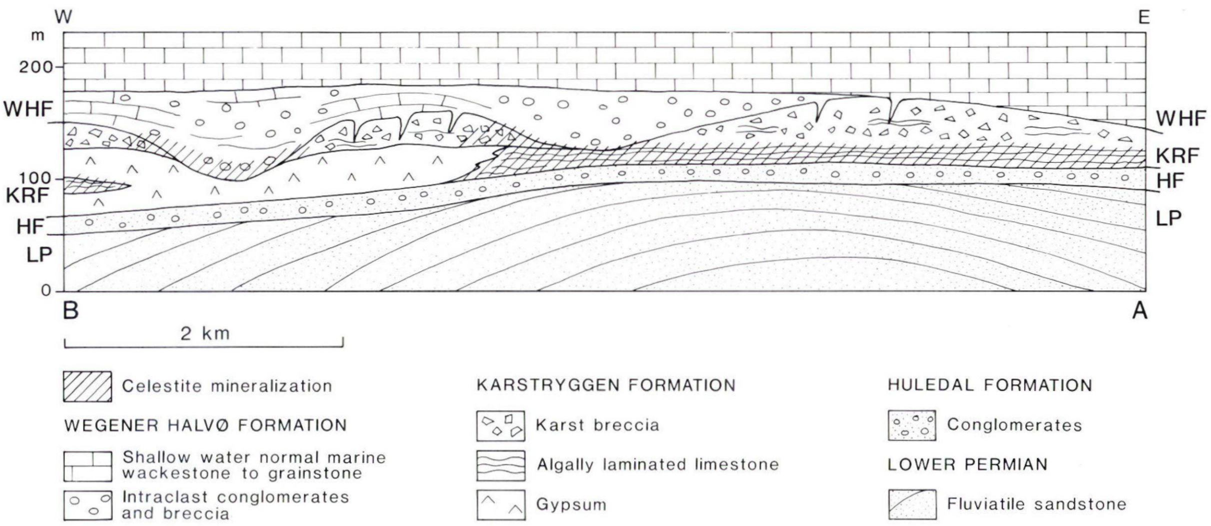


Fig. 24. Simplified stratigraphical section of the Karstryggen and Huledal Formations (from Scholle *et al.*, 1990).

The Wegener Halvø Formation consists of 10-200 m of karst related limestone conglomerates, sandstones, and an upper section of up to 200 m of marine limestone. The basal part of the formation is dominated by polymict limestone conglomerates and karst breccias cut into the Karstryggen Formation. Celestite occurs as replacement celestite (replacing algally laminated limestone), as cement in karst breccies and as veins and cave fillings in karst fractures, the latter being the most prominent; vein thickness are mainly in the range 5-20 cm. Veins are observed more than 50 m above the base of the formation. No prevailing direction of the veins has been observed. The intensity of the mineralisation in the Karstryggen area varies considerably, both vertically and laterally, from close to zero to large bodies grading 50-60% $SrSO_4$. In addition, massive bodies (up to 100 m x 20 m) occur, grading up to 90% $SrSO_4$.

### 3.1.3 **Technical data**

The exploration programmes encompassed geological mapping, scattered chip-sampling, and sedimentological studies. No drilling or geophysics has been undertaken.

Table 5. Mineral potential of celestite at Karstryggen

| Area | Average grade % $SrSO_4$ | Average area $km^2$ | Case 1 ($\times 10^6$ t) | Case 2 ($\times 10^6$ t) | Case 3 ($\times 10^6$ t) |
|---|---|---|---|---|---|
| 1 | 50 | 0.3 | 15 | 8 | 4 |
| 2 | 50 | 0.9 | 56 | 28 | 14 |
| 3 | 50 | 1.3 | 80 | 40 | 20 |
| 4 | 20 | 4 | 240 | 120 | 60 |
| 5 | 20 | 4 | 60 | 36 | 12 |
| Total | 30 | 10.5 | 466 | 232 | 110 |

Table 5 shows the mineral potential calculations based on Harpøth (1981). Case 1, 2 and 3 are based on average thicknesses of 20, 10 and 5 m respectively; except for area 5 which represents thicknesses of 5 m, 3 m, and 1 m. Average density applied is 3 $g/cm^3$.

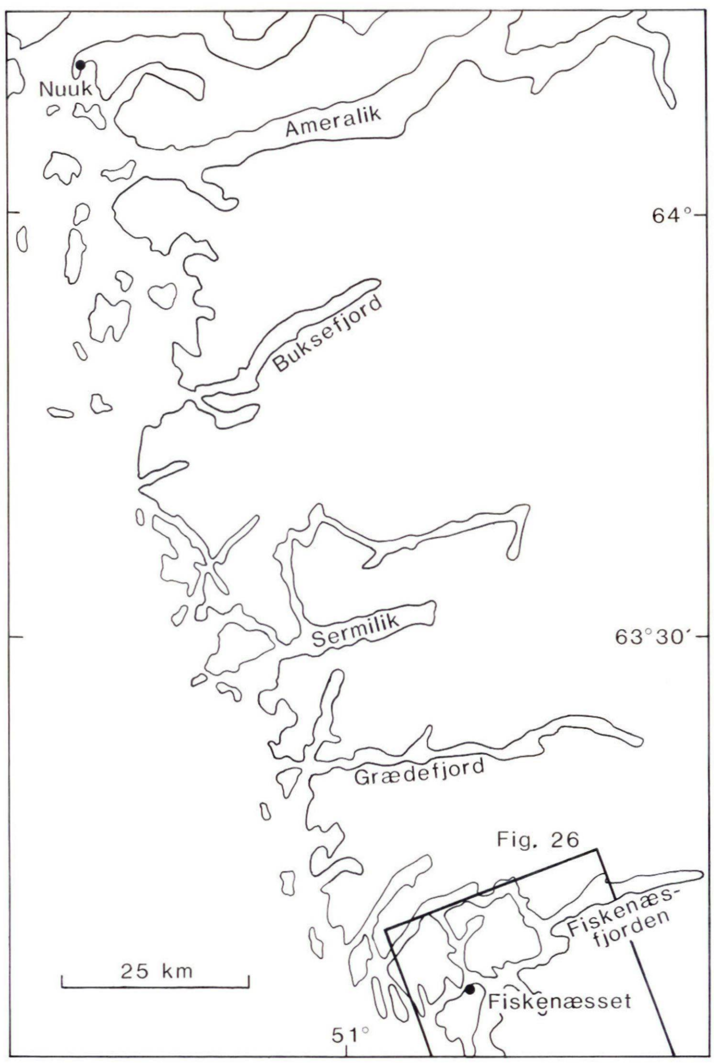


Fig. 25. Locality map showing the location of the Fiskenæsset chromite occurrence. The outline of the Fig. 26 is indicated on the figure.

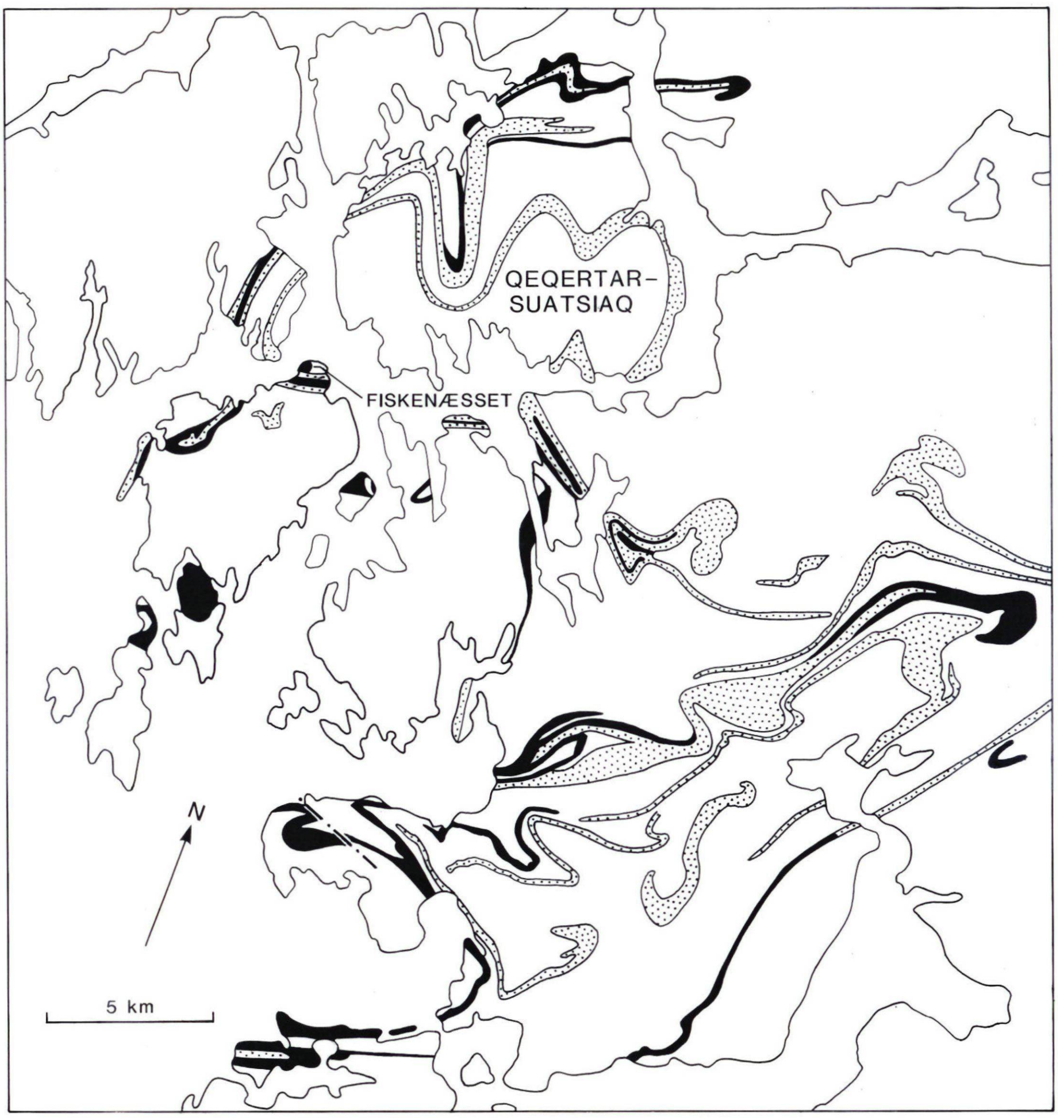


Fig. 26. Simplified geological map of the western part of the Fiskenæsset region indicating the amphibolites (black) and anorthosites with related rocks (dotted) (from Ghisler, 1976).

