GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT Nr. 56

The Geological Survey of Greenland
Report No. 56

A survey of the economic geology of Greenland (exclusive fossil fuels)

by

Bjarne Leth Nielsen

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index

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Abstract

A short summary of the major geological divisions in Greenland and the mineralizations within each region is presented. Each economically important element is treated separately.

CONTENTS

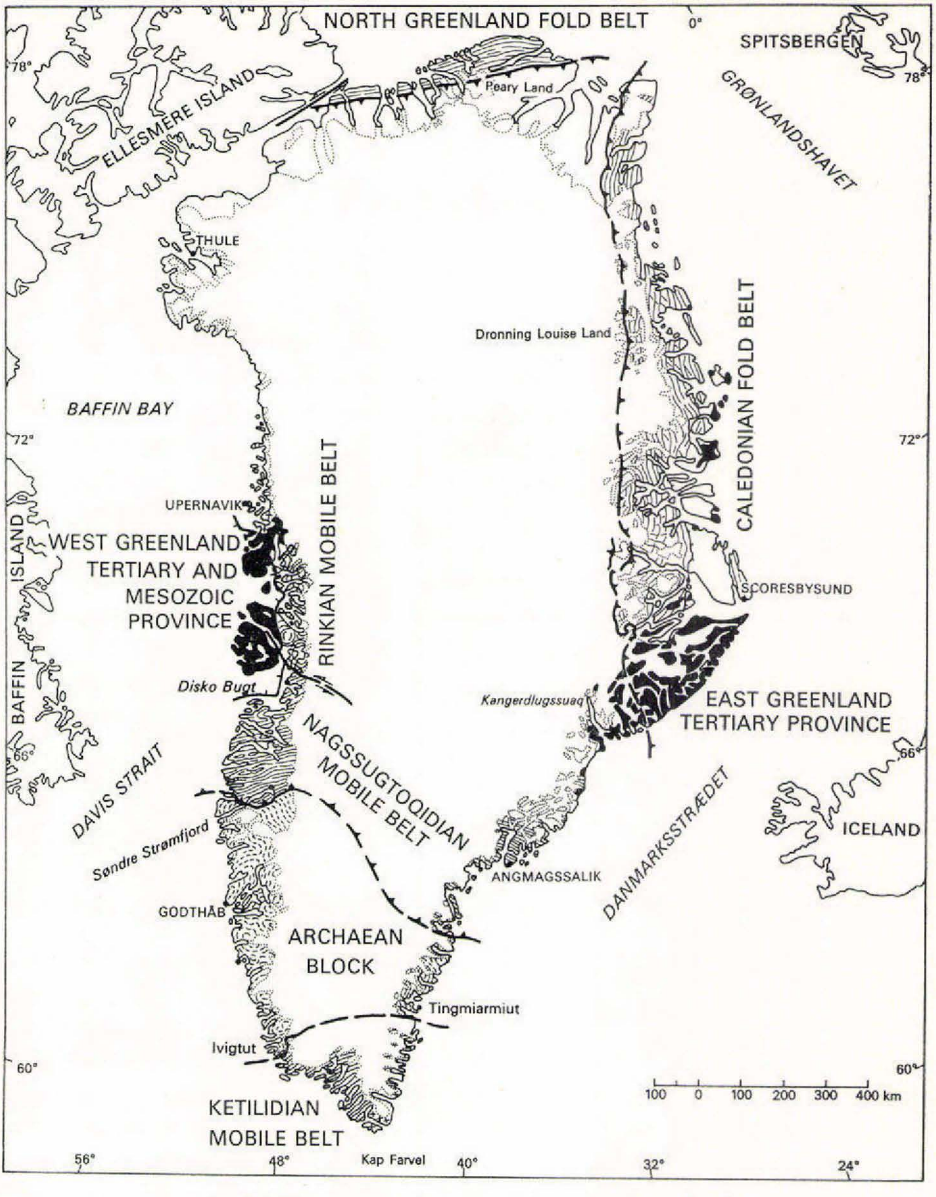

Fig. 1. The main geological divisions in Greenland.

INTRODUCTION

The most recent summary of the economic geology of Greenland is that of Ball (1922) although some general aspects have been outlined by Petrascheck (1971) and Ridge (1972). Further information is to be published by P. W. Guild (in prep.) who is compiling a Metallogenic Map of North America. Mining operations have been limited up to the present. The cryolite quarry at Ivigtut in South-West Greenland and the lead-zinc mine at Mesters Vig in central East Greenland have been the only major operations before 1970. Development is now in progress at Mârmorilik in the Umanak area of West Greenland where a lead-zinc deposit has been known for a number of years.

Subdivision of Greenland into metallogenic provinces is not satisfactory at present due to the scattered nature of the known occurrences and the sparse information available. In this account a subdivision of Greenland into seven main geological divisions is used based on the regional mapping by the Geological Survey of Greenland. Each division, which represents a major tectonic or geological province, is briefly described and its economic potential considered. The divisions are shown in fig. 1. The localities and known deposits described in the text are given on map 1.

1. The Archaean gneiss block, central West Greenland (age 2500–3800 m. y.)

The Archaean area is dominated by high-grade gneissose rocks. Gneisses of recognizable supracrustal origin form about 10–15 % of the total rocks exposed. These are predominantly amphibolites with minor amounts of ultrabasic and aluminous schists. One belt of quartz schist, a major ironstone unit and amphibolite occurs within the Archaean block at Isua bordering the inland ice to the north-west of Godthåb. Sulphides occur within the belts of supracrustal material but so far the supracrustals are regarded as being of limited economic potential compared to the greenstones of Archaean terrains such as southern Africa, Canada and Australia. Layered basic igneous complexes form 1–5 % of the Archaean block and contain appreciable amounts of chromite. They are particularly well exposed in the Fiskenæsset area where prospecting for chromite and gemstones has taken place.

The remaining 80–90 % of the Archaean complex consists of quartzo-feldspathic gneisses of general granitic and granodioritic composition together with noritic and intermediate intrusive suites. Prospecting for nickel has been carried out on the basic members of these suites. Molybdenum is found on a regional scale in the gneisses. The Archaean block extends under the inland ice to South-East Greenland. No information on mineral occurrences is available from the eastern area.

2. The Ketilidian mobile belt, (age 1600–2500 m. y.), and the Gardar igneous province (age 1000–1300 m. y.), South Greenland

The southern tip of Greenland is an area where intense magmatic activity and metamorphism took place between 1600 and 2500 m.y. ago when the Ketilidian mobile belt was formed, and again between 1000 and 1300 m.y. ago when Gardar igneous activity occurred situated in an approximately E-W zone within the Ketilidian mobile belt.

The Ketilidian mobile belt can be divided into a number of zones approximately parallel to a general ENE-trending structure within the belt (Bridgwater *et al.* 1973):

(a) A northern zone in which low-grade metasediments and lavas overlie older basement rocks in the Ivigtut area (fig. 2). Both the cover rocks and the basement are progressively affected by metamorphism as they are traced south-eastwards. Exploration has been concentrated on the low-grade metamorphic lavas in the Grænseland and Midternæs areas on the northern margins of the belt. Small copper showings have been noted from amphibolite grade greenstones in the southern part of the Ivigtut area. Berthelsen & Henriksen (in prep.) give a summary of the economic geology of the Ivigtut area.

(b) A granitic zone (the Julianehåb granite) extends below the ice to the east coast and forms a belt of igneous rocks with little sign of mineral potential. A small copper mine was opened at Frederik den VII Mine near Julianehåb, but was soon abandoned. It is noteworthy for the occurrence of tellurides and selenides.

(c) A migmatitic gneiss zone with remnants of medium to high-grade supracrustal rocks many of which appear to have been derived from acid volcanics. No major deposits have so far been located in these rocks although sulphides have been reported from a number of localitites. Graphite schists occur within the succession. A small mine was operated near Nanortalik from 1912 to 1922.

(d) A high grade migmatitic gneiss zone at the southern tip of Greenland. It consists of cordierite-amphibolite facies gneisses intruded by a late to post-tectonic suite of norites, monzonites and rapakivi-like granites. Small hornblende-rich basic and ultrabasic bodies belonging to this suite are known from several localitites, especially north of Nanortalik. These contain sulphide cumulates with copper and nickel but not in known economic amounts. Platinum has been found associated with these bodies. The other igneous rocks appear barren apart from a regional distribution of molybdenite.

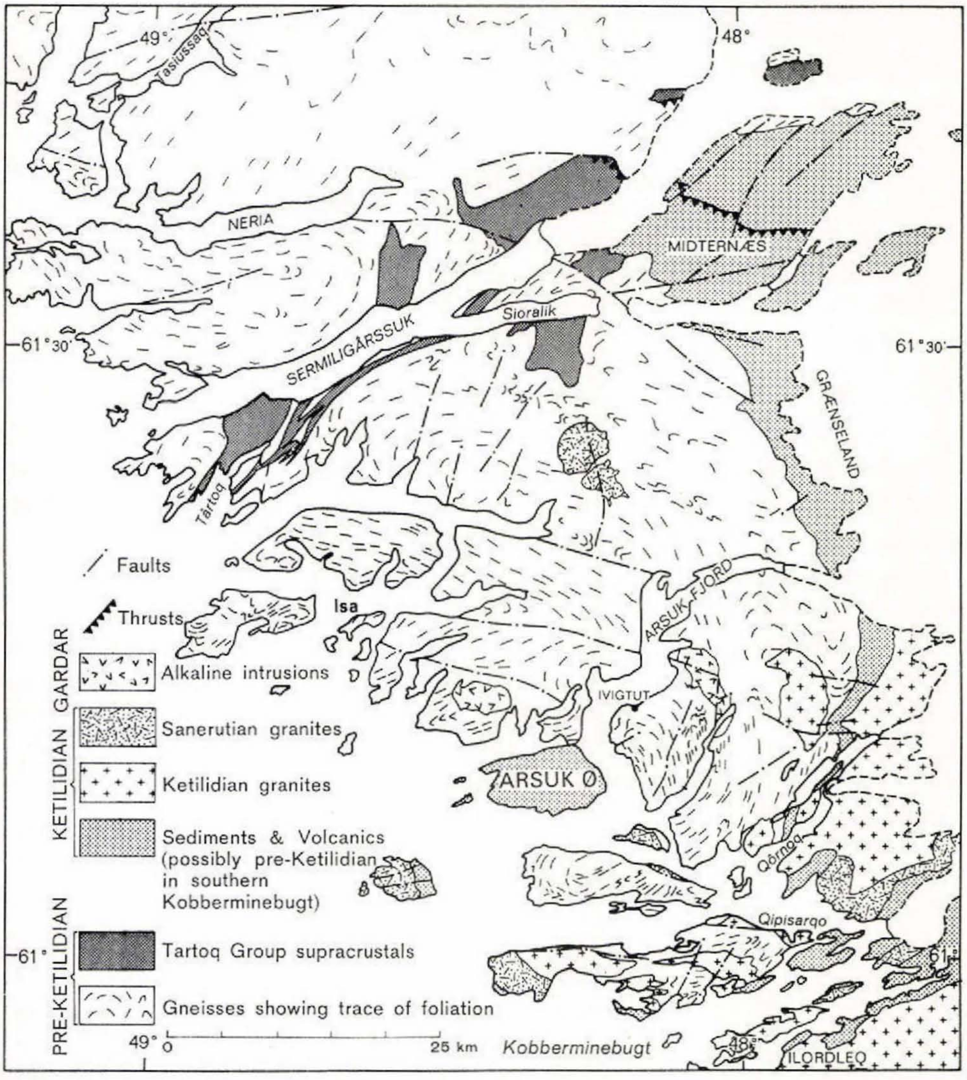

Fig. 2. Geological sketch map of the area between Kobberminebugt and Neria, South-West Greenland. After Higgins (1970).