The indicated mineral potential of the celestite potential in the Revdal-Huledal area is given by Harpøth (1981). The calculations are based on visual inspections of outcropping mineralisation and scattered chip-sample analyses (along the cliff-sides), in combination with volume estimate achieved by simple trigonometric interpretations of the topographic map along with geological observations. For calculation purpose, the area was subdivided into five smaller areas.

According to Stemmerik (personel communication, Sept. 1993) the majority of the resource is thought to belong to the Karstryggen Formation. The results are shown in Table 5. These figures show that the Karstryggen celestite occurrence can be classified as a large tonnage, low grade, celestite resource.

Remarks on potential mineral production. In the Huledal-Arkosedal area the resource is covered by 25-75 m of overburden. The fine-grained ore may cause recovery problems. According to analytical results on 15 samples from the Karstryggen area, the ore material seems to fullfill commercial requirements, containing low barium, low fluorine and low alumina; silica, however, varies between 0.1% and 10.4% ($SiO_2$) (Scholle et al., 1990).

## 3.2 Chromite, Fiskenæsset, West Greenland

### 3.2.1 **Introduction**

The Fiskenæsset chromite occurrences are found over a wide area north-east of the settlement Fiskenæsset [Qeqertarsuatsiaat], within close proximity to navigable fjords; one of the major horizons are located about 8 km N-E of Fiskenæsset, at the island Qeqertarssuatsiaq (Fig. 6, 25, 26). Topographical variations of the region range up to *c.* 300 m, and in the eastern parts of the region to 1000 m. No infrastructural facilities are available. The site can be reached by chartered helicopter (about 10 minutes flight from Fiskenæsset or 1 hour flight from Nuuk), or by chartered boat. Fiskenæsset can easely be reached by ship from the capital, Nuuk, *c.* 150 km to the north.

Between 1968 and 1983 Platinomino Ltd held an exploration licence, and in 1990 two licences were held by Northern Resources Ltd and Platinova A/S, targetting chromite, PGE, nickel-copper and rubies. Exploration programmes have been carried out by these companies and also by GGU, covering geological mapping, chip-sampling, chemical analysis, various petrographic surveys, channel-sampling, bulk-sampling, and beneficiation tests.

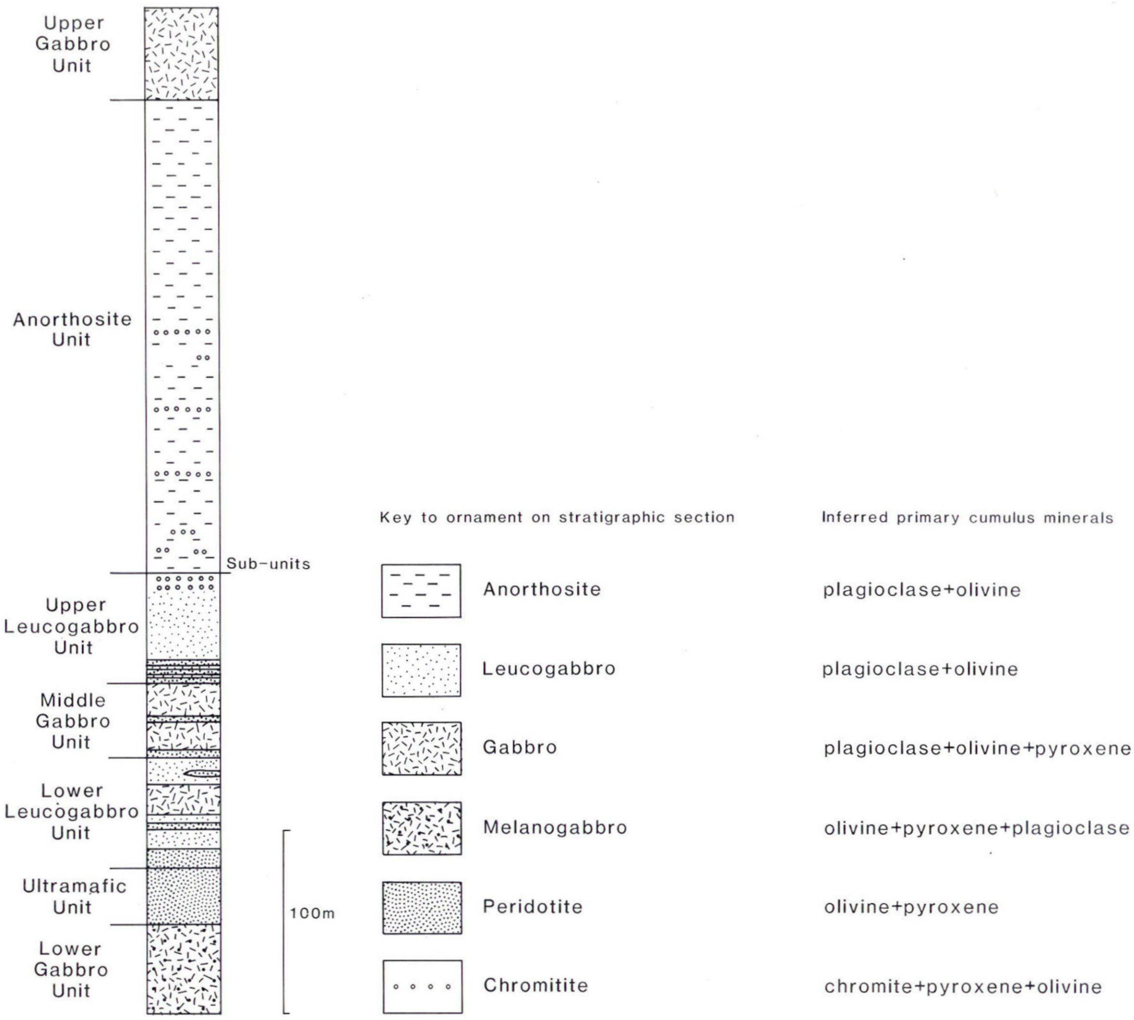


Fig. 27. Simplified stratigraphic succession of the anorthosite complex (from Myers, 1985).

### 3.2.2 **Geological description**

The Fiskenæsset Anorthosite Complex is of Archaean age and comprises anorthosites and associated layered plutonic rocks, intruding supracrustal amphibolites which have been strongly deformed and metamorphosed (amphibolite-granulite facies metamorphism).

The complex occurs as disrupted fragments within a 100 km by 50 km area. The preserved fragments or sheets are generally less than 500 m wide, with outcrop lengths of about 25 km. The complex can be subdivided into seven stratigraphical units (Myers, 1985). Fig. 27 shows the simplified stratigraphic succession. The igneous layering was folded during three major ductile deformation events, resulting in complex folds, pinch and swell structures, and steeply dipping horizons of varying thicknesses.

The 250 m thick, Anorthosite Unit (unit 6), hosts the majority of the chromites, and occurs in one or two distinct stratigraphic chromitite horizons as discontinuous layers and lenses; locally then forming massive, mafic layers or lenses of chromite-hornblende-biotite rock up to 1 m thick. The chromitite horizons can rarely be traced continuously for more than about 100 m along strike. In the western part of the complex, chromite is confined to a small number of more continuous layers 1-2 m thick. At Majoqqap Qaava chromite also occurs in substantial amounts in the Upper Leucogabbro Unit.

Petrographically, the chromitites occur both as hornblende chromitites (max. 1 m thick) and augen chromitites (up to 20 m thick), yielding 53-60% of the massive hornblende chromitite and about 50% in chromitites layers of the augen chromitites, though lower grades dominate (30-40 vol.%) (Appel, 1992). In both types of chromitites the mineral assemblage includes hornblende and biotite, along with accessory quantities of rutile, ilmenite, and sulphides. The chromite grains vary in size between 0.05 and 0.7 mm, on average 0.3 mm. Rutile occurs as 0.02 to 0.04 mm grains, grading about 0.35 wt%. Ilmenite occurs rarely, but appears in the same way as rutile. The sulphides include pyrite, chalcopyrite, pyrrhotite and pentlandite.

Ghisler (1976) compared the Fiskenæsset Complex with the Sittampundu Complex of India, both having high Ca-plagioclase, and an anorthosite mafic rock ratio of 4:1, as well as comparable chromite layers.

### 3.2.3 **Technical data**

Geochemical surveys include microprobe analyses and wet chemical analyses on chromites, as well as XRF analyses on anorthosite rock concentrates. Results are shown in Table 6. The most common type of ore consists of chromite, hornblende and plagioclase, containing about 30% chromite corresponding to 38% $Cr_2O_3$. Chromite extracted from the ore contains *c.* 32% $Cr_2O_3$ and *c.* 37% $Fe_2O_3$, showing a low Cr/Fe ratio; the concentrates have a high aluminium content (*c.* 19% $Al_2O_3$), hence the ore is considered as a low grade ore.

Table 6. Geochemical data on chromite from the Fiskenæsset anothosite complex

| | $Cr_2O_3$ | FeO | $Fe_2O_3$ | $Al_2O_3$ | MgO | $SiO_2$ | $V_2O_5$ | $P_2O_5$ | Ti | Ni | Co |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 35.1 | 29.4 | 13.4 | 18.6 | 3.5 | | | | | | |
| B | 32.1 | 36.4 | | | | | | | | | |
| C | | | | | | | 0.36 | <0.01 | 0.44 | 0.04 | 0.02 |
| D | 16.8 | 13.2 | 4.5 | 19.8 | 7.8 | 22.5 | | 0.01 | | | |

Geochemical data, based on Appel (1992). Type A: major element composition of 33 chromites from anorthosites determined by a combination of microprobe analyses and wet chemical methods. Type B: major element composition of 168 chromite concentrates from anorthosites, determined by X-RF. Type C: Miscellaneous unspecified geochemical data. Type D: bulk sample composition on a chromititite (Appel, 1992).

Several ore beneficiation studies were carried out during the 1970s, and a summary of the tests is given in Table 7. The major object of the studies was an improvement of the Cr/Fe ratio and a reduction of the $Al_2O_3$ content of the ore, in order to meet metallurgical chromite grade specifications. In general these efforts were not successfull, and FMC Pocatello, suggested that chemical or pyrometallurgical upgrading should be carried out in order to reach more than 34% $Cr_2O_3$ with a Cr/Fe ratio higher than 1 (Appel, 1992).

A rough estimate of the mineral potential of the complex indicates the presence of a resource in the order of 100 million tonnes of chrome ore (Ghisler, 1976). At the eastern

Table 7. Ore beneficiation tests on the Fiskenæsset chromite materials (based on Appel, 1992)

| Lab-name | Year | Techniques | Grade of runs (%) | Results<br>Chromite concentrate characteristics<br>Recovery | $Cr_2O_3$ | FeO | Cr/Fe | $Al_2O_3$ | $SiO_2$ | $V_2O_5$ | Subject |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Outukumpu | 1971 | magnetic | - | max. 88 | 39.4 | 44.6 | 0.78 | | | | rutile |
| Woodall | 1972 | electrostatic | | | | | | | | | |
| | | magnetic, dry | | | | | | | | | |
| | | wet table | | | | | | | | | |
| | | acid extraction | - | - | 20.5 | 26.5 | 0.68 | 20.2 | 17.7 | 0.3 | chromite |
| Pittsburg | 1976 | electrostatic | | | | | | | | | |
| | | magnetic, dry | 15 | - | 33.5 | 31.5 | 0.93 | 26.0 | 1.6 | | chromite |
| Wrightson | 1976 | magnetic, wet, H.I. | - | - | | | | | | | chromite |
| NRC | - | fluidization | - | 85 | | | | | 2.6 | | |
| G.f.M | 1977 | Humphry spiral | | | | | | | | | |
| | | magnetic | 16.8 | - | 29.3 | | | | | | chromite |
| FMC | 1978 | elutriation | | | | | | | | | |
| | | tabling | - | 82 | | | | | | | chromite |

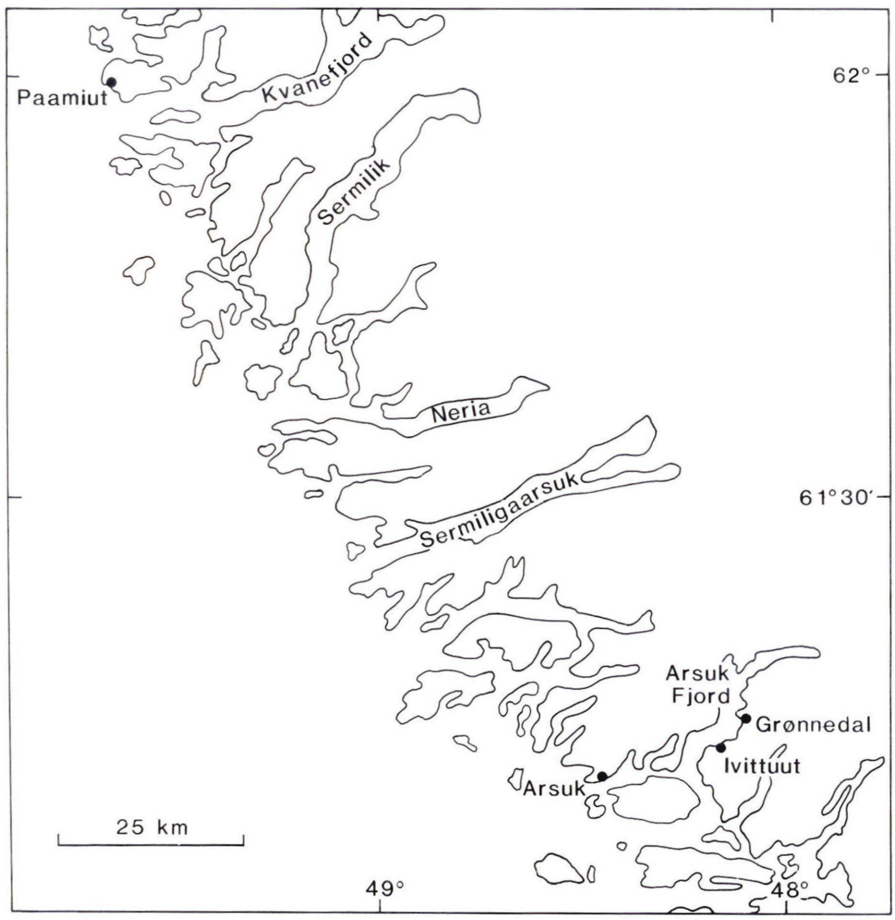


Fig. 28. Locality map showing the position of the Ivittuut cryolite mine.

part of Qeqertarssuatsiaq, the uppermost 50 m part of a steep dipping 1400 m long and 1 to 7 m thick chromite horizon is claimed to have a mineral potential of about 2.5 million tonnes, corresponding to 350,000 tonnes of $Cr_2O_3$ and 3000 tonnes of $V_2O_5$ (Ghisler & Windley, 1967).

Mining of the very complexly folded and thin chromite horizons would best be achieved by selective, open cut techniques.

## 3.3 Cryolite, Ivittuut, West Greenland

### 3.3.1 Introduction

The abandoned cryolite pit is located at the small mine site named Ivittuut, adjacent to the navigable Arsuk Fjord; it is about 5 km west of the naval base Grønnedal and 15 km east of the settlement Arsuk (Fig. 8, 28). The site can be reached either by chartered boat or by regular helicopter to Grønnedal and from there by car; transportation between Ivittuut and Arsuk is by chartered boat only.

Due to the previous mining activities, some infrastructural facilities still exist including a harbour, a pier, bunk-houses, electricity, and an unsurfaced road connecting Ivittuut and Grønnedal (Fig. 29).

Mining of the cryolite was started in 1858 by Kryolitselskabet Øresund A/S (KØ) and continued until the end of 1987, when the the high-grade cryolite material was exhausted.

The only place where cryolite has ever been mined is at Ivittuut, although cryolite is known at a number of localities outside Greenland.

Since 1847 cryolite ($Na_3AlF_6$) has mainly been used for the manufacture of soda, alum and aluminium sulphate. From 1889 cryolite was used for the molten bath in which alumina was dissolved for electrolytic reduction to aluminium metal (the Hall-Heroult process). Cryolite is also used within the ceramic industry as a whitener for enamels and as an opacifier in glasses. It is also used as an abrasive, and in insecticides.

Due to the gap in the supply of natural cryolite, the aluminium industry began to use synthetic cryolite, manufactured from hydrofluoric acid, sodium carbonate, and aluminium hydrate. In recent years the manufacture of synthetic cryolite has also been based on fluorides recovered from Florida fertilizer plants, converted to synthetic cryolite and aluminium fluoride (Emigh, 1983).

The geological and technical notes given below are mainly based on Bondam (1991).

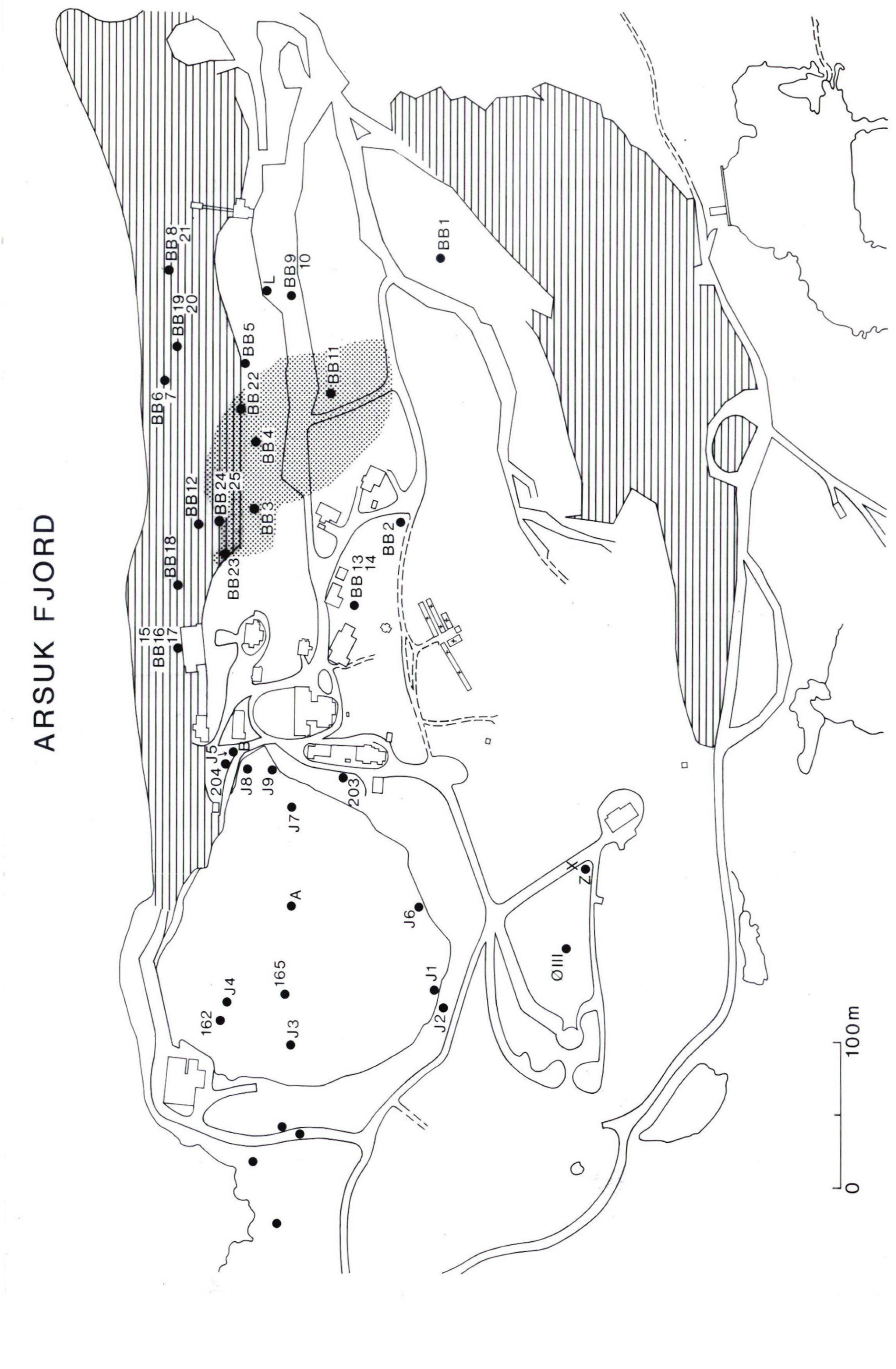


Fig. 29. The exploration drill holes in the immediate vicinity of the cryolite deposit at Ivittuut. Shaded areas indicate the low grade waste material (from Bondam, 1991).