The Gardar igneous province is found in an approximately E-W zone between Ivigtut and Julianehåb and extends to the east coast. The province contains a large number of major alkali bodies one of which contains marked concentrations of uranium, thorium, zirconium, beryllium, niobium and rare earths. The cryolite deposit at Ivigtut also belongs to the Gardar igneous suite. It contains, apart from cryolite and associated fluoroaluminates, sphalerite, galena, siderite and fluorite.

3. The Nagssugtoqidian mobile belt (age 1700–2600 m. y.)

This belt forms a 300 km wide zone north of the Archaean gneiss block. With the exception of some late intrusions on the south-east coast, the mobile belt consists almost entirely of Archaean gneisses reworked in several periods of Proterozoic tectonism which have imparted a general approximately ENE-trending fabric on the gneisses. Small patches of presumed early Proterozoic supracrustals has been reported near the boundary of the mobile belt. The gneisses contain scattered sulphide occurrences which appear to be mainly pyritic. Graphite occurs at many localities in the supracrustal horizons preserved within the gneisses.

4. The Rinkian mobile belt

The Rinkian mobile belt is situated north of Jakobshavn and is separated from the Nagssugtoqidian mobile belt to the south by a major wrench fault. The Rinkian consists of Archaean basement rocks together with a major sequence of presumed Proterozoic supracrustal rocks (Henderson & Pulvertaft, 1967) which include a major unit of greywacke. A major lead-zinc deposit has been located associated with an extensive marble sequence within the reworked Archaean gneisses at Mârmorilik.

In the Thule district the Precambrian basement is overlain by mid- or upper Precambrian sediments and Lower Palaeozoic strata. Apart from limited iron mineralization in the Melville Bugt area, placers containing ilmenite have been reported recently from around Thule Air Base.

5. North Greenland

The eastern extension of the Innuitian orogenic system of Canada forms the extreme northern part of Greenland. Undeformed Precambrian to at least Upper Silurian platform sediments in the south overlying Precambrian crystalline basement, pass northwards into the Franklinian geosyncline which in the extreme north is deformed into an E-W trending zone of deformation and metamorphism - the North Greenland fold belt. Amphibolite facies schists on the northern coast represent the highest grade of metamorphism. Platform and folded rocks are overlain by Upper Palaeozoic to Tertiary sediments of the Wandel Sea Basin.

The main diastrophism in northern Greenland is of mid-Palaeozoic age (pre-Pennsylvanian) and both geosynclinal and Wandel Sea Basin sediments were deformed in the late Phanerozoic (Cretaceous-Tertiary). At this time the Lower Palaeozoic metasediments of the fold belt were thrust northwards over the Kap Washington Group of presumably Tertiary, mainly acid, volcanics.

Mineral exploration has only been carried out in recent years. So far the main discoveries are lead and zinc mineralizations in the Lower Palaeozoic reef carbonate rocks, as well as sulphide mineralization in geosynclinal sediments of comparable age.

6. The Caledonian fold belt in East Greenland

The Caledonian fold belt consists of a variety of rock assemblages ranging from mid-Precambrian gneiss complexes and metasedimentary sequences to late-Precambrian miogeosynclinal and Lower Palaeozoic sedimentary sequences. These are affected to a varying degree by Caledonian deformation and metamorphism and by the intrusion of late-kinematic granites. The western part of the fold belt is characterized by thrusts generally dipping eastwards. A general description of the fold belt is given by Haller (1970). Information on mineralizations in the region is very limited and no general metallogenetic patterns have been established. Only small vein-type occurrences have so far been recorded.

The post-Caledonian cover rocks in East Greenland comprise Upper Palaeozoic molasse-like sediments (sandstones, arkoses, conglomerates) and Mesozoic marine to epicontinental shales and sandstones. A few mineral showings are known from the sediments and from Tertiary hydrothermal impregnations. Sulphides have been discovered in sediments south and east of Werner Bjerge, and placers containing thorium and zirconium have been found in Jurassic sandstones on Milne Land. Uranium mineralization has been located in a fault zone between late kinematic granites and Permian arkoses.

7. Tertiary igneous activity

Tertiary plateau basalts cover large areas in both West and East Greenland. Post-basaltic granitic, gabbroic and alkaline intrusions are present on the east coast. The alkaline intrusive activity in East Greenland resulted in many occurrences, usually small, of hydrothermal lead mineralizations in the Palaeozoic sediments. One of these, a lead-zinc sulphide deposit near Mesters Vig, has been worked out. A large molybdenum mineralization occurs associated with the alkaline intrusion of Werner Bjerge. In West Greenland the Igdlukúnguaq nickeliferous pyrrhotite mineralization on Disko is of Tertiary age.

METALS

Iron

Isua

At Isua, north-east of the head of Godthåbsfjord, Kryolitselskabet Øresund A/S located a wide magnetic structure by an aeromagnetic survey in 1965. During the following two years, 1966 and 1967, the company carried out comprehensive investigations in the area, which resulted in the delimitation of the Isua iron ore deposit.

The iron ore deposit is located in the easternmost part of an approximately 80 km² magnetic anomally at the rim of the ice cap, and partly covered by it. The measured thickness of ice over the covered part of the ore zone varies up to a maximum of 100 m.

The ore body forms a conformable, steeply dipping sheet with a thickness of about 200 m in the visible parts. The taconite ore is typically composed of thin-banded, quartz-magnetite rock with carbonate minerals as a common accessory constituent. According to a conservative estimate the total ore reserves are about 2×10^9 tons with an average grade of 38 % Fe.

The general geological structure of the area is that of an elliptic antiform in basement gneisses surrounded by a belt of metamorphosed supracrustal rocks. The latter comprise siliceous schists, the iron formation and greenschists having recognizable sedimentary and volcanic characteristics. The supracrustal series is isoclinally folded.

The Isua iron formation, which genetically can be compared to the Superior type metataconite formations in the sense of Gross (1965), has a thickness of more than 1.5 km. It consists of two sequences which reflect different environmental conditions during the deposition of the material.

The lower section represents a siliceous facies and consists of garnet-chlorite-biotite schists characterized by iron-rich varieties of constituent minerals. Magnetite is among the accessory minerals.

The upper sequence, which represents a calcareous facies, comprises a banded series consisting of quartzite, magnetite-rich bands, calc-silicate rocks, amphibolites and siliceous limestone. In the main ore zone the principal rock is a thin banded magnetite-bearing quartzite. Metamorphism and tectonic deformation have caused secondary enrichments in the ore zone.

Magnetite is the main ore mineral throughout the iron formation. Haematite has been observed only as an alteration product of magnetite (martite) or as secondary specularite.

Grønnedal-Íka (Jernhat)

At Grønnedal-Íka near Ivigtut iron-rich carbonatites have intruded the syenites of the alkaline complex (Emeleus, 1964). The carbonatites contain siderite, mag-

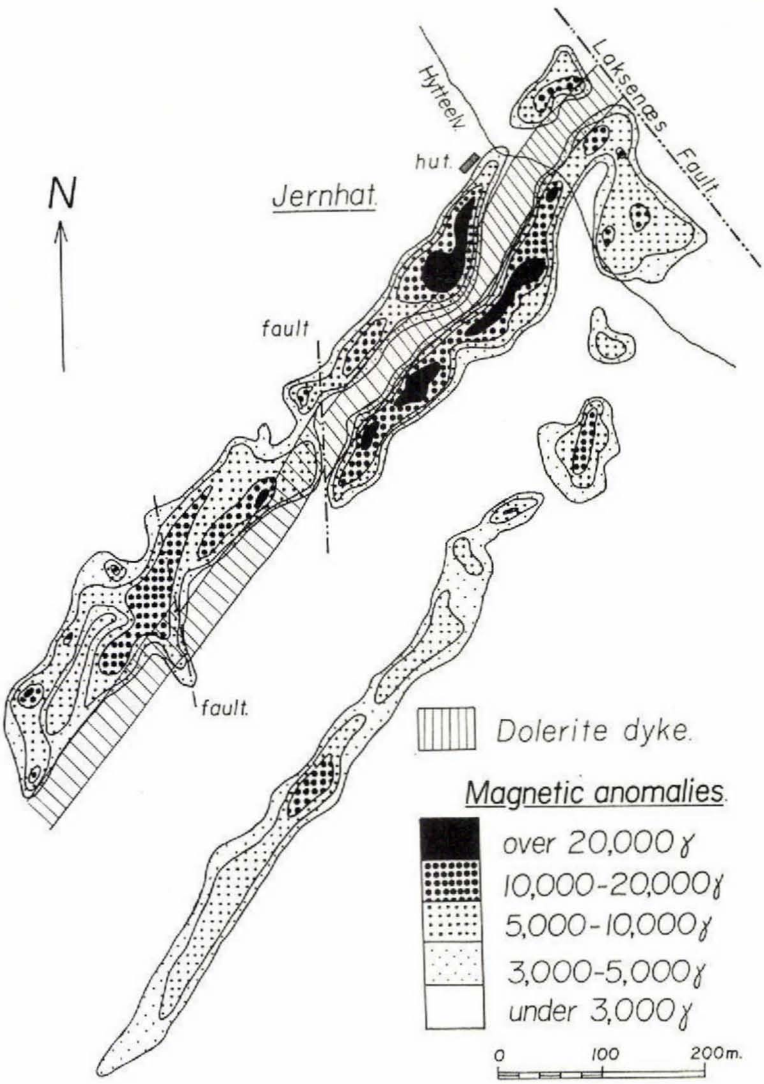

Fig. 3. Sketch map showing the magnetic anomalies associated with the iron ore body at Jernhat, near Ivigtut, South-West Greenland. The southern, smaller anomaly is associated with a swarm of close-spaced dykes of microporphyritic basalt. After Emeleus (1964).

netite and a little sphalerite. The magnetite, which is most abundant where the carbonatites are cut by dolerite dykes, seems to occur as pseudomorphs after siderite. This suggests formation of magnetite during contact metamorphism of the siderite-bearing carbonatite at the time of dyke intrusion. The sites of magnetic anomalies (fig. 3) have been drilled, and on the basis of this work the occurrence is regarded as without economic importance (Bøgvad 1951). Workable amounts of ore containing 25–30 % iron were estimated at 800,000 tons. The carbonatites are fairly rich in strontium, lanthanum and yttrium. Radioactive anomalies caused by thorium have been detected.

Grænseland

In the Ketilidian supracrustal series at Grænseland north-north-east of Ivigtut some magnetite-bearing horizons occur in quartz conglomerates in the lowermost part of the supracrustal sequence. The conglomerates have a thickness of 4 to 6 metres and the main magnetic band is 0.8 metres thick. The concentration of iron is 20–40 % Fe. The conglomerates and associated quartzites are of a black or rusty colour due to a small content of pyrite, suggesting a reducing chemical environment during their formation. Thin horizons of marl of a schistose character are intercalated with the quartzite. This magnetite occurrence has been described by Bondam (1961), Bondesen (1961) and Ketelaar (1961). It is considered to be of no economic importance.