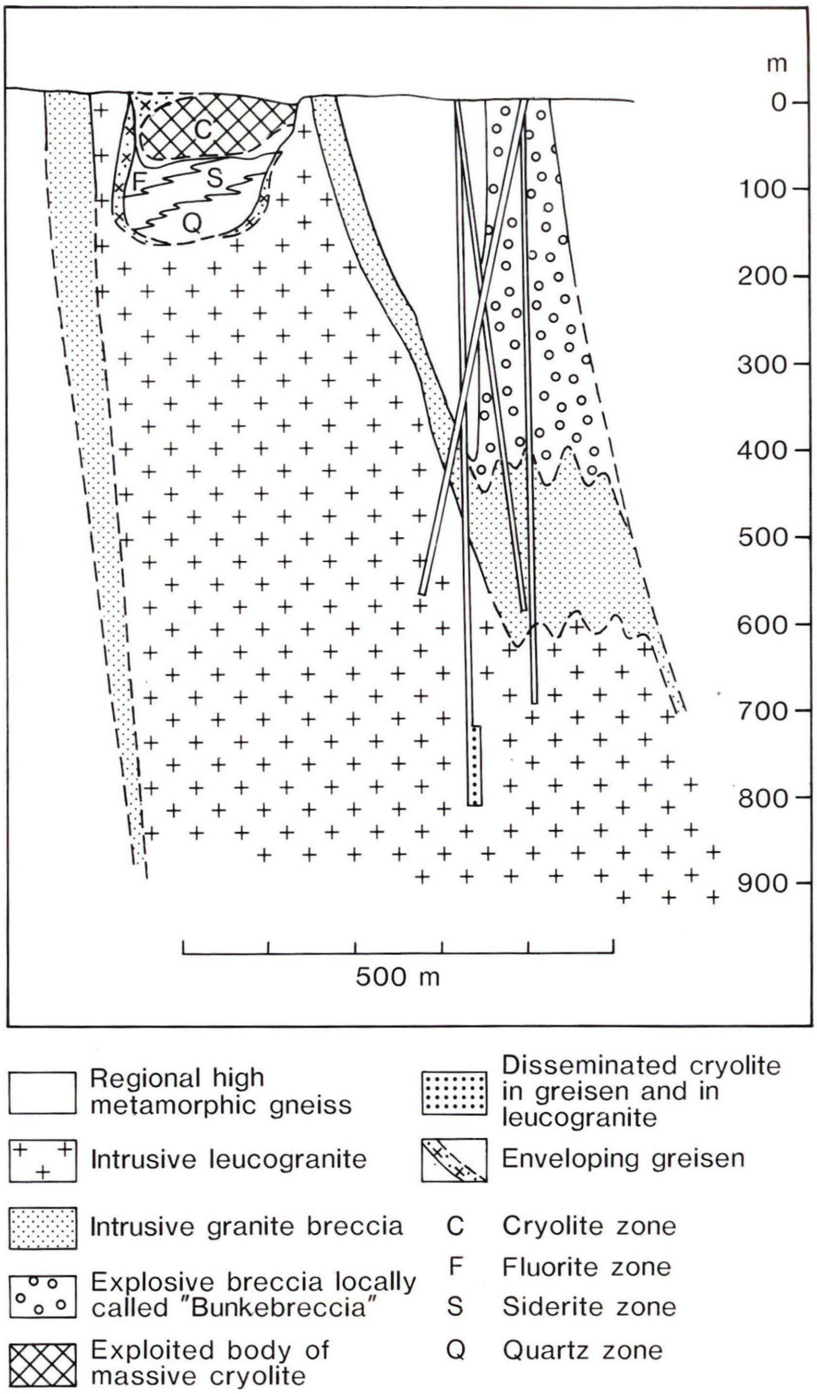


Fig. 30. Simplified profile of the emplacement of the cryolite deposit within the granite intrusion; orientation of the profile is WSW-ENE (from Bondam, 1991).

### 3.3.2 Geological description

The cryolite ore deposit, belonging to the Gardar Province, was a zoned mineralised body within a cylindrical leucogranite intrusion, which is enveloped by an intrusive breccia in contact with high grade metamorphic, granodioritic gneiss. A leucogranite intrusion extending in depth and a separate minor breccia, both impregnated with cryolite, have been proven by drilling close to the main cryolite body.

The cryolite ore formed an inhomogeneous body, with the following subdivisions: (a) an upper cryolite zone; (b) intermediate fluorite and siderite zone; and (c) a lower quartz zone; the extent of the zones are indicated on Fig. 30.

The average grade of the cryolite zone has been estimated at about 58% cryolite, 25% siderite, 8% fluorite, 8% quartz and 2% sulphides; considerable variations have been observed. The principal sulphides are sphalerite, galena, chalcopyrite and pyrite. The deep seated cryolite-impregnated leucogranite grades 3.6% cryolite.

The lower quartz zone consisting of pegmatitic quartz has been assayed, and indicates a potential of high purity quartz totalling about 6 million tonnes (Bondam, 1986).

Approximately 90 different minerals have been found in the cryolite deposit, several of which have not been found elsewhere.

### 3.3.3 Technical data

Drilling campaigns were carried out in the years 1948-1958 and 1984-1987, and included development drillings and exploration drillings. All core samples are now stored at the The Geological Survey of Greenland (GGU). Exploration also included magnetic and electromagnetic surveys, VLF and gravimetric surveys, although no reliable indications of either the extent of the granite intrusion or a second cryolite deposit at depth has been obtained.

The cryolite was worked by open pit mining techniques, and a total of 3.7 million tonnes of crude ore were mined and shipped in the period between 1858 and 1985 to the processing plant in Copenhagen, operated by Kryolitselskabet Øresund A/S, and to a processing plant located in the USA, operated by Pennsalt Chemicals Corp. About 2.4 million tonnes were processed in the Copenhagen plant, producing *c.* 1.4 million tonnes of cryolite concentrate.

Prior to shipping from Ivittuut, the crude ore was crushed and sorted by hand. At the concentrating plant in Copenhagen the ore was further concentrated by means of flotation to produce an endproduct containing 98% to 99% cryolite.

The probable mineral reserve of the intermediate cryolite zone was estimated by Kryolitselskabet Øresund A/S in 1988, on the basis of simple ore-block calculations and 1074 chemical assays on 3086 m of drill core. The study established a classification of seven different types of mineralisation according to the dominant minerals cryolite, fluorite and siderite (cf. Table 8), the following overall average *in situ* grades were, 8% cryolite, 18% fluorite and 38% siderite; the zinc resource is too scarce to have economic importance. The cryolite potential is composed of: (a) massive cryolite; and (b) cryolite impregnated greisen, of which the latter occurs as a specific rock type forming a steep, homogeneous body mainly confined to the contact between the cryolite deposit and the enveloping granite.

Table 8. Probable *in situ* reserve of each of the mineral components within part of the cryolite deposit, based on Bondam (1991)

| Unit | Mineralization | Cryolite | | Fluorite | | Siderite | | Sphalerite | |
|---|---|---|---|---|---|---|---|---|---|
| | type | % | tonnes | % | tonnes | % | tonnes | % | tonnes |
| | cryolite | | | | | | | | |
| 1 | - massive | 46 | 10,000 | 9 | 2,000 | 4 | 1,000 | | |
| | - impregnated | 29 | 30,000 | 2 | 2,000 | 4 | 4,000 | | |
| 2 | fluorite | 11 | 53,000 | 50 | 250,000 | 2 | 12,000 | | |
| 3 | siderite | 2 | 22,000 | 5 | 35,000 | 65 | 559,000 | | |
| 4 | cryolite-fluorite | 30 | 24,000 | 33 | 26,000 | 2 | 2,000 | | |
| 5 | fluorite-siderite | 5 | - | 25 | 1,000 | 36 | 2,000 | | |
| 7 | sphalerite | 2 | 3,000 | 3 | 5,000 | 52 | 97,000 | 5 | 17,000 |

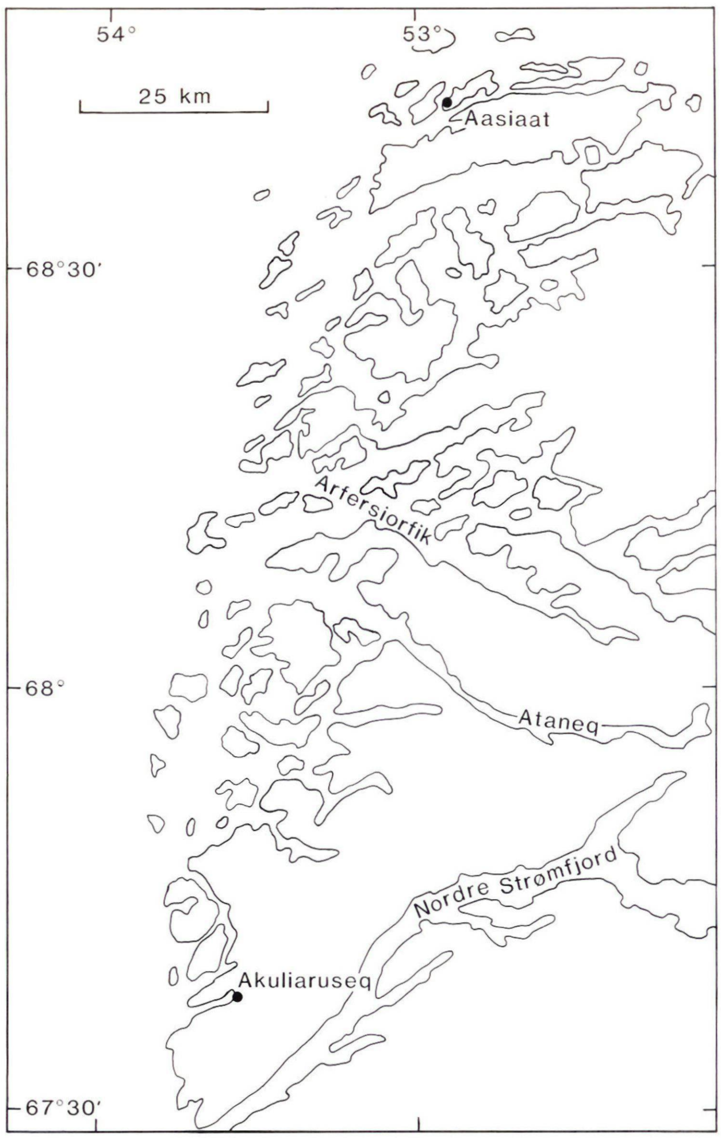


Fig. 31. Locality map showing the position of the Akuliaruseq graphite occurrence.

An additional resource is made up by the waste material from the previous mining, scattered around the mine and used as land fill; it represents a low grade, although recoverable cryolite resource, assaying about 900,000 tonnes grading 13% cryolite (Bondam, 1991).

The environmental impact of lead pollution in the fjord has been monitored, and indicates lead accumulation during the mining period. The main source of lead dispersion has been the waste material used as fill in the construction of a quay. However, recent studies indicate that the lead pollution is now decreasing.

## 3.4 **Graphite, Akuliaruseq, West Greenland**

### 3.4.1 **Introduction**

The Akuliaruseq graphite occurrence is found on a small peninsula adjacent to the navigable inlet Eqalussuit, about 140 km NW of Kangerlussuaq airport (formerly Søndre Strømfjord) and 90 km north of Sisimiut (Fig. 12, 31). The site is only accessible by chartered boat or helicopter. No infrastructural facilities exist in the area.

The site of the occurrence is a low lying undulating coastal plain, terminated by 50-70 m high rugged hills to the north and north-east. Degree of exposure is *c.* 30%.

Exploration programmes were carried out by Kryolitselskabet Øresund A/S (KØ) in the period 1977 to 1987, and included geological mapping, ground geophysical mapping (magnetics and electromagnetic), core drilling, core assaying, ore reserve estimate, bench-scale tests, and pre-feasibility studies, focusing on an area of 7 km by 0.5 km in size. In 1990 the project was taken over by Nunaoil & Minerals A/S, who undertook graphite analysis, metallurgical tests, and re-estimations of the capital investments and production costs.

### 3.4.2 **Geological description**

The graphite occurrence is hosted in Archaean high-grade supracrustal rocks consisting of schists, amphibolites and ultramafic rocks, which form a narrow, steep dipping, synformal structure downfolded into the hypersthene gneiss basement. The graphite mineralisation is confined to 3 separate horizons in the northern limb, and predominantly hosted in sillimanite schists, which can be followed along strike for about 6 km. Drill hole

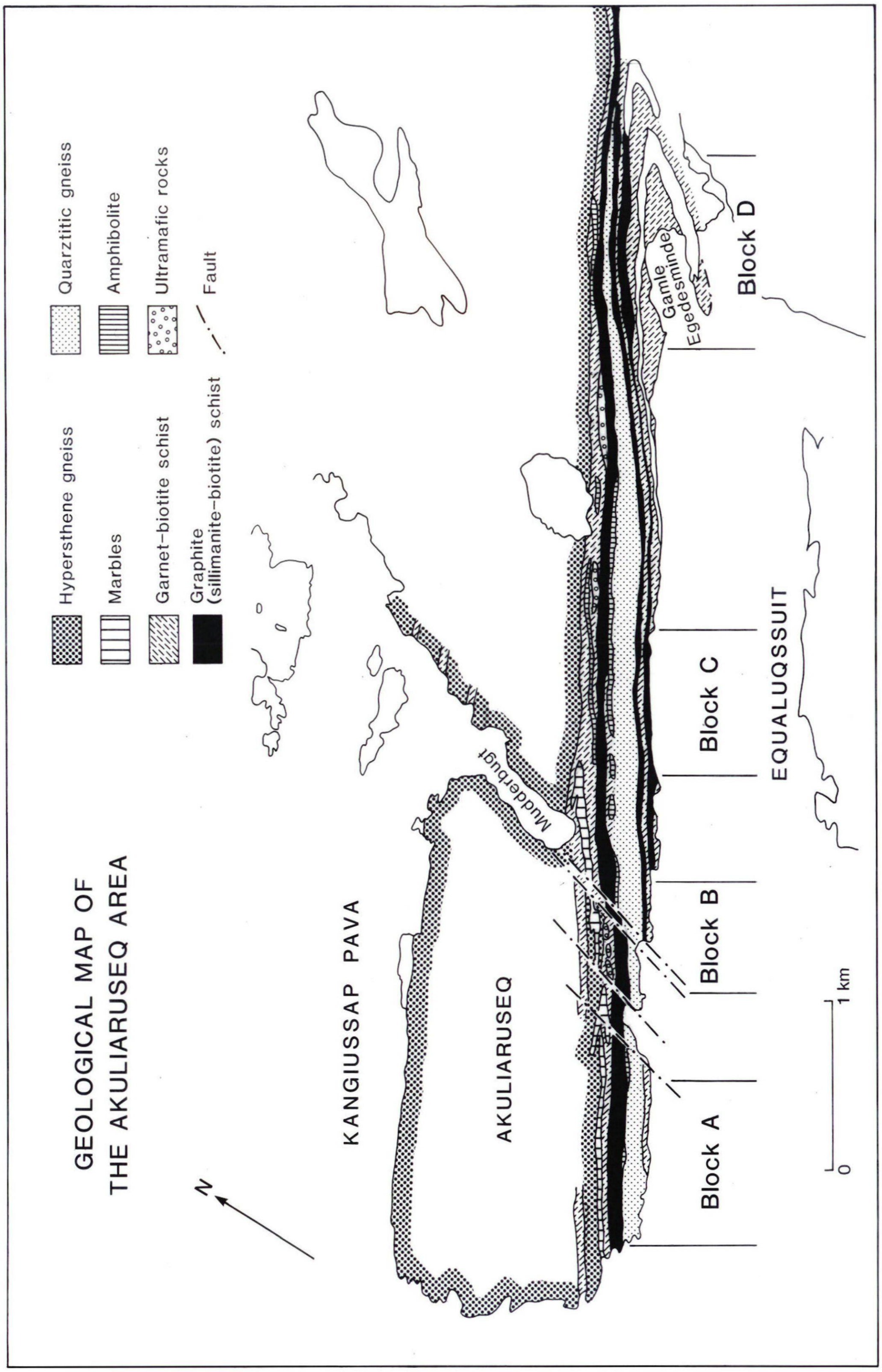


Fig. 32. Simplified geological map of the Akuliaruseq area, indicating the extension of the blocks used for sampling, drilling and resource estimates (based on Nunaoil A/S, 1992).

data and surface mapping show the ore body to be lenticular in fashion both along strike and down dip.

Graphite appears as two different types, both hosted in the sillimanite schist: (a) disseminated graphite flakes, grading 6-8% graphite, occurring as large lumpy flakes and small brittle flakes, none of which contain impurities; and (b) massive graphite occurring in intensely deformed parts of the sillimanite schists, grading up to 20-24% graphite carbon (Cg). The thickness of the graphite-bearing rocks varies considerably, between 35-60 m, but contains numereous 1-20 m wide low-grade zones (Nunaoil, 1992).

### 3.4.3 **Technical data**

The eastern part of the occurrence (block D) was drilled in 1982 (Fig. 32); a total of 2.4 km of core from 50 holes, drilled on a regular 30 m by 50 m pattern; 167 samples totalling 515 m were analysed for carbon. During 1983, 74 holes totalling 3.4 km were drilled on 51 profiles along strike lengths of 2.5 km in blocks A, B and C; 178 samples totalling 558 m were analysed for carbon.

The probable mineral reserve was estimated by Kryolitselskabet Øresund A/S, on the basis of simple ore block calculations and analytical or visually estimated values from the drill hole intersections. Ore blocks were calculated separately for each drill hole and were extended to 40 m below surface. The total probable mineral reserve of the areas A, B, C and D amounted to 5.3 million tonnes of ore grading 9.5% C, and for an enriched zone 1.2 million tonnes of ore grading 14% C, applying a figure of 4 m as the minimum mineable width and a cut-off grade of 12% C (Nunaoil, 1992). Nunaoil (1992) claims the figures are inaccurate due to: (a) the assay technique applied; (b) the restricted number of assays; (c) lack of down-dip continuity; and (d) potential additional reserves outside the drilled blocks.

Metallurgical work carried out by Kryolitselskabet Øresund A/S in the period from 1983 to 1991, was based on various types of bulk samples, including composite core samples trench samples, composite grab samples, and included grinding and flotation tests on samples representing the eastern part of the occurrence. The results of these tests are given in Table 9, based on Nunaoil A/S (1992).

Table 9. Results of metallurgical tests on the Akuliaruseq graphite occurrence

| Sample | Flake size mesh | Flake size % | Carbon in conc. (%) |
|---|---|---|---|
| AKU-BS | +150 | 38.3 | 92.5 |
| AKU-I | +150 | 46.8 | 83.3 |
| AKU-P | +150 | 43.7 | 79. |
| AKU-C | +48 | 3.4 | 9.6 |
| | -48+100 | 18.8 | 0.0 |
| | -100+150 | 12.4 | 89.6 |
| | -150 | 65.4 | 79.0 |

Results of metallurgical tests, carried out Kryolitselskabet Øresund A/S on miscellanous bulk samples, from Nunaoil (1992). Note that the results are not completely comparable, due to individual sample treatments.

The AKU-C bulk sample was reassessed by Nunaoil in 1991, and the following conclusions indicate a high quality graphite ore potential (Nunaoil, 1992):

- the ore is easy to crush and grind;
- moisture is low and volatile matter is normal;
- no carbonates occur in the ore, concentrates, or flake grades;
- simple primary flotation produced flake concentrates with +90% C;
- flake size obtained: 1.6% >28 mesh, 21.4% >48 mesh, 49.5% >100 mesh, and 67.2% >150 mesh.