Disko

On the island of Disko some Tertiary basalt flows contain native iron (Ball, 1922). The occurrence is recorded from a single sequence of lava flows of Miocene age where lenticular blobs are found in the basalt; its origin has been a subject of much discussion. A favoured theory explains the native iron as having been formed in a reducing environment since there is also graphite in the rock. The native Fe content of the basalt is less than 10 %.

Lersletten

An occurrence of mainly iron sulphides of metasomatic origin has been located at Lersletten near Egedesminde by Kryolitselskabet Øresund A/S. The mineralization is found in a folded supracrustal series, the structures of which are cut by pegmatitic granites. The sulphide minerals were originally related to horizons in the metasedimentary sequence. During formation of the granites they were remobilized and redistributed. The paragenesis comprises pyrrhotite and pyrite as main constituents together with chalcopyrite and sphalerite as accessories. A little molybdenite and arsenopyrite have been found.

The ore reserves are about 3.5 million tons of probable ore and about 12 million tons of possible ore, and the grade is 30–35 % Fe. The copper content can be as much as 0.5 % and the zinc content approximately 2 %. The grades of copper and zinc in the ore are, however, rather low in economic terms.

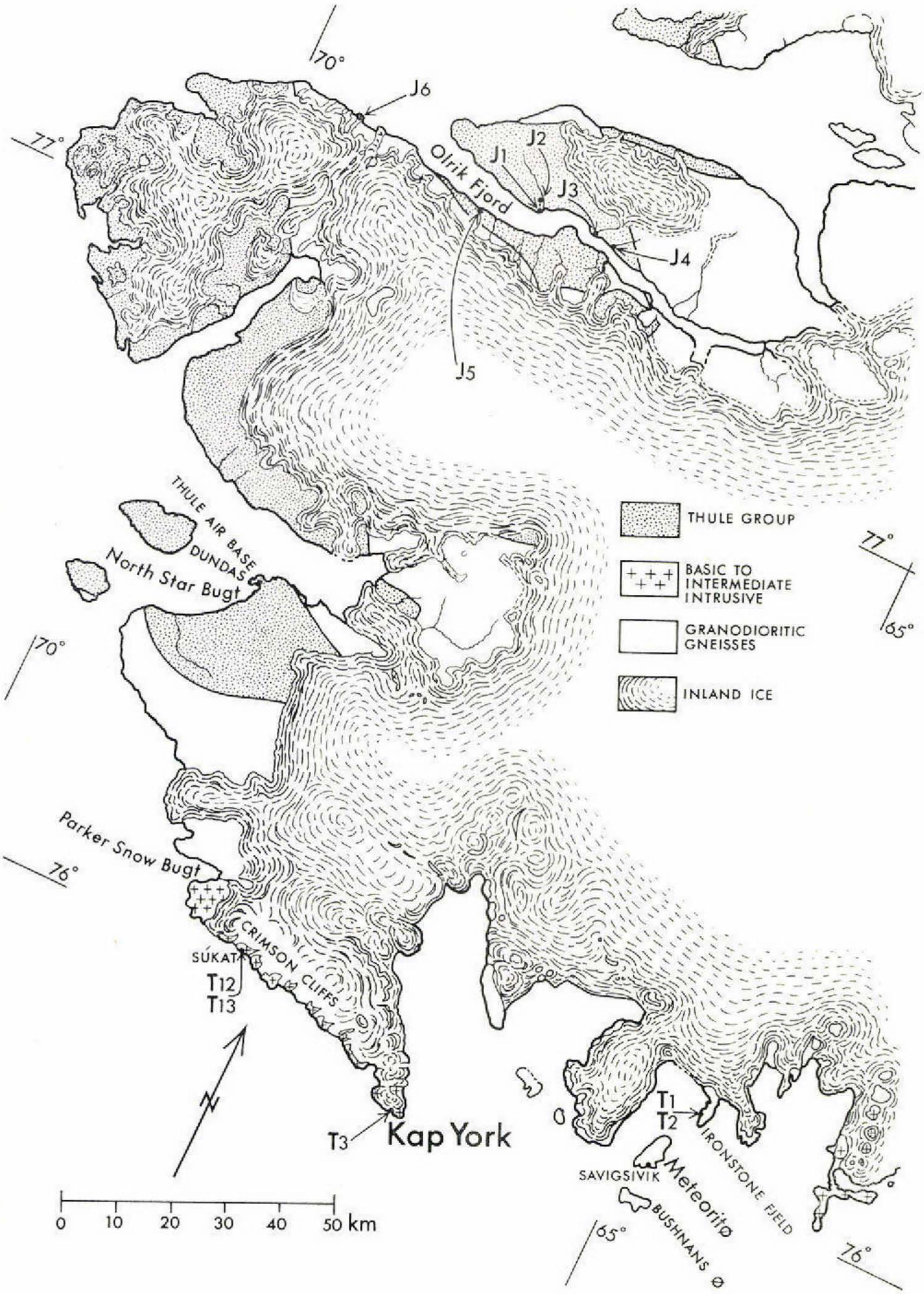

Fig. 4. Geological sketch map of the Thule area, North-West Greenland, redrawn after the Tectonic/geological map of Greenland (Geological Survey of Greenland, 1970), indicating titanium-bearing sand sample locations. After Ghisler & Thomsen (1971).

Melville Bugt

Some iron deposits have been reported from the northern part of Melville Bugt (fig. 4) near Bushnan Ø and Parker Snow Bugt (Bøggild, 1953). The ore is fine grained and quartz banded, containing both haematite and magnetite; Bøggild mentions a grade of 35–40 %. The dimensions of the ore bodies are unknown.

Copper

Copper sulphides are found at a great number of localities along the west coast of Greenland, but up to the present no deposits of major economic importance have been discovered. Copper sulphides are abundant in the Sermiligârssuk area and in the Kobberminebugt area around Ivigtut (fig. 2). The mineralization is almost exclusively confined to supracrustal successions, mainly the greenschist members.

Kobberminebugt

At the south coast of Kobberminebugt two small deposits, Josvaminen and Lilianminen, were mined at the beginning of the century; the total production was about 90 tons of copper. The mineralization has been described by Ball (1922), Harry & Oen Ing Soen (1964) and Ghisler (1968). The copper ore, which is regarded as of hydrothermal origin, was deposited along faults and as fracture fillings in a metavolcanic series; the mineralization is associated with a mylonitized uralite porphyrite. The copper minerals are chalcocite and a smaller amount of chalcopyrite and bornite; magnetite is also present. The size of the ore body at present is estimated at 2000–3000 tons of ore containing 30–40 tons of copper; it is therefore of no economic value.

Within the same area copper mineralization also occurs at Kînâlik and Qipisarqo. They were investigated by Kryolitselskabet Øresund A/S. At the former locality copper sulphides, mainly chalcopyrite, have crystallized in contact-metasomatized calcareous rocks. The sulphide paragenesis is similar to that at Josvaminen, and in addition a few grains of gold have been found. At Qipisarqo the sulphides occur as impregnations in black shales and as a matrix in breccia zones. The dominant sulphide is pyrrhotite and the Cu content is generally less than 0.05 %.

Sermiligârssuk

In the Sermiligârssuk area some copper sulphides have been found in quartz veins. The copper is probably derived from the greenschists by hydrothermal activity.

Holsteinsborg-Umanak

On the west coast between Holsteinsborg and Umanak, Kryolitselskabet Øresund A/S has discovered several sulphide mineralizations. They are generally iron sulphides with a low copper and nickel content. The mineralizations are located in association with the following rock types:

1. Carbonaceous schists of low to medium metamorphic grade,
2. Carbonaceous banded gneisses of medium to high metamorphic grade,
3. Layers of basic rocks in the gneisses,
4. Basic and ultrabasic intrusive bodies,
5. Fault and fracture zones of various origin.

A sulphide mineralization between Nordre Strømfjord and Ataneq, belonging to groups 2 and 4 and described by Platou (1967) is located parallel to an overthrust in the migmatite complex of Isortoq. The mineralization is found as lenses 5 to 100 metres long, with quartz as the gangue mineral. Pyrrhotite and a small amount of pyrite and chalcopyrite have been identified and graphite is found within the lenses. The copper and nickel content is at present considered too low to be of economic importance.

Julianehåb (Frederik VII Mine)

On a small Island east of Julianehåb a small copper deposit, Frederik VII Mine, was discovered at the beginning of the 19th century (Ball, 1922). Selenides, tellurides, bornite, chalcocite and secondary malachite and azurite were found contained in a pegmatitic quartz pocket in the Julianehåb granite. In 1851, when the deposit was exhausted, only about 15 tons of ore had been recovered.

Nanortalik

In the Nanortalik area a small quantity of sulphides occurs in meta-conglomerates in a supracrustal series (H.K. Schønwandt, personal communication). These conglomerate horizons have a maximum thickness of 100 metres. The following ore minerals have been identified: chalcopyrite, bornite, sphalerite, galena, ilmenite, magnetite and graphite. The sulphide content is about 2 % in the richest zones.

Sukkertoppen

In the Suppertoppen district, in the area between Søndre Isortoq and Fiskefjord, Kryolitselskabet Øresund A/S has investigated several sulphide mineralizations. Detailed geological and geophysical field investigations as well as drilling have been carried out extensively. The following description is based on unpublished company reports.

The most interesting type of mineralization from an economic point of view is an early magmatic sulphide segregation type containing nickel and copper with appreciable amounts of platinum metals.

The mineralizations are found in a series of plutonic rocks of predominantly noritic composition. The rocks in this series show compositional variation from ultramafite to norite in a manner which indicates in situ differentiation.

The norite association is found in an arcuate belt with an extent of about 15 × 75 km. Within this belt norites form a number of plutonic bodies which are conformable with the enclosing high metamorphic gneisses. The lateral dimensions of the individual bodies vary from about 2 × 4 km to only a few metres across.

The rock in these bodies is medium- to coarse-grained, with randomly oriented hypersthene and andesitic plagioclase as main constituents. Along the host rock contacts and in certain zones within the noritic intrusives deformation produced foliated and partly cataclastic rock varieties, with mineral parageneses indicating retrograde metamorphism.

The mineralizations, of which more than 50 have been closely studied at different localitites, show uniform mode of occurrence and composition. The intensity of the mineralization varies from a weak interstitial dissemination to a continuous network of sulphides enclosing silicates. Secondary, epigenetic enrichment is observed in zones of tectonic weakness but only within the noritic host rock.

The ore mineral paragenesis is the same everywhere: pyrrhotite-pentlandite-chalcopyrite-pyrite, with magnetite and ilmenite as the most common accessories. Bravoite (or violarite) and "wasserkies" occur frequently as secondary minerals. Covellite, chalcocite, cuprite, native copper, azurite and malachite have been observed as supergene alteration products.

Massive sulphide ore has the following ratios; all calculated from weight percentages:

$$\text{Ni in the pure sulphide phase: } 9\,\%$$
$$\text{Cu} : \text{Ni} : \text{Co} = 40 : 100 : 3.3$$
$$\text{Ni} : (\text{Pt} + \text{Pd}) = 43000 - 56000 : 1$$

Tentative estimates of ore reserves have been made for ten potential deposits, but so far tonnages have been considered insufficient for economic exploitation.