Based on a potential scale of production equal to 15,000 tonnes of graphite concentrate per year, Kryolitselskabet Øresund A/S in 1986 estimated the required capital investment to be about $33 millions, production costs at $440 per tonnes of concentrate, together with $1.8 millions per year to cover administration and shipping costs; this would not provide a sufficient return on the capital investment (Nunaoil, 1992). However, Nunaoil (1992) recommend further exploration programmes, targetting a second pre-feasibility study.

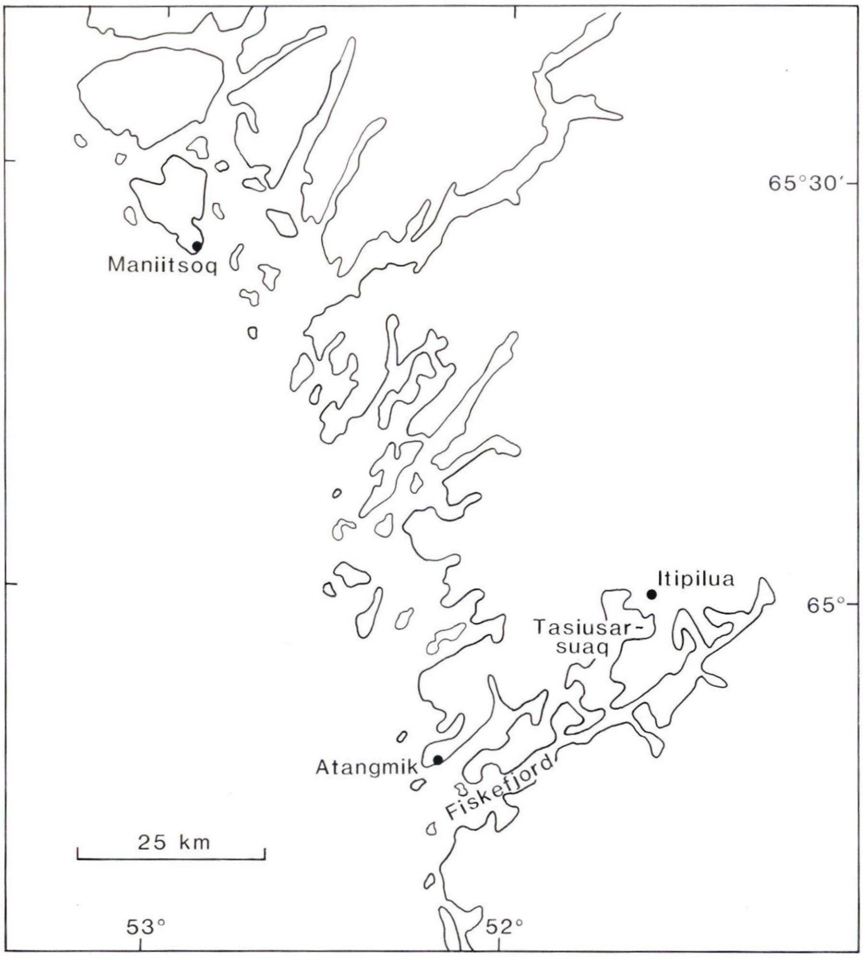


Fig. 33. Locality map showing the position of the Itipilua olivine occurrence.

## 3.5 Olivine, Itipilua, West Greenland

### 3.5.1 **Introduction**

The Itipilua dunite occurrence is located adjacent to Tasiusarsuaq, a branch of Fiskefjord about 35 km west of the settlement Atammik (*c.* 200 inhibitants), and about 80 km north of the capital Nuuk (Fig. 15, 33). No infrastructural facilities are available at the site area. The site can be reached either by chartered helicopter from Nuuk, or by chartered boat. In general the fjords are navigable, except for a few narrow inlets dominated by strong currents.

The distance between the dunite and the shoreline is about 0.5 km; the dunite covers an area about 1100 m by 450 m, and has a maximum elevation of about 140 m a.s.l. The area of exposure consists of abundant dunite outcrops and talus and debris slopes, with almost no soil and vegetation. As a result of erosion an appreciable accumulation of unconsolidated olivine sand has been formed adjacent to the intrusion covering an area of about 200,000 $m^2$.

The region surrounding the dunite and associated rocks was explored by Kryolitselskabet Øresund A/S (KØ) in the 1970s; the work included geological mapping, geophysical surveys, sampling programmes, diamond drillings and ore beneficiation tests. Regional geological studies were undertaken by The Geological Survey of Greenland in the mid 1980s. Technical beneficiation studies of the dunite raw materials were carried out by MDI in the late 1980s. Nunaoil & Minerals A/S held a prospecting licence in 1990.

### 3.5.2 **Geological description**

The Itipilua dunite is one of a series of Archaean ultrabasic intrusions in the Archaean gneisses of the Fiskefjord area. The Itipilua massif is a concentric intrusion composed of a central dunite, rimmed by peridotites and pyribolites (cf. Fig. 34, geological map of massif). Serpentinised alteration zones are widespread, up to 50 cm thick and traceable for up to 25 m. The peridotites and pyribolites generally appear as massive rocks. Some faults are seen, but fractures and joint patterns occur everywhere.

The dunite is present as: (a) a massive dunite; and (b) a rythmic-layered dunite hosting metre-thick chromite-rich layers. The overall rock texture is a medium-grained, massive dunite composed of forsterite (75-85 vol%) (Fo=6-9 mol% Fa), plagioclase (5-15 vol%),

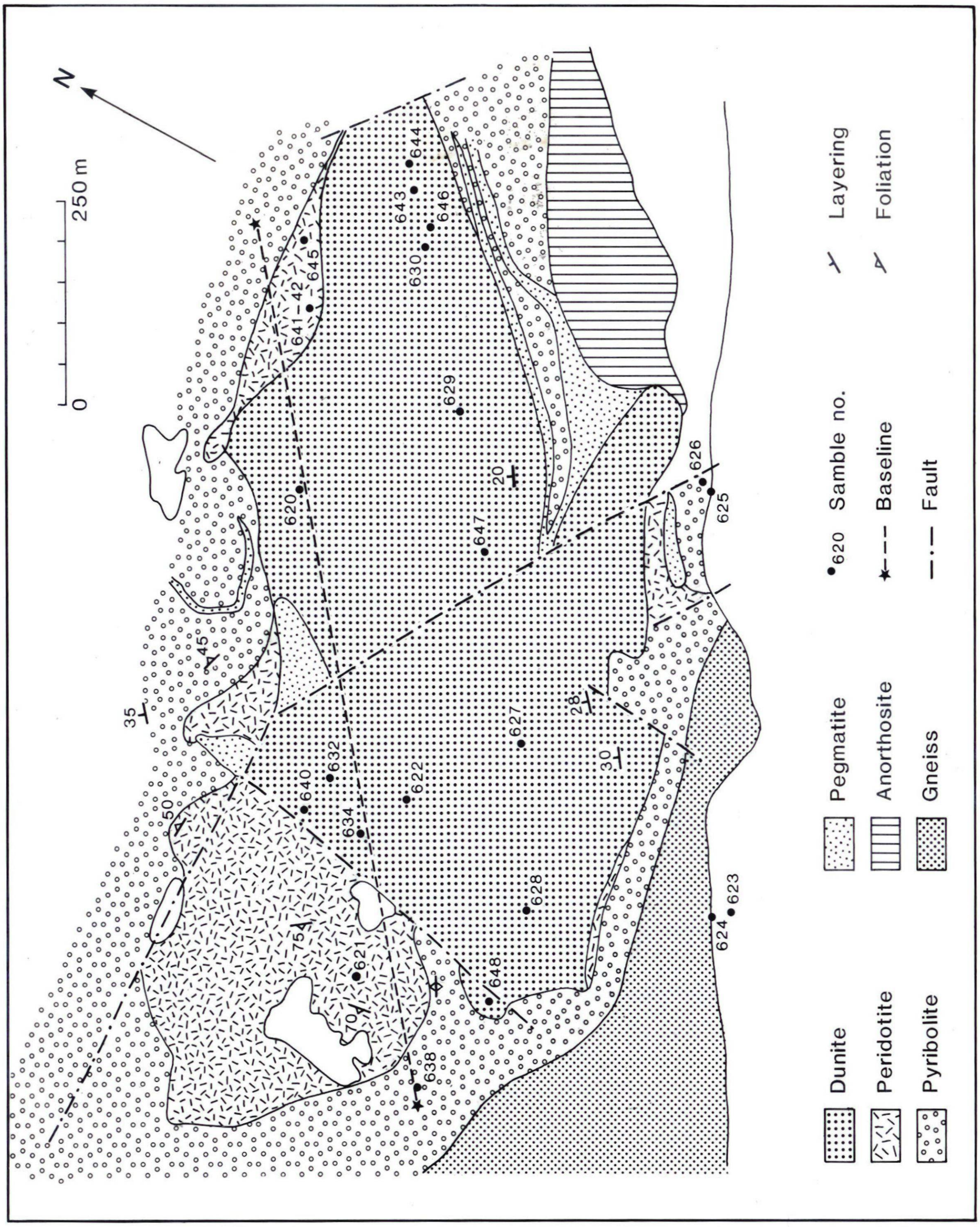


Fig. 34. Simplified geological map of the Itipilua olivine occurrence (from Kalvig, 1990).

and accessory pyroxene, biotite, chromite, rutile, leucoxene and serpentine (chrysotile?). The layered dunite carries up to about 3 vol% chromite, locally developed as up to 2 m thick chromititic layers.

Serpentine minerals are confined to narrow alteration zones, frequently associated with tremolite and talc (Kalvig, 1990).

Average chemical assays of the dunite are given in Table 10, indicating that the rock with respect to chemical composition fullfills commercial product requirements (Table 11).