Wegener Halvø

On Wegener Halvø in central East Greenland (fig. 5) disseminated sulphides occur in Permian bituminous shales interbedded with bituminous limestone (Thomassen, 1973). The mineralization is classified as syngenetic sedimentary comparable to the European Kupferschiefer. A profile, trenched and investigated by Nordisk Mineselskab A/S, revealed that the known mineralization is at present con-

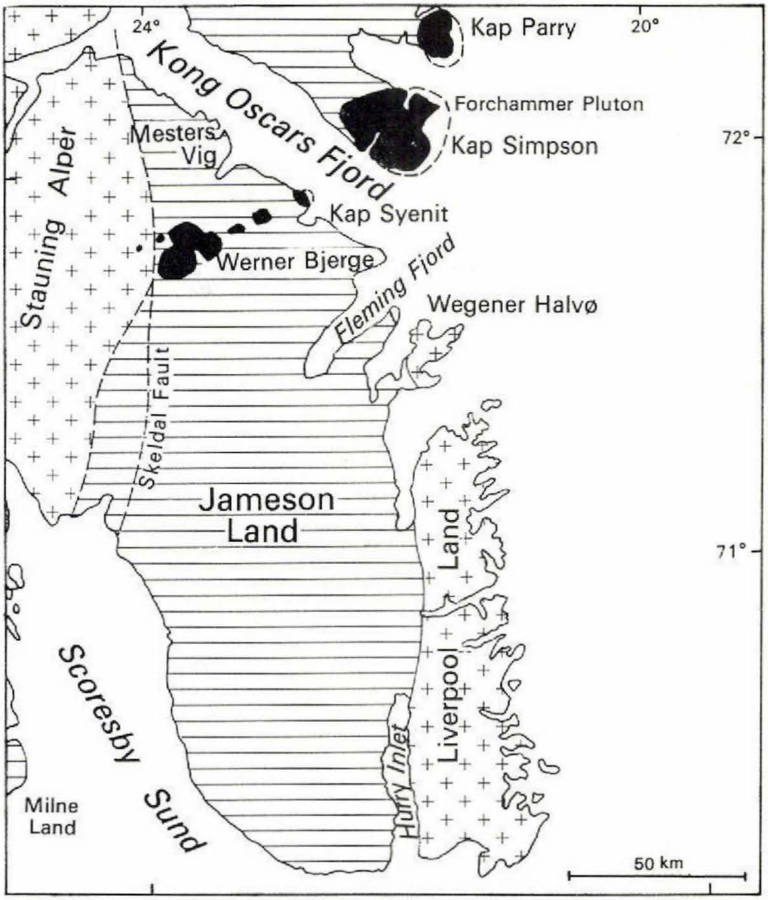

Fig. 5. Geological sketch map of part of central East Greenland showing the economic mineral localities at Mesters Vig and Werner Bjerge. *Black:* Upper Cretaceous to Tertiary igneous rocks; *ruled:* Palaeozoic and Mesozoic sediments; *crosses:* Caledonian crystalline complex and late Precambrian metasediments.

sidered without economic value. Minerals identified include pyrite, chalcopyrite, galena, sphalerite, molybdenite and arsenopyrite. Optical spectrographic and XRF analyses showed the following metal concentrations:

Cu:	0.05 %
Zr:	0.05–0.15 %
Pb:	0.10–0.70 %
Ni:	0.02 %
V:	0.01–0.03 %

Lead and Zinc

Mesters Vig (Blyklippen)

In the Mesters Vig area in central East Greenland (fig. 5) several minor lead-zinc mineralizations are found. Some of the localities are Lomsøen, Biskop Alfs Gletscher (Breithorn Gletscher), Rungsted Elv and Blyklippen. Except for the Breithorn Gletscher occurrence the ore minerals are found in quartz veins genetically related to the Tertiary alkaline intrusives of Werner Bjerge (Bearth, 1959).

The largest occurrence, that at Blyklippen, is now exhausted and has been abandoned. The ore body was situated within a series of sandstones with intercalated conglomerates, shales and arkoses ranging in age from Upper Carboniferous (Westphalian) to Lower Trias. The deposit is described by Bondam & Brown (1955). The sedimentary environment is limnic fluviatile and the mineralization occurred in the Blyklippen Series of the lower Upper Carboniferous. The sandstone is faulted and brecciated along the faults, the mineralization of galena and sphalerite occurring in NNW-striking veins dipping steeply to the ENE. The gangue is normally quartz. The width of the veins varies from a few metres to more than 50 metres. The mineralization was mainly confined to veins of medium width close to the footwall of the main fault.

The deposit was discovered in 1948; drilling was undertaken in 1951 and 1953 and mining operations lasted from 1956 to 1963; 58,000 tons of galena concentrate and 75,000 tons of sphalerite concentrate were recovered. The mean concentrations of the ore were 12 % Pb and 10 % Zn. Kempter (1961) reported veins of galena, sphalerite and barytes in shear zones in arkoses in southern Scoresby Land. They are not accompanied by quartz like the mineralization in the northern area.

Mârmorilik (Sorte Engel)

A lead-zinc mineralization was discovered in 1938 at Mârmorilik in the Umanak area. The occurrence was named Sorte Engel (Black Angel) after an angel-like black outcrop of pelitic schists on the steep cliff facing the fjord (fig. 6). The mineralization is, however, located in a rusty looking zone above the "angel". Because of very difficult accessibility the occurrence was not explored in detail until the 1960s. Recent investigations have shown that the sulphides occur in at least two separate zones: (1) the Black Angel zone, and (2) the Cover zone. Drilling to the end of 1967 by Greenex A/S, who hold an exploitation concession, indicated the mineralized zones as reaching about 10 metres maximum thickness. Reserves were estimated at 2.5 million tons of ore containing 16.5 % zinc, 4.5 % lead and 27 g/ton silver. Underground development and drilling in 1972 revised these estimates upwards to 4.5 million tons, and production development has begun.

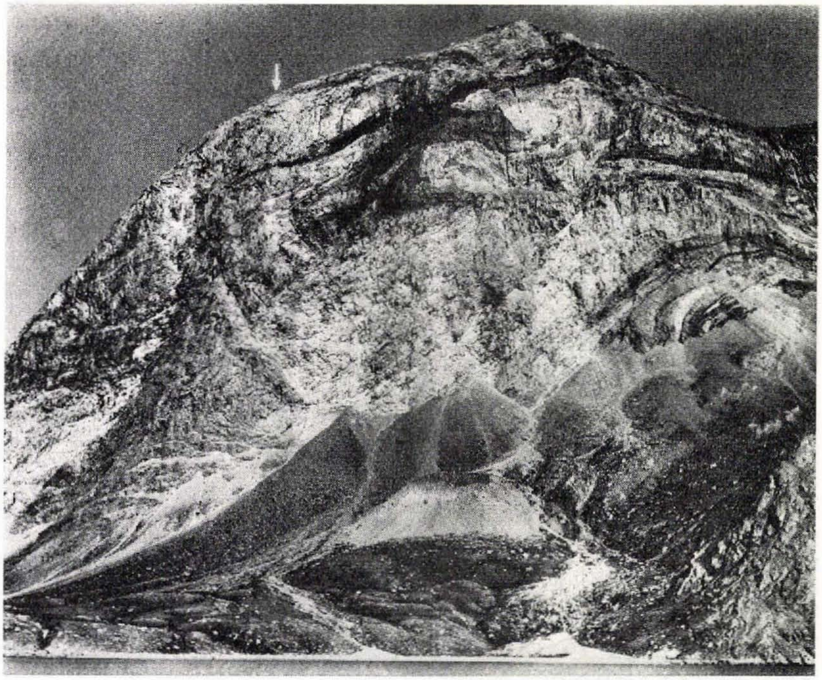

Fig. 6. Sorte Engel. The cliff at Mârmorilik (northern West Greenland) before mining development started. The angel-like figure just below the mineralization is seen in the top of the picture. The arrow indicates the ore-bearing horizon.

Chromium

Fiskenæsset

In 1964 chromite layers were discovered in a folded anorthosite complex in the Fiskenæsset area. The chromite-bearing horizons were found to extend over an area of more than 10,000 square kilometres (fig. 7). The chromite-layered anorthosite is associated with a series of ultramafic rocks including hypersthene amphibolite, pyroxenite, peridotite and hornblendite (Windley, 1967, 1969). Some of the rock types within the ultramafic series may contain sapphirine, corundum, spinel and garnet. The anorthosite is conformably enclosed in the surrounding gneiss complex. The chromite-bearing units are of two types: (a) chromitite and anorthosite alternate in few centimetres thick layers (fig. 8) and, (b) porphyroblastic augen of calcic plagioclase occur in a matrix of chromitite (fig. 9). The ore-bearing units may reach a thickness of about 20 metres. They are commonly from 0.5 to 3 metres wide.

Windley concludes from the layering in the chromitite that the anorthosites formed as a pre-orogenic stratiform complex by gravitational accumulation in a

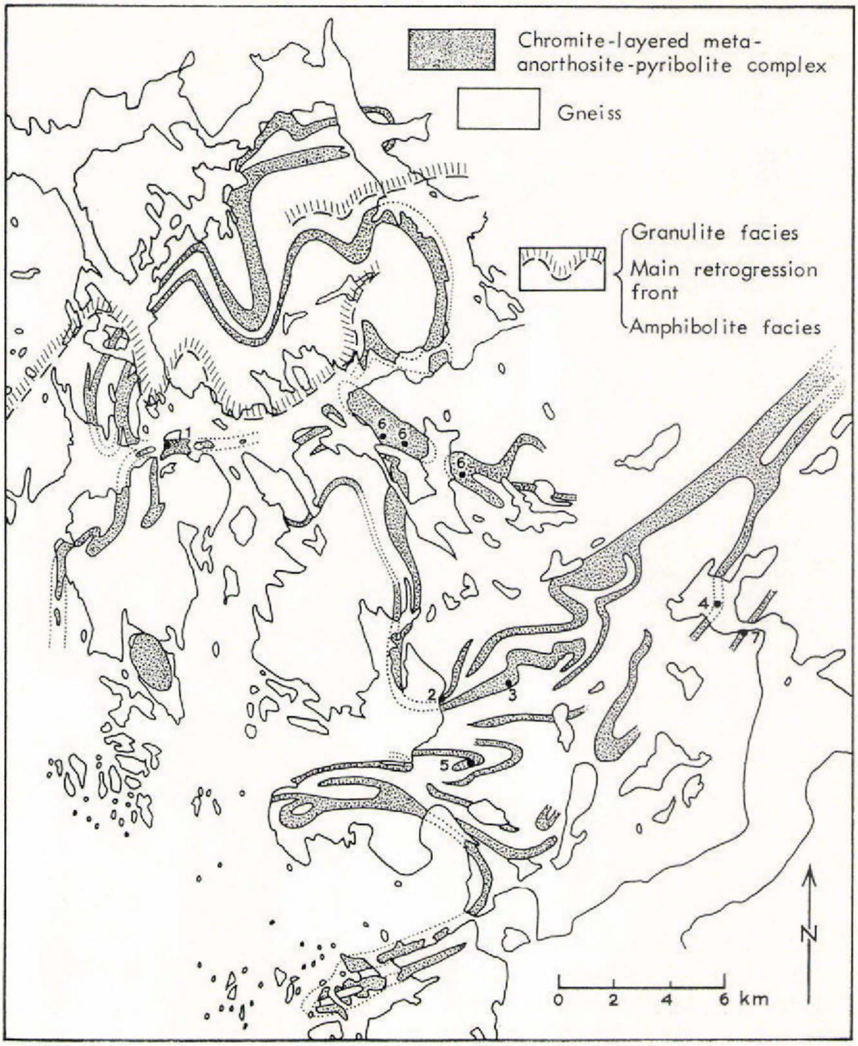

Fig. 7. Sketch map of the Fiskenæsset region showing the chromite-bearing anorthosite complex. The numbers refer to sapphirine localities. After Herd *et al.* (1969).

basic magma. The complex was subsequently affected by folding and regional metamorphism.

The mean content of Cr_2O_3 of the chromite-bearing horizons is 32.7 % (Ghisler & Windley, 1967), the FeO content is 31.8 % and the V_2O_5 content about 0.3 %, the Cr/Fe ratio averaging 0.93. A preliminary tonnage calculation estimates about 2.5 million tons of chromium ore containing 350,000 tons Cr_2O_3 and 3,000 tons V_2O_5. The latter figures refer to a restricted area comprising

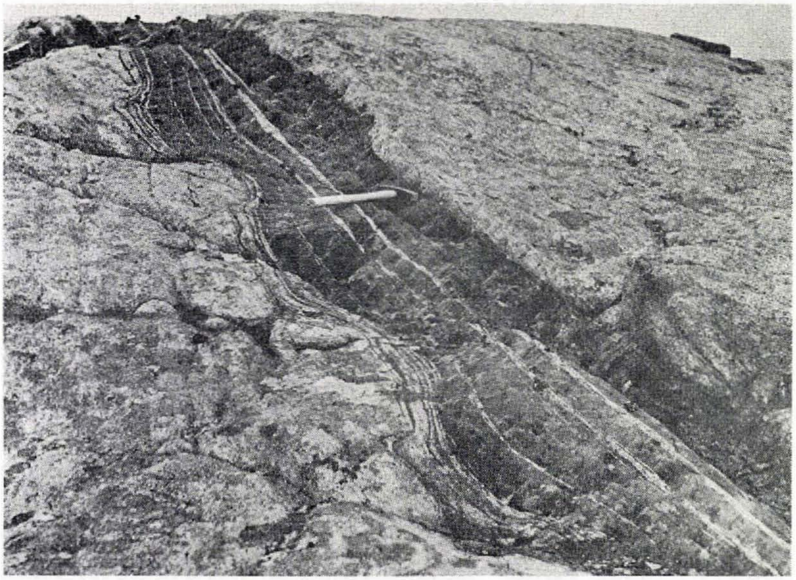

Fig. 8. Chromite horizon of layered type with thin intercalated anorthosite layers. (After Ghisler & Windley, 1967)

Fig. 9. Detail of an augen-type chromite horizon. The sample shown is 25 cm across. (After Ghisler & Windley, 1967)

the main chromite horizons. An estimate of the total amount of ore within the whole region has not been attempted. At present it is not known if mining of the chromite would be economically viable.

Itipilua

Chromite occurs in the Itipilua dunite (see p. 37) mostly as an accessory constituent. However, in the northern part of the massif the peridotite forms a chromite-banded variety in which chromite-rich bands vary from 0.5 cm to 30 cm in thickness. The dimensions of this "ore zone" are about 5–9 m × 600–700 m, but the grade, averaging 5 % Cr_2O_3, renders the deposit at present uneconomical.

The mean Cr_2O_3 content of the pure chromite is 44.3 % and the ratio Cr/Fe is about 1.2.

Fiskefjord

In the Fiskefjord region chromite-banded peridotitic layers similar to those at Itipilua have been observed in pyroxene amphibolite horizons at six localities.

Molybdenum

Molybdenite is known from a fairly large number of localities in Greenland, most of which only contain insignificant indications of ore. Two localities which have been investigated will be described in some detail.

Werner Bjerge (Malmbjerg)

In 1954 a molybdenite occurrence named Malmbjerg was discovered in Werner Bjerge in central East Greenland (fig. 5), immediately east of the fault zone which separates the late Caledonian Stauning Alper from the Upper Palaeozoic and Mesozoic sediments of Jameson Land and Scoresby Land. The Werner Bjerge are composed of a number of Cretaceous-Tertiary intrusive complexes, which were intruded along the coastal zone of East Greenland between Angmagssalik and Kejser Franz Josephs Fjord.

The complexes described by Bearth (1959) comprise a series of pyroxene granites, alkali granites, alkali syenites and nepheline syenites. The intrusive episodes were followed by pneumatolytic and hydrothermal activity which affected both the intrusive rocks proper and the surrounding Carboniferous sediments. Within the intrusive area the mineralization is limited to the alkali syenites and alkali granites.

During the decomposition of the older rocks, ore-bearing solutions were introduced diffusively along fissures and cracks in the host rocks. The impregnated

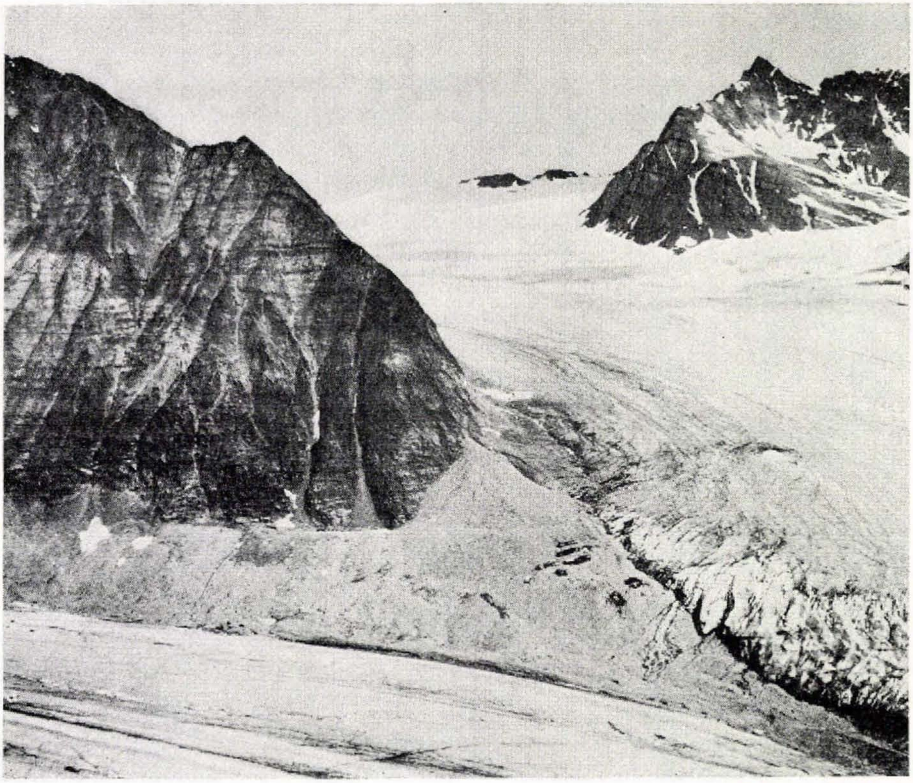

Fig. 10. The old drill camp at the foot of the molybdenum mineralization at Malmbjerg, central East Greenland. Note the unfavourable position of the deposit between the two glaciers.

zones are conspicuous by their multicoloured appearance in red, yellow and ochre shades caused by coatings of haematite and limonite. Both sediments and granites are locally pyritized.

The ore-impregnated zones are enriched in the following elements: Fe, Mn, Ti, Zr, Nb, W, Bi and Mo. Among these Ti, Zr and Nb are thought to have originated from the decomposition of the mafic minerals in the alkali syenites and were later redeposited together with the other elements enriched in the magmatic residues. The molybdenum deposits in Werner Bjerge also contain a little silver.

At Malmbjerg alkali granite was intruded into Carboniferous sandstones, arkoses and shales. Both the granite and the sediments were later mineralized. Several ore parageneses have been demonstrated representing magmatic, pegmatitic, pneumatolytic and hydrothermal phases. The following ore minerals have been determined: molybdenite, wolframite, galena, sphalerite, chalcopyrite, pyrite, pyrrhotite, marcasite, siderite, magnetite, rutile, ilmenite, titanite, zircon and bismuth. Patches with molybdenite are found in the sediments up to 200 metres from the contact to the granite. At the border zone between sediments and granites both rocks are altered into a 1 m wide greisen characteristically containing topaz and wolframite. The molybdenite mineralization of the inner granite stock is mainly found as joint and fissure impregnations. The ore grade decreases downwards in the granite. Mineralization younger than the molybdenite encompasses quartz veins with galena, sphalerite and chalcopyrite. Such ore-bearing quartz veins can be found several kilometres from Malmbjerg. Also dykes and late hydrothermal veins of fluorite and calcite can be mineralized.

The mineralizations at Malmbjerg show a general resemblance to the pneumatolytic molybdenite mineralizations in the "Erzgebirge" (central Europe) and the deposits of Climax in Colorado.

The deposit has been extensively investigated by drilling by Arktisk Minekompagni A/S and the reserves have been estimated at 117 mill. tons with a grade of 0.25 per cent MoS_2. The deposit has not yet been put into production mainly on account of large initial costs arising from the difficulty of establishing transport facilities in this remote area (fig. 10).

Ivisârtoq

It Ivisârtoq peninsula, at the head of Godthåbsfjord, a molybdenum showing was discovered and explored by Kryolitselskabet Øresund A/S in the early 1960s.

The geological features of the peninsula are dominated by a supracrustal series of schists and amphibolites which are cut by ultrabasic bodies, dolerite dykes and granite pegmatites. The supracrustal rocks are of both sedimentary and volcanic origin.

Sulphide accumulations are found in shear zones and the most marked of these is found as a rusty horizon between a layer of quartz-feldspar schists and an overlying amphibolite. In this zone molybdenite occurs as an accessory in a pyrite mineralization together with sporadic chalcopyrite. The mineralization is considered to be a metasomatic product formed by reaction between the supracrustal rocks and hydrothermal solutions and volatiles introduced during late-kinematic phases. The mineralization was controlled by shear zones. At its best the sulphide mineralization occupies an area with dimensions of about 10–15 m × 2500 m. Chemical assay figures vary from 0.10 % to 0.80 % MoS_2 in individual samples, but the grade as a whole is too low to justify further exploration at present.

Nickel and Platinum

Nanortalik

In the Nanortalik area of South Greenland ultramafic dyke-like bodies were intruded during Ketilidian time into the granitic and gneissic basement. These ultramafic bodies are sometimes mineralized and may contain iron, copper and nickel sulphides and associated platinoids, gold and silver (Berrangé, 1970). The principal localities are: Amitsoq, Sarqâ and the south coast of Søndre Sermilik north of Nanortalik, and Eggers Ø at Kap Farvel.

On Amitsoq occurs an ultramafic body 1.5 kilometres long and 100 m wide (H. K. Schønwandt, personal communication). In the west the body constitutes a differentiation series from hornblende-peridotite to quartz-biotite-diorite; in the east it is a hornblende-peridotite. The sulphides which are thought to be early magmatic segregations are found in the intercumulus phase. The richest mineralizations, containing about 5 % sulphides, are located in areas where there is a change in the general strike direction of the body; they comprise mainly chalcopyrite and pentlandite intergrown with pyrrhotite and magnetite. Compared with mean figures (Berrangé, op. cit.) the pluton is considerably enriched in platinoids, gold, silver, chromium, copper and nickel.

Igdlukúnguaq

At Igdlukúnguaq on the north coast of Disko, nickeliferous ore is found in a dyke forming an element of the Tertiary basalt province. The mineralization so far located consists of a single block of about 28 tons weight, whose genesis has been described by Pauly (1958). The ore mineral is nickeliferous pyrrhotite. The nickel content of the ore varies from 1.91 to 4.72 % and the copper content from 0.80 to 2.35 %. The locality was excavated in 1931, and has lately received some renewed interest.