Table 10. Geochemical data on Itipilua dunite

| Elements | Itipilua | | Åheim, Norway |
|---|---|---|---|
| | A | B | C |
| | % | % | % |
| $SiO_2$ | 40.98 | 40.45 | 41 |
| $Al_2O_3$ | 0.28 | 1.74 | 0.5 |
| $Fe_2O_3$ | 0.96 | 0.92 | 7.0 |
| FeO | 6.28 | 6.46 | - |
| MgO | 49.89 | 47.94 | 49 |
| CaO | tr | 0.30 | 0.05 |
| $Cr_2O_3$ | <0.10 | <0.10 | 0.4 |
| NiO | 0.38 | 0.34 | 0.35 |
| $CuO^*$ | | 0.02 | - |
| $CoO^*$ | | 0.02 | - |
| MnO | | - | 0.10 |
| LOI | 0.44 | 2.00 | - |
| Total | 99.31 | 99.04 | 98.4 |

(A) Massive dunite; (B) Composit sample based on 30 subsamples (KØ, 1966); and (C) Commercial dunite specifications from Åheim, Norway (Frederiksen & Secher, 1984).

### 3.5.3 **Technical data**

A mineral resource study, based on five drill holes (in total *c*. 300 core m) and geological surface data, yielded a measured mineral resource of *c*. 52 million tonnes of dunite (Kalvig, 1990). The indicated mineral resource of the olivine sand is about 800,000 tonnes, of which *c*. 400,000 tonnes are at the bottom of the lake (max. depth *c*. 30 m) (Kalvig, 1990).

The massive occurrence is favourable for the application of open-pit mining techniques; due to the incoherent character of the dunite ripping techniques might be considered. Production of olivine sand would be carried out by dredging techniques.

Kryolitselskabet Øresund A/S reports various technical specifications on the forsterite. The forsterite percentage of the dunite is slightly lower than comparable commercial deposits. However, beneficiation tests on the dunite proved satisfactory refractory grades (Kryolitselskabet Øresund A/S, 1965, 1966; Frederiksen & Secher, 1984) (cf. Table 11). No data are available on use as slag conditioners and fluxing agents, which are the markets consuming the great majority of the world production of dunite.

Beneficiation tests on the olivine sand proved that commercial specifications for uses such as sand blasting products and foundry sand can be met, provided size classification is carried out in advance; a slightly higher rate of consumption was noted for the sand. Asbestos minerals were not observed in the sand (Kalvig, 1990).

Table 11. Technical specifications for the Itipilua forsterite (Based on KØ, 1965, and Frederiksen & Secher, 1984)

| Refractory grades<br>Rock type | Method | Refractory temperature (°C) |
|---|---|---|
| Massive dunite | Cone-fall | 1705-1710 |
| Olivine sand | Cone-fall | 1540 |
| | | |
| Massive dunite | Sintering point | 1300-1400 |
| Olivine sand | Sintering point | 1300 |

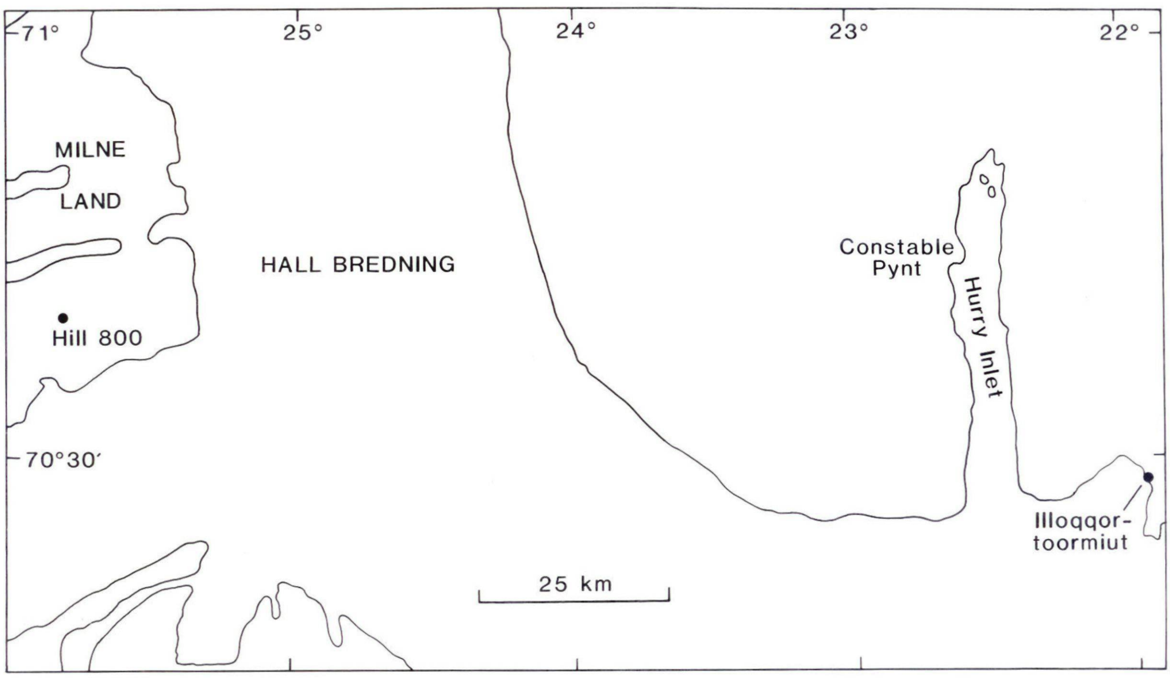


Fig. 35. Locality map showing the position of the Milne Land paleoplacer occurrence (named The Hill 800), hosting zircon, monazite, garnet and $TiO_2$-minerals.

The dunite has been subject to a research project testing the possibility of using dunite as raw material for production of periclase fibres, applying a carbothermal reduction technique (Kalvig, 1990).

## 3.6 Zircon, monazite, garnet, $TiO_2$-minerals Milne Land, East Greenland

### 3.6.1 Introduction

The Milne Land palaeoplacer occurrence is located about 12 km north of Mudderbugt, at "Hill-800" (800 m a.s.l.), about 140 km due west of the settlement Scoresbysund (Fig. 21, 35). Access to the site is by chartered aircraft from Iceland to Constable Pynt, and from there by chartered helicopter. Navigable access to Mudderbugten, is possible by ice-strengthened vessels for three months of the year. No infrastructural facilities are available in the area.

The occurrence was explored by Nordisk Mineselskab A/S (NM) in 1968, and further exploration programmes were carried out from 1970-73 (Nordisk Mineselskab), involving geological mapping, surface grid-sampling, trenching, shallow diamond drilling (8 holes, total of 127 m), scintillometer (Th), x-ray spectrometer (Zr, Ce+La), and airborne radiometric surveys. Follow-up programmes were carried out in 1989-1990 as a joint operation by Nordisk Mineselskab, Nunaoil & Minerals and Coffs Harbour Rutile N.L., focusing on product evaluations of the "Hill-800" occurrence by means of bulk-sampling, trenching, scintillometer surveys, general heavy mineral exploration and ore dressing studies (Brown, 1990; Ross & Brown, 1991; Ross, 1991).

### 3.6.2 Geological description

The clastic sediments of the eastern part of Milne Land are Middle Jurassic to Lower Cretaceous ages, resting unconformably on Proterozoic kaolinised, migmatitic granite basement with a pronounced palaeorelief. The heavy mineral potential is mainly confined to the basal 20 m of the lowermost formation, the 100-200 m thick Charcot Bugt Formation. The middle and upper part of the formation is dominated by laminated and cross-bedded sandstones and gravels. The basal 20 m of the Charcot Bugt Formation, which hosts the anomalies displays a variable lithology. According to Harpøth et al. (1986) it comprises: (1) sedimentary breccias immediately above the basement; (2)

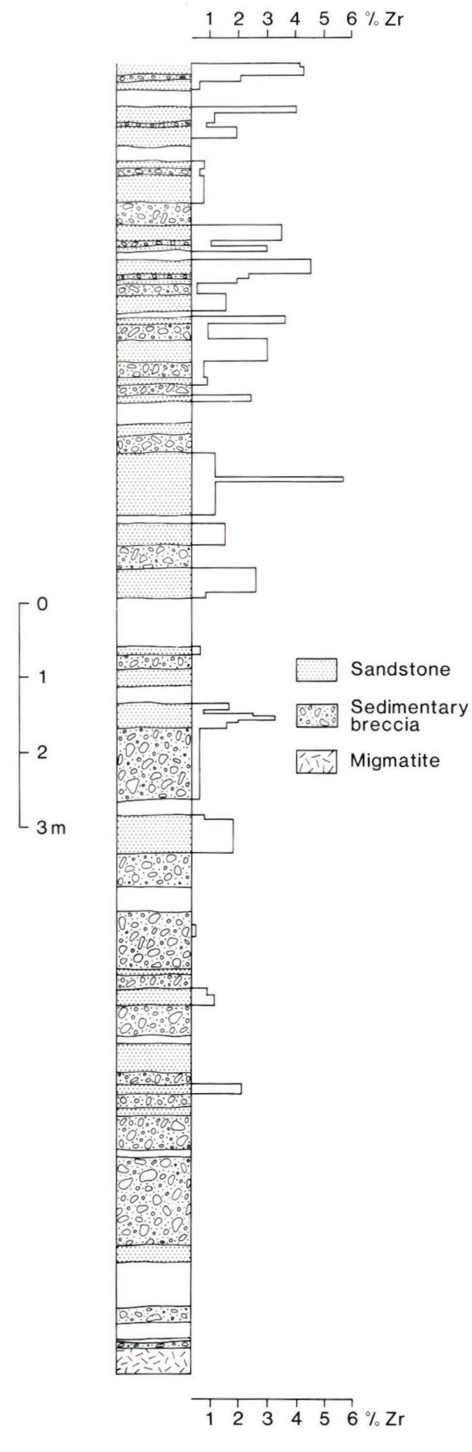


Fig. 36. Log of drill core from the basal unit of the Charcot Bugt Formation. Zr-values assayed by means of XRF (from Harpøth *et al.*, 1986).

coarse-grained arkosic sandstone with accessory garnet; and (3) mainly unconsolidated, heavy mineral sands rich in garnet (almandine), ilmenite (probably anatase), rutile, zircon, and monazite, forming irregular distributed 10-40 cm thick lenses within the unit (Fig 36). The heavy mineral sands are regarded as coastal or fluviatile placers formed by erosional material from the immediate hinterland.

### 3.6.3 **Technical data**

Selected geochemical assayes of the heavy mineral sands from the Charcot Bugt Formation are shown in Table 12, which gives the highest values from the trench samples. Harpøth (1990) reports calculated figures on the *in situ* grades of two mineralised section lines (Table 13), which indicate anatase, zircon and monazite as the major economic contributors.