Sulphide mineralizations containing nickel are also described in the section on copper.

Uranium and thorium

Ilímaussaq (Kvanefjeld)

At present only one deposit of radioactive minerals of some importance is known from Greenland. It is situated at Kvanefjeld in the northern part of the Ilímaussaq intrusion in South Greenland (fig. 11).

The Ilímaussaq intrusion is the youngest of a number of alkaline plutons, which were intruded into the granitic and gneissic basement and a continental series of sandstones and lavas during the Precambrian Gardar period (Upton, 1962, 1964; Bridgwater, 1965; Watt 1966). General descriptions of the Ilímaussaq intrusion have been given by Ussing (1912), Sørensen (1958) and Ferguson (1964, 1970).

The intrusion consists of an older series of alkaline syenites and granites and

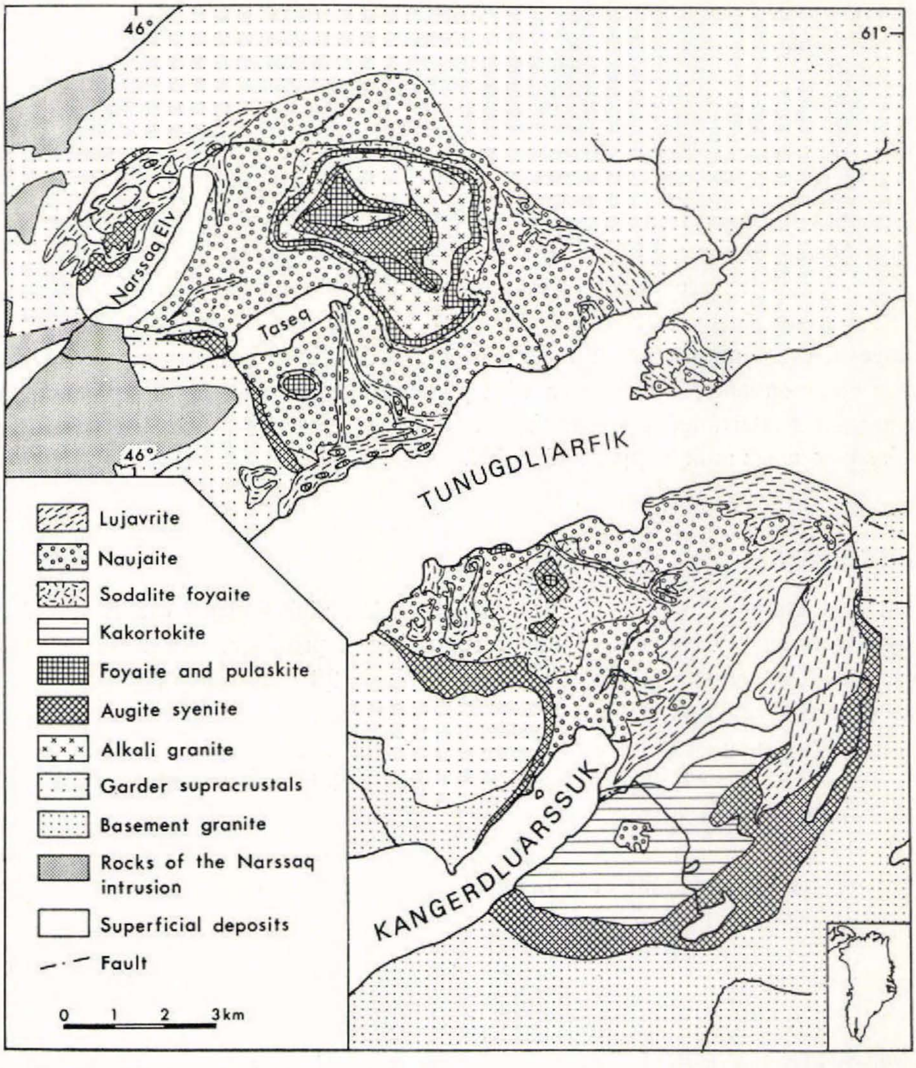

Fig. 11. Simplified geological map of the Ilímaussaq alkaline intrusion in South Greenland, based on the map of Ferguson (1964).

a younger series of undersaturated nepheline syenites. The latter are characterized by an increasing trend towards undersaturation (agpaitic) during magmatic differentiation. The highest concentrations of uranium, thorium and other rare elements occur in the latest derivates, the lujavrites: these are essentially arfvedsonite-aegirine/acmite nepheline syenites. The lujavrite magma intruded and brecciated the earlier crystallized rocks. In the Kvanefjeld area the lujavrites also intrude the overlying cap of lavas and it is here that the most intense concentra-

Fig. 12. Kvanefjeld radioactive deposit in the Ilímaussaq alkaline intrusion. The highest radioactive lujavrite is situated within the dashed lines. The lower part of the Taseq slope is in the foreground.

tion of radioactive elements occurs. The geology of the Kvanefjeld area has been described by Sørensen *et al.* (1969). The radioactivity is due to the content of steenstrupine, $Na_2Ce(Mn, Ta, Fe^{3+})H_2[(Si, P)O_4]_3$, and to a smaller extent of monazite, pigmentary material and thorite. Uranium contents of the steenstrupine range from 1000 to 1500 ppm, and thorium from 2000 to 60,000 ppm (Wollenberg, 1971). Whole rock radio-element contents of the Kvanefjeld lujavrites vary from 100 to 800 ppm uranium and 200 to 2000 ppm thorium (Løvborg *et al.*, 1971). High concentrations of radio-elements are also found where the lujavrites are cut by hydrothermal veins.

In the Kangerdluarssuk area in the southern part of the intrusion the lujavrites are characterized by eudialyte, the thorium and uranium content of which is usually a few hundred ppm. The amount of eudialyte controls the distribution of the whole-rock radioactivity (Wollenberg, 1971). Rhythmically layered agpaitic rocks termed kakortokite, characterized by varying abundances of arfvedsonite, eudialyte and feldspar, also outcrop in the Kangerdluarssuk area (see the section on zirconium).

Fig. 13. Uranium mineralization in Arkosedal, central East Greenland. The fault zone between the Stauning Alper granite and the Permian arkoses is marked with a dashed line. The mineralization is above the arrow.

The economic evaluation of the Kvanefjeld area has included detailed geological mapping and radiometric surveys (Løvborg *et al.*, 1971). A trial excavation supplied material for studies of uranium extraction processes. The radioactive minerals are refractory; the ordinary leaching techniques cannot therefore be applied (Asmund *et al.*, 1971). During the exploration of the area 35 holes were drilled. In the subsequent extensive laboratory work a large number of surface samples and drill cores were analysed to evaluate the ore reserves. The ore body within the most intensively drilled area encompassed about 18 million tons averaging approximately 300 ppm uranium (Løvborg *et al.*, 1972). The location of this ore body on Kvanefjeld is shown in fig. 12. With the current price of uranium on the world market and the expected development of supply and demand it is not at present feasible to mine the uranium at Kvanefjeld.

To the east of the Ilímaussaq intrusion radioactive veins containing rare earths, monazite and bastnäsite are found in granite, lavas and sandstone (Hansen, 1968 a).

Ivigtut

In the Ivigtut area radioactive anomalies have been located in fault zones and pegmatites: they are apparently mainly due to thorium enrichment. Pegmatites often contain allanite, as on the island Isa just south of Tôrnârssuk. The investigation of radioactive materials in this area is described by Berthelsen & Henriksen (in prep.).

Stauning Alper

In central East Greenland a uranium deposit was discovered by Nordisk Mineselskab A/S in 1970. The deposit is situated in the fault zone between the late Caledonian granites of the Stauning Alper and the younger sedimentary formations of the Jameson Land basin (fig. 5 and 13). The mineralization occurs in irregular fluorite and barytes veins where sheared and partly brecciated granite is in contact with Lower Permian arkoses. Megascopic examination coupled with gamma-spectrometric assays and fission track analyses on thin sections shows that the uranium is associated partly with the fluorite and partly with brown pigmentary material lining fluorite veinlets (Wollenberg, 1971). Uranium contents in surface samples range from a few to more than 3500 ppm, but no primary uranium minerals have been found. The mineralizations are scattered over a distance of a few hundred metres in the strike direction of the fault, though the width of the mineralized zone is seldom more than 1 metre. The age of the hydrothermal event is unknown; it is thought to belong genetically either to the process of faulting or to the magmatic activity of Tertiary age in East Greenland.

Milne Land

On Milne Land in the western part of Scoresby Sund Mesozoic sediments rest unconformably on an irregularly eroded surface of the Caledonian and pre-Caledonian crystalline basement (Håkansson *et al.,* 1971). The base of the Upper Jurassic Charcot Bugt sandstone is developed sometimes as a fossiliferous organic sandstone and sometimes as a calcareous shell-fragment conglomerate. Within these beds varying quantities of radioactive heavy minerals are found. Accessory monazite and zircon from the eroded crystalline basement occur in this fossil placer deposit. Uranium and thorium contents of 100–200 ppm and 800–1800 ppm respectively have been reported.

Zirconium

Ilímaussaq (Kringlerne)

A spectacular sequence of rocks, the kakortokites (Kringlerne), constitute the southern part of the Ilímaussaq intrusion (fig. 11 and 14). The sequence is formed by a number of repeated units each of which comprises a black, a red and a white layer. The zirconium ore is contained within the red layers in which one of the important cumulus minerals is the eudialyte ($Na_5Ca_2FeZrSi_9O_{24}Cl(OH_2)$). The black and the white layers are dominated by arfvedsonite and microcline respectively. The geology of the kakortokites has been described by Ferguson (1964, 1970). Bohse *et al.* (1971) appraised the economic potential of the kakortokite based on analyses using portable X-ray fluorescence equipment. The highest grades were found in a 3.5 m thick red layer in the upper part of the kakortokite succession and in the border pegmatite separating the kakortokites

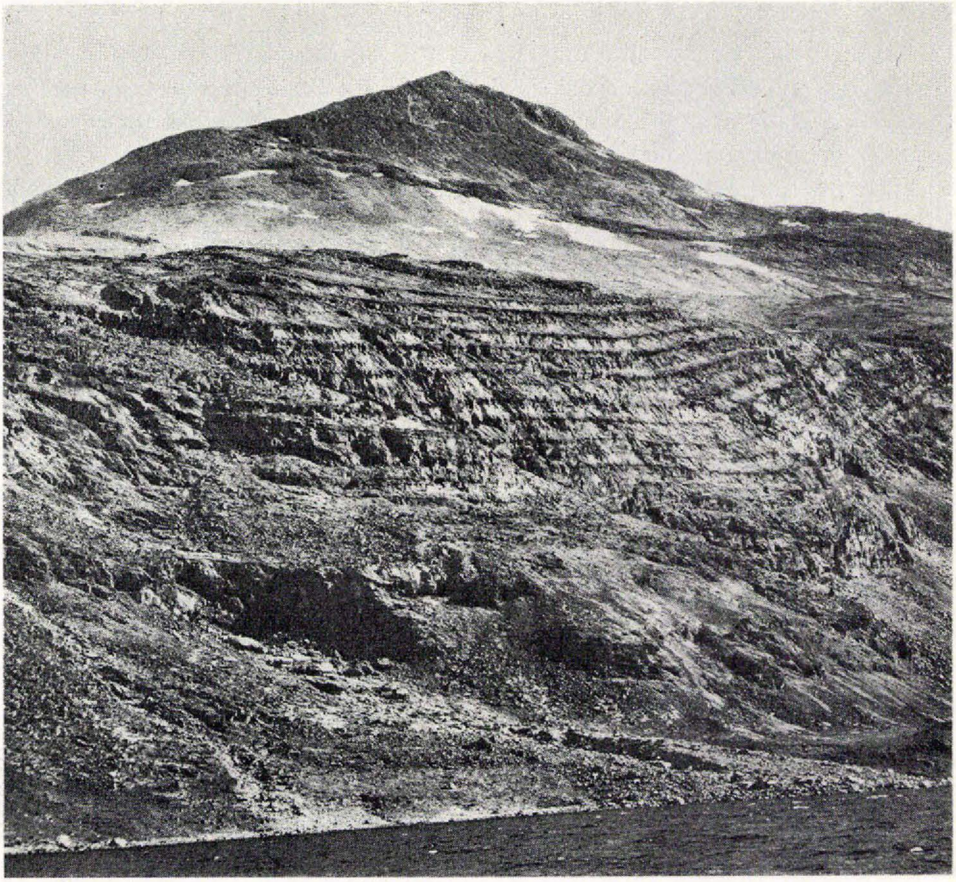

Fig. 14. Kringlerne with the layered sequence of kakortokites in the southern part of Ilímaussaq alkaline intrusion. Each unit, consisting of a black, a red and a white layer, is accentuated by the black layer at the base of the unit.

from the marginal augite syenite of the intrusion. The single red layer at the top of the plateau was estimated to contain 52,000 tons ZrO_2 and 5,500 tons Nb_2O_5 (see section on niobium) with an average grade of 4 % ZrO_2. The reserves of the entire succession are very large, the mean (geometric) ZrO_2 content being 1.2 %. The distribution of ZrO_2 between the three kakortokite types is given in fig. 15).

Titanium

Thule district

Sand samples containing ilmenite have been found in the Thule district (Ghisler & Thomsen, 1971, 1972). The ilmenite occurs in placers in raised beaches which

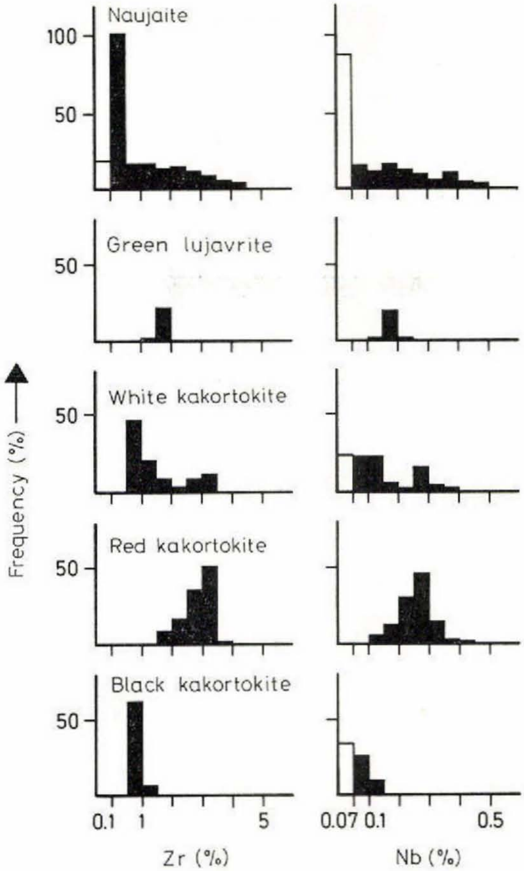

Fig. 15. Frequency distribution of zirconium and niobium in eudialyte-bearing rock types from the Ilímaussaq intrusion. Analyses from laboratory measurements. (H. Kunzendorf, personal communication, 1973)

have a maximum elevation of 125 feet above the present sea level. The source rock of the sand samples containing 37–74 % ilmenite by weight is considered to be a group of basic dykes which were intruded into the Dundas Formation, part of the sedimentary Thule Group of Precambrian age. Ghisler & Thomsen based their investigations on samples collected from Parker Snow Bugt and North Star Bugt (fig. 4).

The composition of the opaque fraction is very constant, being 90 % ilmenite without microscopic exsolutions or intergrowths. Titanomagnetite and magnetite play a minor role. The ilmenite contains 0.17 % vanadium.

Niobium and rare earths

Ilímaussaq

In the Ilímaussaq alkaline intrusion niobium minerals are found in hydrothermal analcime veins associated with the lujavrite of the latest intrusive stages (Sørensen *et al.,* 1969; Hansen, 1968 b). The minerals are mainly pyrochlore and epistolite. Niobium minerals of the epistolite-murmanite group are also found in deformed and metasomatized anorthosites and volcanics in the northern part of the intrusion. In the layered kakortokites in the southern part of the intrusion niobium is associated with zirconium in the mineral eudialyte which constitutes an essential part of the red kakortokite layers. The average niobium content of these layers is 0.4 % Nb_2O_5; the average ZrO_2/Nb_2O_5 ratio is 9.5 (Bohse *et al.*, 1971). An estimate of the tonnage of niobium in the kakortokites is given in the section on zirconium.

Pyrochlore from the hydrothermal veins is rich in rare earth metals: about 3–13 % (Semenov *et al.*, 1968); the cerium group of rare-earth metals predominates.

Rare earths constitute from 15 % to 30 % of steenstrupine which is an ubiquitous mineral of the lujavrites (Sørensen, 1962). In the Kvanefjeld area steenstrupine and monazite possess most of the rare-earth elements found within the radioactive ore body (see page 27). Kunzendorf & Wollenberg (1970) determined rare earth elements by means of isotope-excited X-ray fluorescence in surface samples and drill cores from Kvanefjeld, and in eudialyte-bearing samples from the kakortokites. The amount of rare earths in the eudialyte is about 2 %. The light elements predominate; these are yttrium, lanthanum, cerium and neodymium.

Qaqarssuk

In the Sukkertoppen district, east of Søndre Isortoq fjord, rare-earth and niobium concentrations were found in the Qaqarssuk carbonatite complex. The deposit was discovered during investigations by Kryolitselskabet Øresund A/S.

The Qaqarssuk carbonatite complex forms a concentric, steeply dipping ring dyke structure with dimensions of about 3 × 5 km, enclosed in an aureole of fenitized Precambrian gneisses. The ring dyke structure is controlled by a major deep-seated fracture zone which at the site is intersected by a set of other fractures running almost perpendicular to the former.

Carbonatite rocks are predominant in the complex. Ultrabasic to basic rocks with clear alkaline affinity form a subsidiary group.

Carbonatites occur as dykes and minor veinlets in the fractured wall rocks. The width of individual dykes and veinlets varies from a few centimetres to more than ten metres, the usual width being about 0.5–0.8 m. The carbonatites are commonly foliated parallel to the strike of the dyke. Calcite and dolomite are the main constituents, with phlogopite, magnetite and apatite as the most common accessories.

Barium, strontium, manganese, rare earths, niobium, thorium and uranium are characteristic minor elements in the carbonatite complex. At several places economic concentrations have been observed and studies concerning the distribution and size of these anomalous concentrations are in progress.

The variation of some of the rare elements in selected sections of the Qaqarssuk carbonatite is seen in table 1.

Table 1. Rare element contents in the Qaqarssuk carbonatites

BaO	<0.05 – 6.7	wt %
SrO	<0.2 – 4.7	
MnO_2	<0.15 – 2.8	
P_2O_5	<0.7 – 45.0	
CeO_2	<0.1 – 6.0	
La_2O_3	<0.02 – 6.0	
Nd_2O_3	<0.15 – 1.5	
Y_2O_3	<0.005– 0.10	
Gd_2O_3	<0.01 – 0.07	
Eu_2O_3	<0.003– 0.04	
Nb	200– 50000	ppm
Zr	30– 700	
Th	<700– 3200	
U	<500– 1600	

Niobium and zirconium mineralizations have been discovered by Nordisk Mineselskab A/S in quartz veins in the sediments bordering the Tertiary Kap Simpson intrusion on Traill Ø in East Greenland.

Beryllium

Ilímaussaq (Taseq slope)

Hydrothermal veins in the Ilímaussaq intrusion contain up to ten different beryllium minerals. Some of these are: chkalovite, tugtupite, sorensenite, bertrandite, beryllite, epididymite and eudidymite. The highest concentration of these minerals is located on the Taseq slope about 8 km north-east of Narssaq (Engell *et al.,* 1971), (fig. 11). The predominant mineral, chkalovite (11–13 % BeO), occurs in veins composed of mainly analcime, sodalite, ussingite and natrolite which have widths of a few centimetres to 2 m and form a 500 m long zone (fig. 16). Together with lujavrite veins they cut the naujaite, a poikilitic sodalite-bearing nepheline syenite. The beryllium-bearing veins are thought to have formed from fluids expelled from the lujavritic magma (Engell, 1968). A beryllometer survey (Løvborg *et al.*, 1968) has been undertaken in the area and on this basis an average concentration of 0.1 % BeO in the most strongly mineralized part of the area has been recorded. The amount of ore is estimated to be about 180,000 tons with 0.1 % BeO (Engell *et al.,* 1971). Beryllium minerals have

Fig. 16. Analcime vein containing subhedral crystals of the beryllium-bearing mineral chkalovite ($Na_2BeSi_2O_6$). *White* analcime, *dark* chkalovite. Taseq slope in the Ilímaussaq intrusion, South Greenland. Note matchstick for scale.

been found in small amounts in a few scattered hydrothermal veins elsewhere in the intrusion.

Beryl has been found in pegmatites extending from the Nunarssuit biotite granite northwards to Kobberminebugt (Ghisler, 1968). The crystals can be several centimetres in length. In addition to beryl, amazonite, molybdenite and copper sulphides occur in the pegmatites.

In the Godthåb district at Eqalunguit beryl occurs together with tourmaline in pegmatites. The crystals may attain 13 cm in length (Bøggild, 1953).

NON-METALS

Cryolite

Ivigtut

The cryolite deposit at Ivigtut was formed during the Gardar period in the upper part of a granite intrusion. No comprehensive study of the deposit has yet been published and the mechanism of formation is still a matter for speculation.