The mineral potential of the "Hill 800" occurrence has been calculated applying volume estimations based on section lines and theoretical grade figures (based on drill holes and miscellaneous samples), assuming that all $TiO_2$, $ZrO_2$, and Rare Earth Element oxides are contained in anatase, zircon and monazite (Harpøth, 1990). The *in situ* grades obtained are given in Table 13.

Harpøth et al. (1986) report the indicated mineral resource to be about 3.7 million tonnes, of which about 1.1 million tonnes is not covered by overburden, and the remaining part has an average of 9 m of overburden (cf. Fig. 37). However, Harpøth (1990), states that an area east of the prospect carries the potential for an additional very large resource (estimated potential, 50-100 million tonnes), which is claimed to be more accessible; this target has not, however, been investigated and no further data are available.

Heavy mineral concentrates from "Hill-800" have been examined by means of polished thin sections, XRF, chemical analysis, and miscellaneous mineral processing techniques. Total heavy mineral contents of five selected pit samples range from 12.7% to 61%. Ross (1991) reports the valuable heavy minerals to constitute between 75% and 80% of the heavy mineral concentrate, representing $TiO_2$: 40-45%; zircon: 20-30%; monazite: 10-15%. The distribution of the economic minerals in the various size fractions shows that the titanium minerals (probably entirely anatase) are concentrated in the $+50\mu m$ to $150\mu m$ range, and are common also in the finer fractions with 40-50% of $TiO_2$ minerals passing a $80\mu m$ screen.

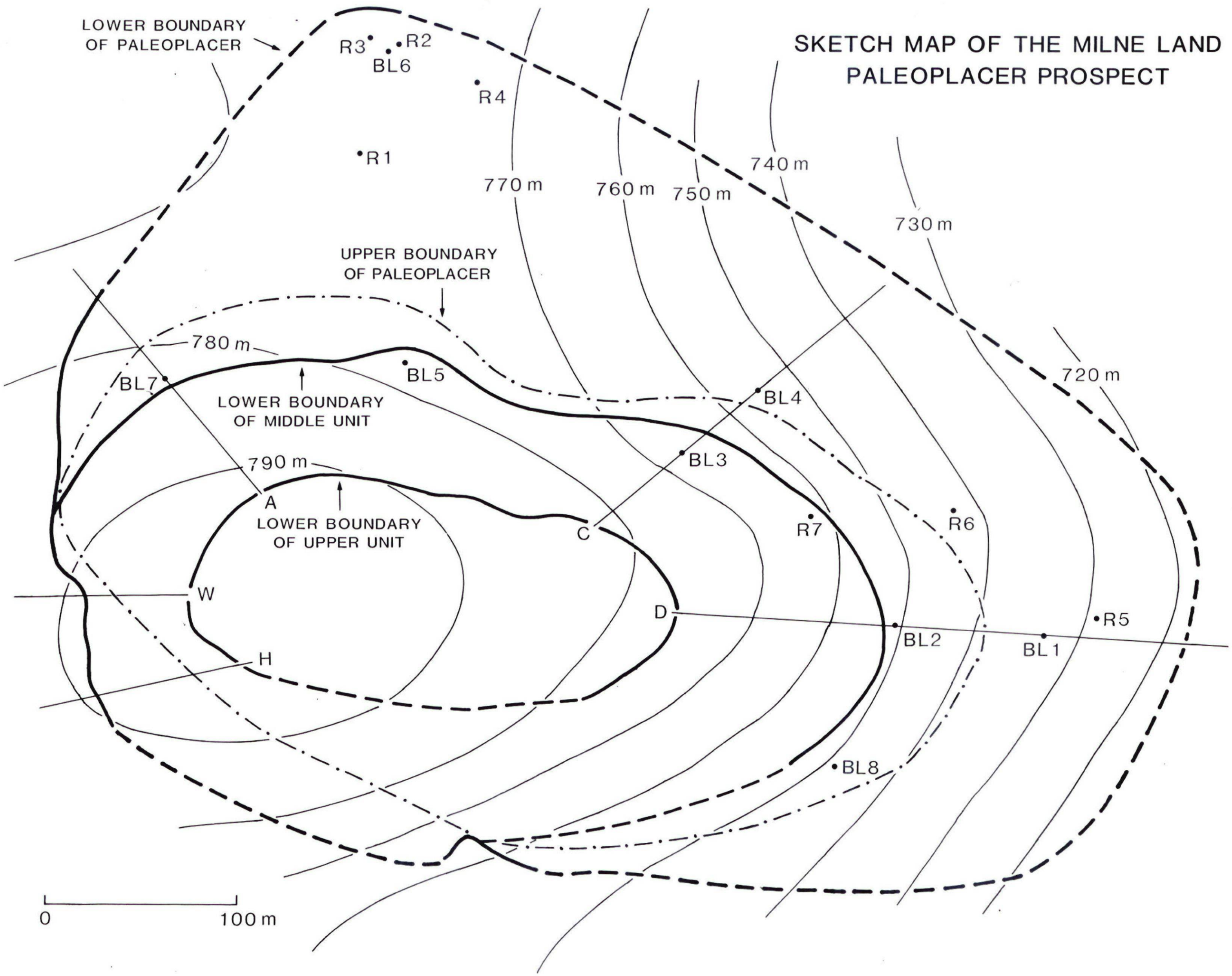


Fig. 37. Sketch map of the Hill 800 paleoplacer occurrence, showing the topography, isopachytes and drill-hole positions (from Harpøth, 1988).

Table 12. Selected geochemical data for the heavy-mineral sands from Milne Land, based on Harpøth et al. (1986)

| Sample | Fe % | Ti % | Zr % | Hf % | Th % | U % | $CeO_2$ % | $La_2O_3$ % | $Nd_2O_3$ % | $Y_2O_3$ % | $Gd_2O_3$ % | $Eu_2O_3$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drill core 9 samples | 6.8 | 3.6 | 4.7 | 0.09 | <0.1 | <0.05 | 1.2 | 0.6 | 0.6 | 0.06 | 0.04 | 0.005 |
| Bulk sample trenches (50 kg) | 3.5 | 12.5 | 14.4 | 0.15 | 0.63 | 0.064 | 3.5 | 1.75 | 1.75 | 0.1 | 0.1 | 0.02 |
| Heavies from trench no. 2 | 9.3 | 13.5 | 5.5 | 0.08 | 0.17 | 0.019 | 3 | 1.5 | 1.5 | 0.07 | 0.09 | 0.02 |
| Grid-samples, 24 | 5 | 2.5 | 0.5 | <0.02 | <0.1 | <0.05 | 0.4 | 0.2 | 0.2 | 0.03 | <0.01 | 0.05 |

| REO (100%) | $CeO_2$ | $La_2O_3$ | $Nd_2O_3$ | $Pr_2O_3$ | $Y_2O_3$ | $Sm_2O_3$ | $Yb_2O_3$ | $Gd_2O_3$ | $(Dy,Ho,Eu)_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|
| | 48 | 17.7 | 16.7 | 4.9 | 4 | 2.7 | 2 | 2 | 2 |

Table 13. Calculated *in situ* grades of two mineralised section lines, used in estimations of the mineral potential (Harpøth, 1990). The assays corresponding to section-line 4084-4270, are the officially applied grade values

| Mineralized section Sample nos. | Anatase % | Zircon % | Monazite % | Xenotime % | Garnet % |
|---|---|---|---|---|---|
| 4093-4100 | 3.5 | 2.0 | 1.0 | 0.05 | 4.2 |
| 4084-4270 | 2.6 | 1.1 | 0.5 | 0.03 | 3.1 |
| 4077 | 1.9 | 0.6 | 0.4 | 0.025 | 2.8 |

Metallurgical studies on bulk-samples (of several tonnes) have proved excellent recoveries for zircon and monazite. Both gave about 93% recovery, utilizing conventional mineral sand processing techniques, based on a feed of 100% passing 600 $\mu$m and minimum grain size in the concentrate of 10 $\mu$m. However, a significantly poorer rate of recovery was obtained for the $TiO_2$ minerals (about 54%) (in spite of the application of a pilot scale Kelsey Jig (Ross, 1992)), indicating that a substantial part of the $TiO_2$ material is present as ultrafine grains of anatase bound up in grain aggregates with iron oxides, and as grain coatings on the larger grains (Ross, 1991). Concentrates obtained from larger scale jig runs assayed about 30% zircon, 20% monazite and 8% $TiO_2$. Attrition of the jig concentrate in order to improve separation performance caused unacceptable loss of $TiO_2$ (*c.* 38% loss).

Zircon concentrate produced by treatment on high tension rollers and screens assayed high values in $TiO_2$ and $Fe_2O_3$ and obtained a low rate of recovery (*c.* 60%); acid washing of the zircon reduced the $Fe_2O_3$ to less than 0.1%. Treatment of the $TiO_2$ upgraded material over high tension rollers and screen plates proved the aggregated nature of these grains (composed of quartz, zircon, monazite and garnet) and prevented the production of $TiO_2$ concentrates to meet commercial specifications (Ross, 1991). The garnet fraction produced by means of Kelsey Jig and permroll magnet, proved to be very fine grained, which may prevent its viability as a mineral of economic interest (Ross, 1991).

Ross (1992) concludes:

- a monazite product could be produced fairly easily from the Kelsey Jig concentrate utilising a permroll magnet and wet table at +85% recovery;
- a zircon product could be produced, although with a low rate of recovery (about 55%), due to iron contamination; surface cleaning will be requirered to meet specifications;
- it is not considered possible to produce an anatase concentrate utilising conventional mineral sands processing techniques, due to complex nature and a very fine grain size;
- a garnet fraction was produced from the Kelsey Jig concentrate utilising a permroll magnet. However, due to the fine grain size it is doubtful whether it will be of any economic interest.

Mining of the loosely cemented sandstones of the Charcot Bugt Formation on "Hill 800" would be by open cut techniques. Provided the heavy mineral sand lenses are unconsolidated then the run of mine feed could easely be upgraded by a simple screening process (Ross & Brown, 1991).

### 3.6.4 **Remarks**

Due to the very low $TiO_2$-recoveries, and to the combination of low-grade and depressed markets for zircon and monazite, the joint venture agreed not to proceed with the project (Ross, 1992).

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ISSN 0903-7322