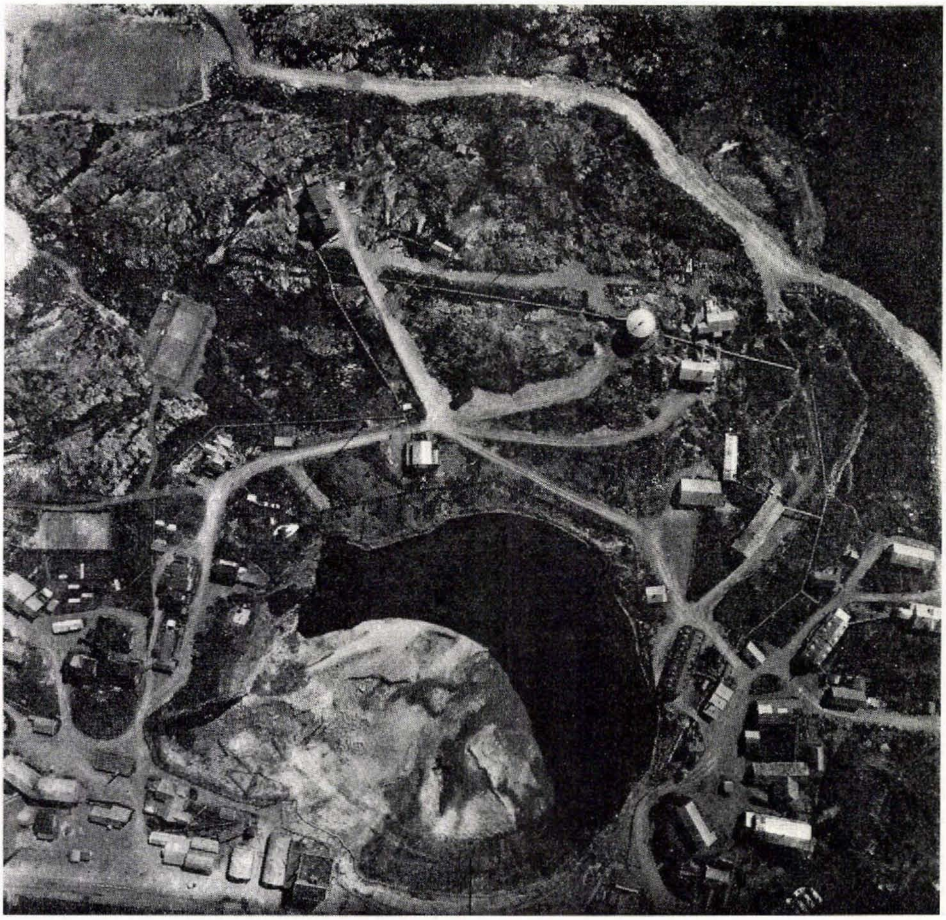

Fig. 17. Open pit and mining town at the cryolite deposit at Ivigtut, South-West Greenland. Mining ceased in 1963 and the pit is now filled with water. (Photo: GGU).

Berthelsen & Noe-Nygaard (1965) presented a survey of the deposit from which the following is abstracted.

The cryolite deposit, which has now been entirely mined out, formed originally an irregular body measuring about 50 m by 115 m in plan and about 70 m in depth.

The main part of the cryolite body consisted of siderite-cryolite rock, i. e. cryolite with about 20 % siderite and 1 %–2 % quartz and sulphides. The principal sulphides were sphalerite, galena, chalcopyrite and pyrite. Sphalerite occurred as both sphalerite proper and as marmatite. The temperature of formation of the siderite-cryolite rocks was estimated to be between 510° and 590° C (Pauly, 1960). Masses of pure cryolite with metre-long crystals occured at several places in the deposit. The chemical composition of cryolite is Na_3AlF_6.

In the western part of the mine the cryolite was mixed with fluorite, 'ivigtite' (a fine-grained potassian mica) and topaz. At deeper levels sulphide-bearing quartz rocks separated the cryolite body from the underlying granite. In all 76 minerals have been identified in the deposit.

Callisen (1943) and Sørensen (1950) interpreted - although in different ways - the cryolite as a product of the enclosing granite. Berthelsen (1962) suggested that the formation of the cryolite was related to the peralkalic magma which gave rise to the tinguaitic dyke intruded after the granite but prior to the mineralization. Isotope measurements (^{87}Sr-^{86}Sr) on barytocelestite from the cryolite body indicate a mafic (basaltic?) source magma rather than a granite source (Moorbath & Pauly, 1962).

The Ivigtut granite and the surrounding gneisses have a radioactivity above normal for the area.

Cryolite was mined in an open pit from the middle of the nineteenth century until 1962 by Kryolitselskabet Øresund A/S (fig. 17). A total of 3.5 mill. tons has been mined, and cryolite is regularly shipped to the processing plant in Copenhagen from the stockpiles at Ivigtut. For a short period of time the cryolite was used for soda processing. The main application however has been as a flux agent in aluminium production. Galena and sphalerite have been extracted as by-products.

Graphite

Graphite occurrences are found at several localities in gneisses and metasediments in the Ketilidian and Nagssugtoqidian complexes; the mineral is almost never present in the Archaean gneisses.

The best known locality is in the Nanortalik area at Amitsoq where graphite occurs in a fine-grained schist. From 1911 to 1922 approximately 6,000 tons of graphite was mined at Amitsoq. In Grænseland an anthracite-graphite deposit amounting to 10,000 tons of graphite occurs in a thin sedimentary unit of the Foselv Formation (Hansen & Larsen, 1961; Berthelsen & Henriksen, in prep.). Graphite has been found at several places in the Holsteinsborg area. It has been mined at Utorqait near Holsteinsborg, where the ore is found in layers 100 metres long and up to 3 metres thick in gneisses. The production was stopped because of a high content of limonite and pyrite in the ore.

Mining of graphite on a small scale has taken place at Qaersut in the Umanak district, where a 16 centimetres thick graphite layer occurs in a sandstone and shale sequence. Further to the north at Langø near Upernavik graphite is found in large quantities in garnet gneisses. Graphite is ubiquitous in the Egedesminde district in the southern part of Disko Bugt.

Recent attempts have been made to establish modern graphite mining, however without success.

Olivine

At Tasiussarssuaq, which is a northern branch of Fiskefjord, a dunite massif called Itipilua occurs (Kryolitselskabet Øresund A/S).

The massif, which has an areal extent of ca. 600 × 1300 m, is composed of a dunitic central part enveloped by an olivine-rich peridotite.

The composition of the olivine in the dunite is 6–8 mol. % fayalite. Chromite, enstatite and tremolite are the most common accessories; their amount varies between 0–10 %.

The dunite has acceptable refractory properties and the melting point has been determined to be more than 1750°C. Probable reserves of dunite have been estimated at about 45 million tons; possible reserves exceed 100 million tons.

Fluorine

Fluorine as fluorite is widely distributed throughout Greenland.

In South Greenland within the belt of the Gardar alkaline intrusions fluorine mineralizations are very common. The fluorine-bearing minerals are found within the intrusive bodies as well as in the country rocks, and the mineralization undoubtedly has its origin in the late hydrothermal phases of the Gardar magmas. Fluorine is an essential element of cryolite and within the cryolite body itself fluorine occurs in a number of fluoroaluminates. Fluorite mineralization in fissures and pockets is found in the Nunarssuit and Narssaq areas respectively. In the Ilímaussaq intrusion, which is also rich in chlorine, drill cores from the lujavrite have yielded large amounts of the soluble fluorine mineral villiaumite (NaF). Fluorite is common in the early Gardar lavas surrounding and capping the intrusion. In pegmatites in the Igaliko intrusive centre, for example at Narssârssuk, fluorite is widely distributed. No exploitation of the fluorine deposits, except for the cryolite at Ivigtut, has taken place.

Several veins of pure fluorite occur in the Kap Franklin area in East Greenland (Graeter, 1957). The veins were formed by hydrothermal events during magmatic activity in Middle Devonian time.

Feldspar and nepheline

The nepheline syenites and syenites of the Gardar alkaline intrusions in South Greenland have been considered as potential sources of feldspar and nepheline for ceramic uses (Miller *et al.*, 1970). Rock samples from the Ilímaussaq intrusion have been studied in detail. Although otherwise suitable for commercial uses the felsic minerals from these rocks contain a significant proportion of iron (above 1 % Fe_2O_3) in the form of microlites of arfvedsonite and aegirine which may be difficult to eliminate by present benification techniques.

Gemstones

Gemstones in economic quantities and qualities have not yet been discovered in Greenland. Nevertheless a few minerals and rocks have been used for ornamental purposes because of their attractive appearance when polished. Minerals with gemstone qualities (hardness and colour) are either not translucent, or are too brittle to be polished. Dragsted (1967) has given an outline of the finds of gemstones in Greenland and their possible use and value. He concludes that at present Greenlandic gemstones can be of no value on the international market, but when carved and polished by the local population they can be part and continuation of traditional Greenlandic handicrafts.

Some minerals and rocks which have attracted interest will be briefly described.

In South Greenland several of the rare minerals from the Ilímaussaq intrusion are notable for their attractive colour. This is especially so with the beryllium mineral tugtupite (Dragsted, 1970; Sørensen *et al.*, 1971; Povarennykh *et al.*, 1971). The mineral, which shows colours varying from white to carmine red, is found in hydrothermal veins often intergrown with other beryllium minerals and needles of aegirine. The local population has mined the mineral extensively. Tugtupite is luminescent in ultraviolet light. The hardness is 6–7 and the refractive index 1.495–1.499.

The beryllium minerals ussingite and sorensenite and the nepheline syenite naujaite have been used for ornaments and polishing on a small scale. A yellow variety of sodalite could be of use for jewellery.

Shillerizing moonstone feldspar occurs in pegmatite in the eastern syenites of the Kûngnât intrusion (Upton, 1960, p. 56; Bøggild, 1905, p. 442). The feldspars can be glass clear.

In the Fiskenæsset region corundum occurs together with sapphirine in an altered ultrabasic rock (Herd *et al.*, 1967). The corundum which is often a ruby variety may reach a length of about 7 cm. Rubies found so far have not been of gem quality, but chances of finding gems exist. Samples rich in blue sapphirine can be polished and might be used for ornamental purposes. Sapphirine localities are shown on fig. 7.

In kimberlites (Andrews & Emeleus, 1971) from the area between Ivigtut and Frederikshåb eight microscopic diamonds have been found in 1972 in 4 rock samples.

Garnets are widely distributed in the crystalline rocks of Greenland; only a few localities will be mentioned. From Akia on Storø in Umanak district deep red transparent garnets have been reported (Bøggild, 1953 p. 196). At a position about eight kilometres east of Ravns Storø, north of Frederikshåb Isblink, idiomorphic crystals are found in metamorphic supracrustal rocks (Dawes, 1970). The size of the garnets varies from a few millimetres to several centimetres across.

The crystals which are not translucent are rhombdodecahedra; their colours vary from brownish to purplish red.

Around Niaqornat on the Nûgssuaq peninsula water clear idiomorphic quartz crystals have been found (Bøggild, 1953, p. 115). The crystals, which are rarely longer than 1 cm, crystallized in late fractures and fissures in the contact zone between basalt dykes and black bituminous shales (A. Rosenkrantz, personal communication).

Agate has been collected on Nûgssuaq, as well as on Disko.

Talc, or soapstone, is known in many localities and for several centuries it has been utilized by the local population for lamps and cooking vessels, and for small carvings. Several occurrences are located in the area between Frederikshåb and Ivigtut, and in the Umanak area at Uvkusigssat, meaning a place where potstone can be found, local mining has taken place.

In a few cases gypsum has been used for carvings. For example gypsum from Klitdal in Jameson Land has been used in East Greenland.

CONSTRUCTION MATERIALS

Marble

Marble has been intermittently quarried in Greenland in the Umanak area for ornamental purposes. From the quarry at Mârmorilik Greenland Stone A/S shipped 4000 tons of marble in the period from 1967 to 1972. The production has been stopped lately. The marble is greyish white with darker waves. The quality is comparable to that of the Italian Carrara marble.

Sandstone

An unusual sandstone of a dark red colour with white round and oval spots occurs at a few localities in the Tunugdliarfik area in South Greenland. The sandstone, known under the name 'Igaliko sandstone' is used for ornamental purposes mainly for local use. The sandstone forms part of the early Gardar supracrustal sequence, the Eriksfjord Formation (Poulsen, 1964).

Gravel

Raw materials for road constructions and concrete are quarried at many places near the towns. At Narssaq in South Greenland a gravel pit is located in a fluviatile terrace. At most places, however, crushed rock or sometimes beach gravels are used.

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INDEX

GRØNLANDS GEOLOGISKE UNDERSØGELSE

THE GEOLOGICAL SURVEY OF GREENLAND

GGU RAPPORT NR. 56 (B. LETH NIELSEN)

MAP 1